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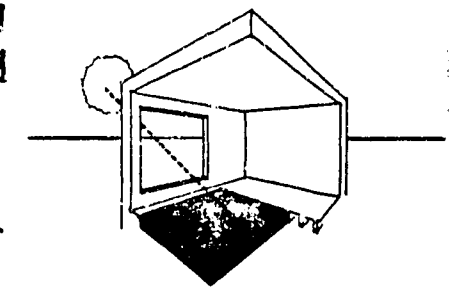
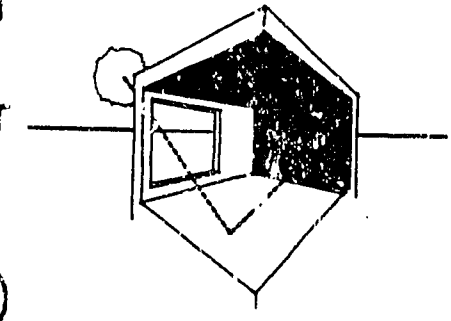
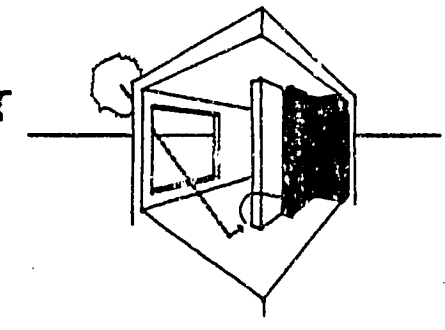
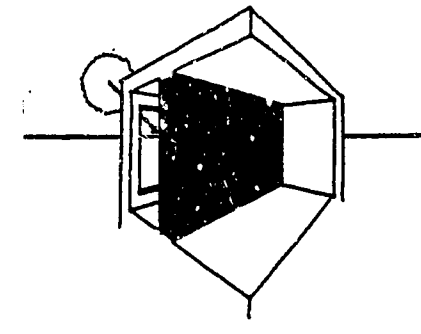
PASSIVE SOLAR HEATING IN LESOTHO HOUSING









POTENTIAL, PROBLEMS, PERFORMANCE ANALYSIS AND FOUR PROTOTYPE HOUSE DESIGNS

Prepared by: David Norris, Solar Architect, Associates in Rural Development, Inc. 362 Main Street, Burlington, VT 05401 USA Sponsor: Renewable Energy Technology Project, Ministry of Co-ops & Rural Development Place: Sechaba Room, Hotel Victoria, Maseru, Lesotho Date: July 21, 1982

Passive Solar Heating in Lesotho

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ACKNOWLEDGMENTS

This report is a primer on energy-conserving, passive solar-heated buildings. Included are descriptions of three prototype building designs which apply the design principles and techniques developed in this primer to low- (rural and urban), middle- and upper-income dwellings, appropriate to the culture, building traditions and materials of Lesotho. Blueprints for these designs can be obtained from the Renewable Energy Technology Project in Maseru or Associates in Rural Development, Inc.

This work was carried out under the Renewable Energy Technology (RET) Project of the Appropriate Technology Section (ATS) of the Ministry of Cooperatives and Rural Development (MINRUDEV), which is jointly funded by the Government of Lesotho and U. S. Agency for International Development. It was carried out under an AID contract with Associates in Rural Development, Inc.

As a consultant, one is only as good as the people who help you. I had the good fortune to have a lot of help from many good people--first, from members of the RET staff. Gary Klein with his concern for and experience in energy building and development in Lesotho was an invaluable guide and counselor throughout the project. Judy Gay and her staff vocally articulated the concerns and desires of Basotho who will ultimately occupy these structures. John Nicholson, faithfully appeared at my hotel room to execute yet another set of Pascalc runs. To Mamathe, we owe all the correctly typed pages of this document. In the public sector, acting chief architect of the Ministry of Works, Chris Lebona, consistently provided not only his personal support of my efforts, but that of his very professional staff as well. In the Quantity Survey (QS) Section, I would like to the thank in particular Larry Morris and Khmo Santho, who developed all the cost figures for the project.

I would also like to thank my predecessors, Blair Hamilton and Ron Alward, whose excellent seminar on ENERGY USE IN BUILDING, held in Maseru during February, 1982, effectively set the stage for my work.

David Norris, Associates in Rural Development, Inc.
Maseru, Lesotho
July, 1982

INTRODUCTION

Solar energy has a long tradition of usefulness in Lesotho. Basotho orient their fronts to it in the morning and their backs to it in the afternoon. Such a clear understanding of its value as a heat source has also been transferred to building construction. More often than not, buildings end up facing the morning sun--east.

Architects and designers in Lesotho have also demonstrated a consistent understanding of energy (though they would probably refer to it as something else) as one of the criteria used to evaluate the success of a building's design. If nothing else, Lesotho's cold winters and hot summers do not permit designers to ignore energy basics, like orientation, without clients paying the consequences.

Nonetheless, Lesotho buildings are almost without exception too cold. Both rondavels and Pitso Mark 5s are cold. Offices are cold, too. There is a real thermal comfort problem in Lesotho. And, although fuel costs are currently reasonable, there are many who cannot afford to heat their homes even at present.

So, there is room for improvement. This report and the three prototype building designs seek to improve the lot of Lesotho's houses and their occupants from an energy perspective. The energy-conserving designs do not require a radical shift in what people can have or expect in their houses, or how they are built, look or cost. What is radical, however, is that energy has been selected as the major, though not exclusive, governing criterion in the long, tortured process of design decisions. So, energy reigns at the level of site selection and orientation, while it also exerts just as powerful an influence in considering the palimset and selecting colors.

Thus, what follows is a way of building which, if learned, followed and refined, can make the structure itself, rather than electricity, coal or paraffin, the answer to "Mollo o kae?" (Where is the fire?).

LESOTHO: CLIMATE & ARCHITECTURE

Lesotho's Climate

Lesotho has an almost perfect climate for solar heating. When heat is needed in quantity, the winter sun is almost always there to provide it. Winter precipitation is minimal, cloud coverage is negligible, and because of the altitude, atmospheric interference is not a problem. As yet, pollution is not critical as the morning sun quickly burns off lowland smoke accumulations.

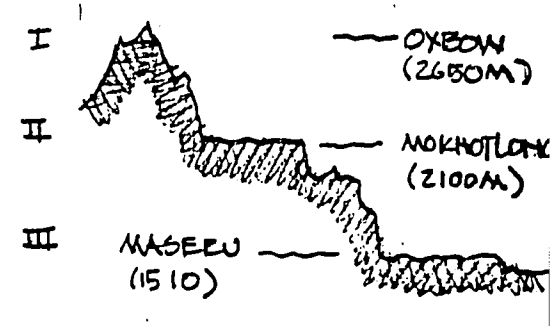
Along with clear, thin and easily penetrated air, Lesotho's 30° latitude means that the sun never gets very low in the sky, even in early morning in the dead of winter. (See "Where to Put the Building.") As a result, the sun gets winter daytime temperatures up to a very comfortable level. Days are warm.

On the other hand, the high altitude and thin air combine to depress temperatures very rapidly at night. The thin air cannot and does not hold heat built up during the day. Nights are cold.

In essence, this reflects and dictates the strategy for solar buildings--design the building with enough glass facing north to capture daytime solar heat and provide enough internal mass to store any surplus heat for use at night. First, however, insulate the building thoroughly to reduce both day and night heat losses. (See "Passive Solar Energy -- Glass/Mass Ratio" for a more detailed discussion.)

Basically, Lesotho has three temperature climates whose severity increases with altitude--Maseru with the mild, lowland climate, where winters are cool and summers hot; Oxbow, where summers are cold and winters frigid; and Mokhotlong with a midland climate is somewhere in between these two extremes. (For a detailed discussion of the solar climate see the "Thaba-Tseka Report" at the RET library.)

CLIMATIC ZONES



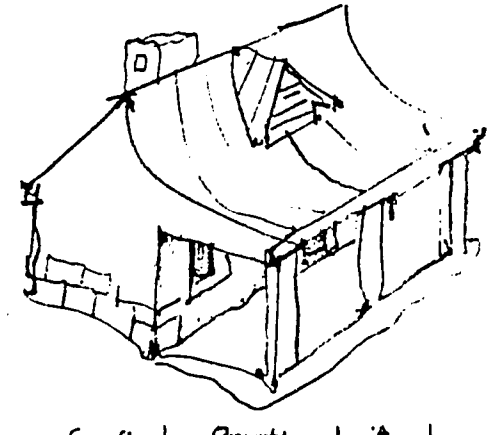
Going from the lowlands of Maseru to the mountains of Oxbow has severe consequences for energy performance. Thermal analysis suggests that over four times as much energy is required to heat a two-room, C4 Core house in Oxbow as it does in Maseru. In America, the cold and high fuel costs caused an exodus from older northeastern cities to the "sun belt" with its jobs, higher temperatures and cheaper fuel. Though difficult to isolate, fuel costs and thermal comfort must play a part in prompting people to leave villages for warmer Maseru and other urban areas.

Lesotho's Architecture: An Energy Perspective

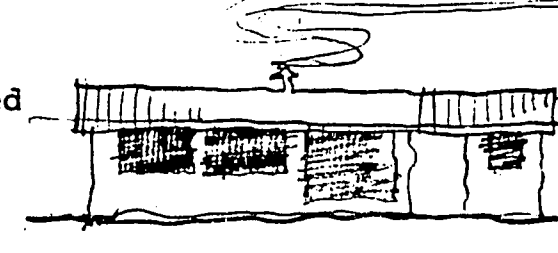
Lesotho's architecture has elements of Basotho, colonial and "modern" traditions. This has led to a curious mixture of energy wisdom and folly in the present building stock.

The rondavel contributed the tradition of facing the building into the sun, though the sensible round form has been discarded. From the colonial period, unfortunate vestiges of deep overhangs, high ceilings and a lot of flow-through ventilation (vent blocks over every window and door) remain that make little sense from a heating standpoint. (These elements are not simply a reflection of Victorian distaste for "vitiated" air or preference for dark interiors, but are, in fact, much more typical of tropical African buildings; probably Africa meant "tropical" to the colonialists, so even high, cold Lesotho got tropical types of buildings.) Finally, "modern" architecture brought glass into Lesotho buildings in a big way, which brought the sun inside for the first time. It was also a boon to the drapery industry, as Basotho suddenly found themselves architecturally naked and exposed, and rushed to reestablish the privacy and security of the windowless rondavel.

BASOTHO



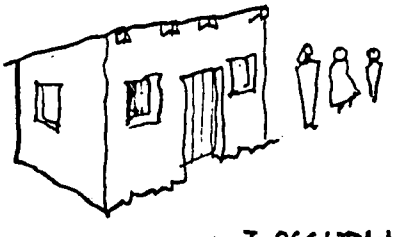
COLONIAL



MODERN

However, throughout all of this, a number of architectural features which make sense from an energy perspective were conserved and maintained. First, Lesotho's buildings, starting with the rondavel, are small. Analysis shows that a two-room house, like the LEH Co-op C4 house, uses six times less energy than the 167-square meter Pitso Mark 5. Fuel use is directly related to building size--small buildings stay warmer with less fuel. Second, Lesotho's buildings are carefully subdivided with each room closed off from the others. This means that at least the lounge or kitchen can be heated to a comfortable level, while other rooms are left unheated, thus reducing the heated space and fuel costs.

Using the 24-square meter, LEH Co-op C4 core house in Maseru as an example, the sensitivity of a small, two-room building to minor internal thermal changes can be demonstrated. Internal gains are the by-product heat of occupants and equipment inside a building, including heat given off by stereo equipment, water heaters and physical activity--all examples of heat sources that boost internal temperatures. Increasing internal gains from the heat generated by three occupants to that produced by 4.5 persons can result in a savings of almost 30 percent in the auxiliary heating required annually. Large families are a social, economic and cultural tradition in Lesotho, but are also of tangible value as a fuel source.



1 C4 CORE WITH 3 OCCUPANTS

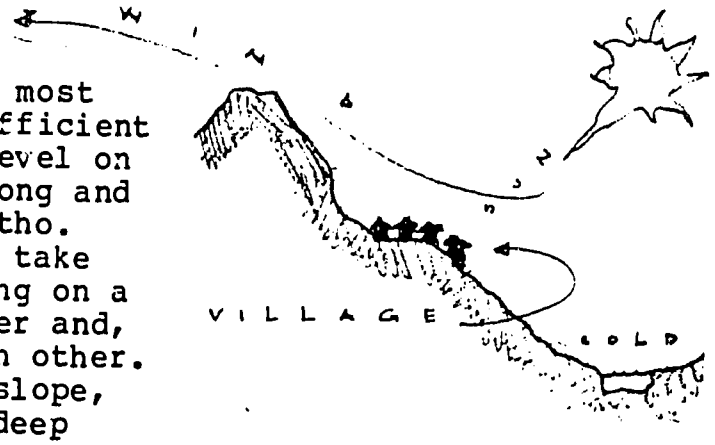
2 C4 WITH 4½ OCCUPANTS

THE FAMILY WITH 4½ OCCUPANTS WILL USE 30% LESS AUXILIARY FUEL.

ENERGY : MACRO - DESIGN

Where to Put the Building

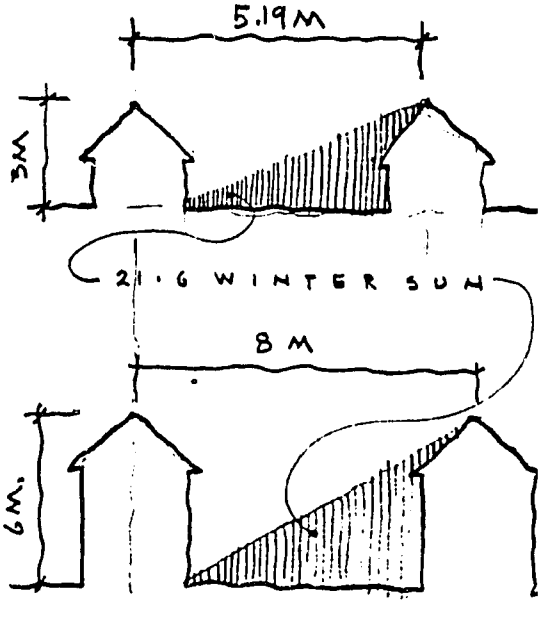
Selecting the site is the first and most critical step in making an energy-efficient dwelling. Locating houses at mid-level on north-facing mountain slopes is a long and very sound siting tradition in Lesotho. Facing north or east, buildings can take advantage of warming sunlight. Being on a slope, they stand one above the other and, therefore, do not usually shade each other. Being located in the middle of the slope, they avoid the low temperatures of deep valleys and cold winds of the ridges.



BASOTHO SITING

The same basic site planning principles hold in an urban development. Avoid low, and therefore cold, sites particularly if they are located near streams or ponds. Cold and wet is colder than cold and dry. Expose the buildings as much as possible to the sun's warming rays. Protect them from the wind as much as possible. (This is a problem in Lesotho--see "Where to Face the Building.")

The shading of one building by another becomes a potentially more significant issue on less steeply sloped sites in urban areas. Fortunately, even at its lowest point in the June sky, the sun in Lesotho remains high enough to avoid "inter" shading of even densely sited, single-level buildings. From the standpoint of usable energy, the "solar" day is from nine in the morning to three in the afternoon. This period covers almost 90 pecent of the available sunlight. On June 21, when the sun is at its lowest winter altitude, a wall three meters high and 5.19 meters north of a house would still not shade the building; the same wall 2.9 meters from the north side would not shade the windows.

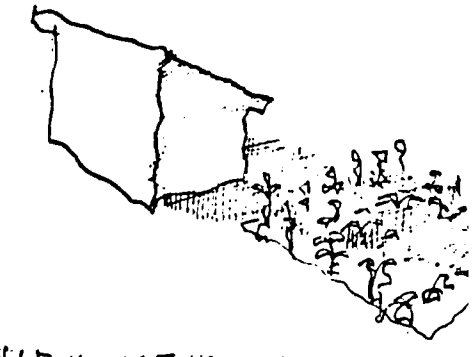


BUILDING SPACING TO AVOID WINTER SHADING OF SOLAR APERTURE

Two-story structures require more space to avoid inter-shading, though this is still not a problem. Assuming a development of multiple-unit town houses that are six meters high, a distance of eight meters is required between buildings to get <u>all</u> available

sunlight into all lower windows throughout the whole heating season. While this is not a problem given present housing densities, it could become one as increased population and less available real estate force denser development. "Sun rights" and orientation should be an integral part of any development planning and zoning criteria.

One interesting consequence of even small buildings on small sites is shading of limited crop-growing area by the building. Whether crops are a more important cultural, health and economic issue among Basotho than energy remains to be answered--it might affect site, building, energy and agricultural policies.



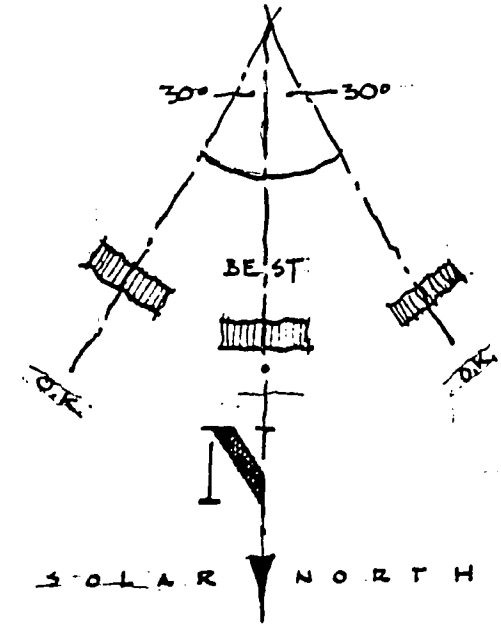
SOLAR HOUSE VS. SOLAR GARDEN

Where to Face the Building

Ideally, the major concentration of glass in a building should face due north (solar north, not magnetic north, which is significant in Lesotho, where magnetic variation is considerable). Nonetheless, it can face up to 30° east or west of due north with only a 10 percent loss in solar heating performance.

A northeasterly orientation means more heat in the morning, a northwesterly, more in the evening. In Lesotho, buildings are traditionally faced toward the east to receive morning light and heat through the open doorway. This strong cultural bias argues in favor of an northeasterly, rather than northwesterly, orientation.

From a thermal standpoint, the consequences of failing to orient most of a building's glass in a northerly direction are severe. In the C4 core house, the heat required to maintain thermal "comfort" increases by almost 17 percent when no window area, as opposed to most of it, is faced north. Misorienting the building and losing this potential heat is all the more misguided when one considers that this is a NO-COST OPTION.

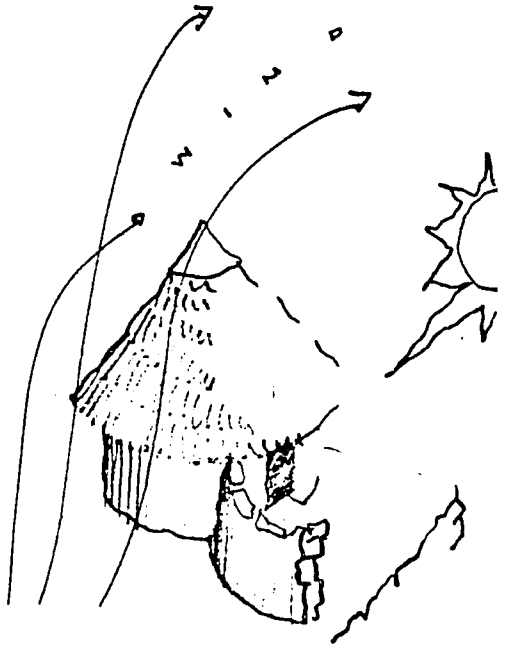


SOLAR ORIENTATION

Do not ignore the summertime consequences of orientation. Although the roof is the major receiving surface of the high, hot, summer sun, solar gain occurs on the south(!), east and west walls. Shading the west wall is most critical because the building's temperature rises steadily all day long to an uncomfortable level, only to have it increased further by the intense gains of the setting sun. Locating shade trees to the west of the building is one solution. Others include locating a deeply overhung terrace, carport or outbuilding on the west side of the dwelling. (See "Pitso-EC.")

Ideally, the building will present its back to the wind and open its front to the sun. This is a problem in Lesotho as the prevailing winter winds accompany the sun from the north. A long-term solution would be to plant hedges to act as a wind barrier. Low pine shrubs with dense foliage are best. A more immediate, though partial, solution is to build wind walls, particularly at the building's entrance. This is traditional in the rondavel.

In a development including many solar residences, a conflict may arise as to how to orient a building if the access road is on the south or back side of the dwelling. The answer is to locate the entrance on the east or west side so that it can serve equally well under any access condition. (See "Pitso-EC.")

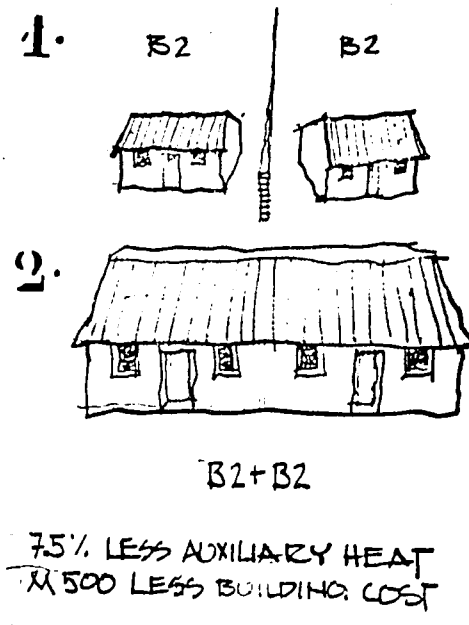


FACE THE SUN
AVOID THE WIND

To Attach or Not to Attach

Detached dwellings are clearly preferred, as well as traditional, in Lesotho for two reasons. First, the easy availability of land has not yet required attached dwellings, and second, the indigenous house type--the rondavel--has a long and distinguished history of being impossible to add on to.

Regardless of tradition or preference, attached dwellings make energy sense. Two attached LHC B-2 houses use 7.5 percent less energy than two separate B-2s. This is because the two end walls of the detached dwellings lose heat to the outside air. When attached, they become a single internal party wall and, as such, no longer lose any heat to the outside. The attached B2s not only save on heat, but because there is one less wall to build, save approximately M500 in construction costs.



This is one rare instance where up-front, as well as long-term energy operating, costs are reduced, and these dual savings argue strongly in favor of denser development or, at least, designing housing with an "attached" option.

What Building Shape

Form follows thermal comfort. From a purely thermal perspective, the ideal form is one which maximizes winter solar gains while minimizing both winter heat loss and summer heat gain. The rondavel is a good example--both the round wall and conical roof geometries are low-volume forms that are relatively easier to heat than their rectangular, flat-roofed successors. Assuming the same floor area, the circular plan also presents the smallest possible target area to the summer sun overhead and so stays cooler than a rectangular plan.

Although a number of complex factors affect energy-efficient form, orientation, distribution of glass and aspect ratio (the ratio of a building's length to its width) are the major ones. Insulation is obviously another, but for the following analysis will be assumed to be identical in all cases.

Orientation has already been discussed as a factor affecting energy efficiency. (See "Where to Face the Building.") As for the redistribution of glass, an increase in the

glass on the north side of a C4 core house from 50 to 100 percent of the total glass area resulted in a predicted drop of 50 percent in auxiliary heating. The impact on building form is that as more glass crowds to the north elevation, the building will, assuming a one-story unit, increase in length along its east-west axis. The desire to let sunlight into as many rooms as possible assists in lengthening the east-west dimension.

(In practice, one should also seek to minimize glass on the south side because it only loses heat, reduce west-facing glass because of intense summer gains and moderate east glass because despite its value as an early morning heat source, it is not as efficient as north glass.)

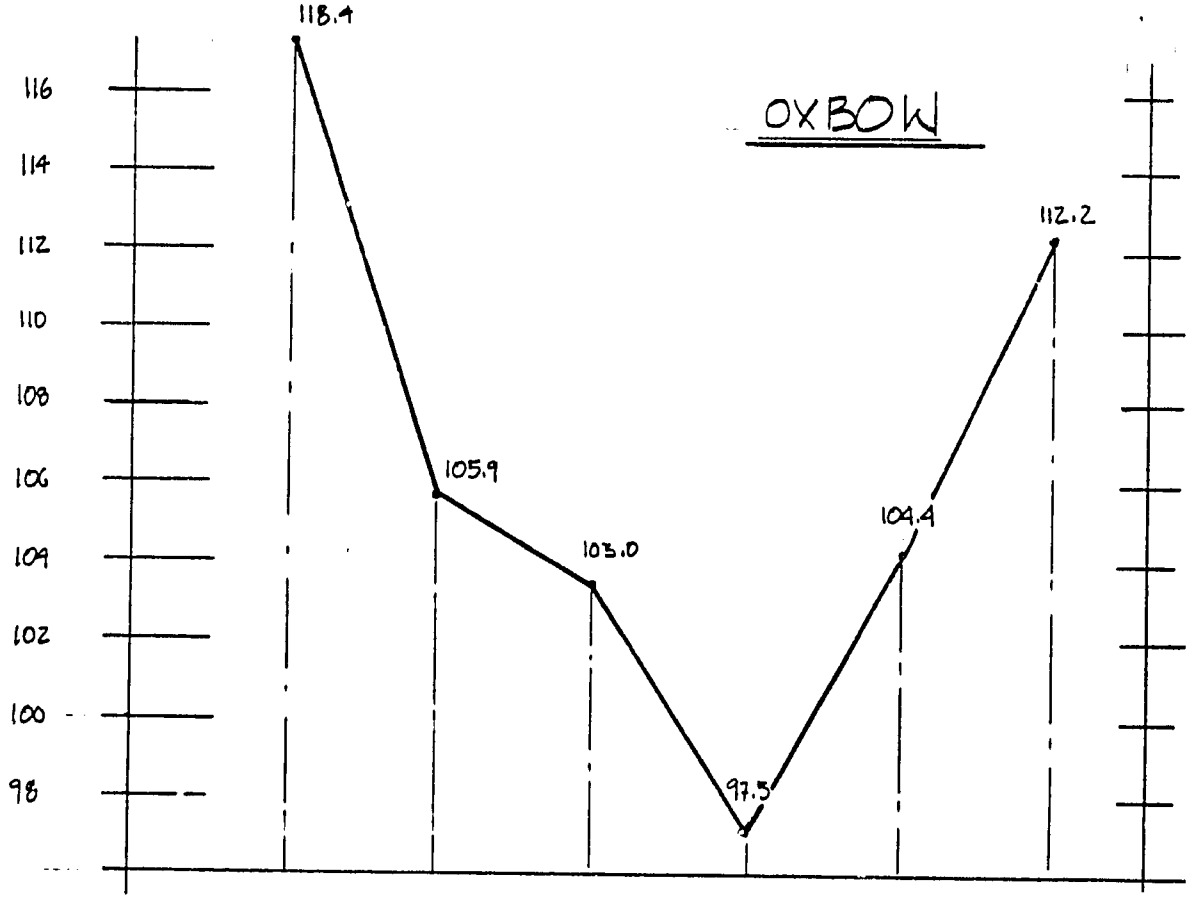
50% OF TOTAL GLASS AREA ON NORTH

100% OF TOTAL GLASS AREA ON NORTH LEADS TO A 50% SAVINGS IN ANNUAL AUXILIARY FUEL. WHEN COMPARED TO NO. 1.

GLASS DISTRIBUTION

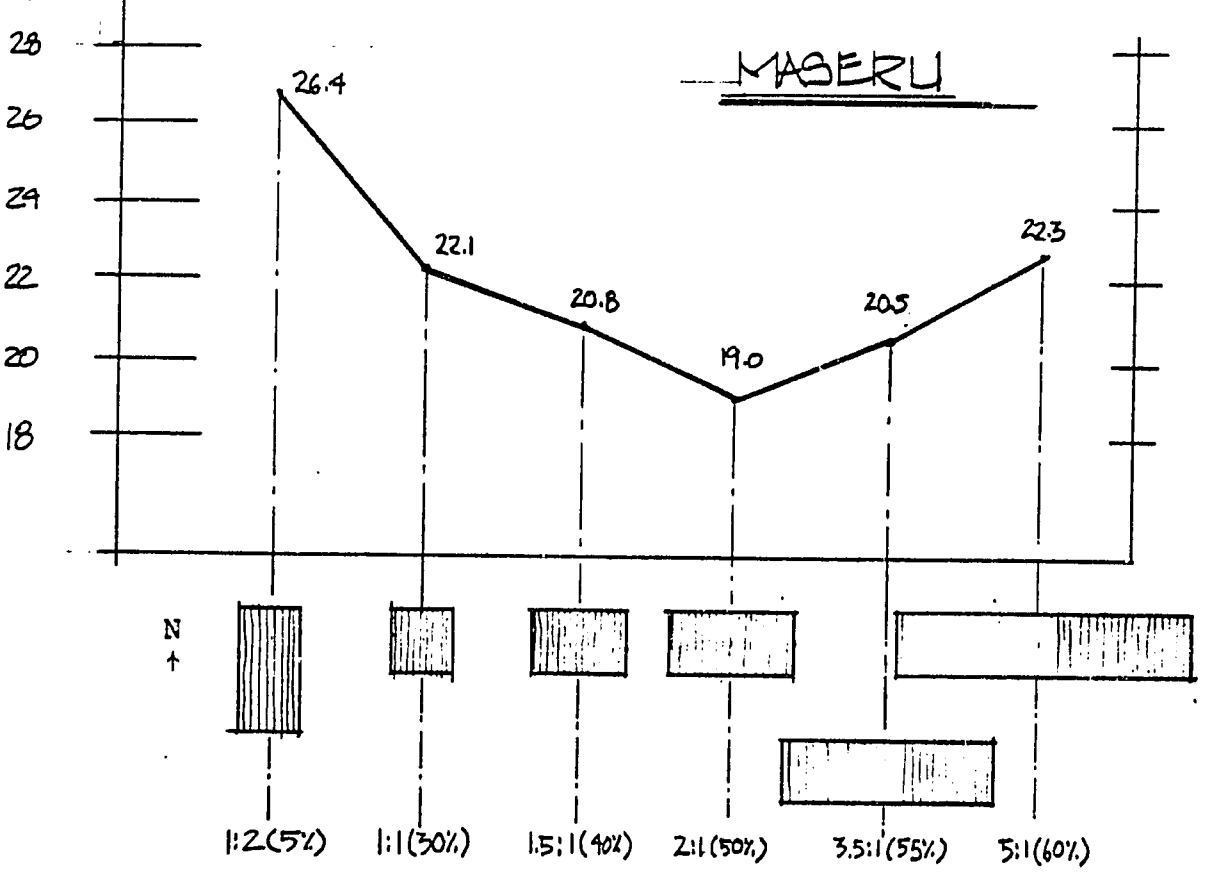
The graph on the following page summarizes much of the orientation and glass distribution discussion and introduces aspect ratio. Aspect ratio is the ratio of the length of the building's east side to the length of its north side. In each case, a building of 125 square meters is assigned an aspect ratio, allocated a reasonable percentage of its total glass area to the north elevation and then analyzed to determine the required annual auxiliary heating.

The results confirm what common sense already suggests--the most efficient form has an aspect ratio of two to one with 50 percent of the total glass on the north. However, it is not the most efficient form by a large margin, and any form from the 1:1 (30 percent) to the 5:1 (60 percent) is acceptable. Indeed, with further insulation and more north glass, these could easily be made to outperform the 2:1 (50 percent). The only form which has severe liabilities is the 1:2 (five percent) because it cannot take advantage of the north sun in winter and faces the consequences of the low setting sun in summer. Note that the reason the 3.5:1



ASPECT RATIO

ASPECT RATIO IS THE RATIO OF EAST-WEST TO THE NORTH-SOUTH LENGTHS. IT IS NOTED 1:2. IN PARENTHESES IS THE % OF THE TOTAL GLASS AREA LOCATED ON THE NORTH. GLASS, BUILDING AREA & INSULATION ARE CONSTANT. UNITS IN 10^9 JOULES.

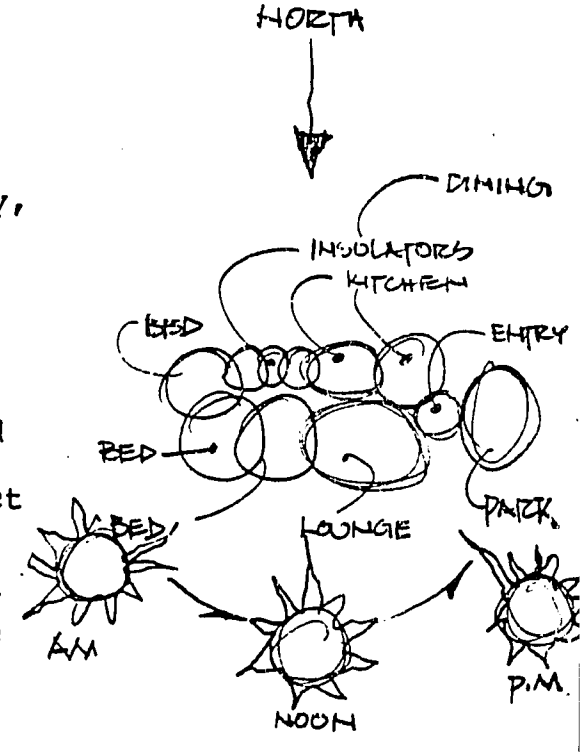


(55 percent) and 5:1 (60 percent) do not perform as well as the 2:1 (50 percent) is that despite their additional north glass, the increased solar heat gains cannot compensate for heat lost through expanded wall and roof areas.

Where to Put the Rooms

From a straight thermal efficiency standpoint, there is no "correct" way to organize and lay out rooms in a "solar" house. If the buiding is oriented correctly, and there is sufficient north glass and insulation, the floor plan does not matter.

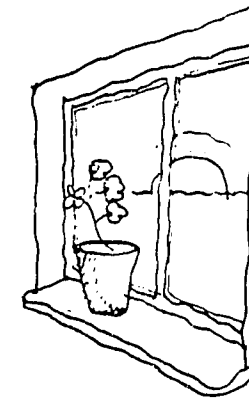
In practice, layout is not divorced so quickly from the sun's path and typically will follow the sun through its daily cycle with bedrooms or early morning gathering and eating spaces to the east, lounge to the north and patio or carport to the west to act as a buffer for the setting summer sun. Additional "insulating" spaces, such as bathrooms and storage closets, are typically arrayed to the south. As already noted, the entrance, at least in dwellings requiring flexible siting, should be midsection on the east or west.



ENERGY : PASSIVE SYSTEMS

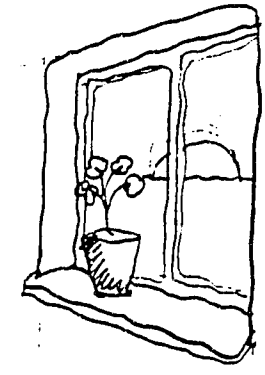
Passive Solar Energy -- System Types

True to their name, passive systems do not move. In addition, if they are made of materials which do not deteriorate, they will last as long as the building does. They do not, in their simplest form, require that occupants operate or maintain them in any special way. In many respects, insulation is a perfect passive system. It lies quietly in the wall or roof, saving energy and money whether or not the occupant cares, and continues to do so until the building comes down.



A GOOD PASSIVE SYSTEM

Active systems are distinguished by supposed higher efficiencies, but also by moving parts which tend to wear out and fail. They do not generally last as long as the building. Passive systems sacrifice a little short-term efficiency for longevity.



A GOOD PASSIVE SYSTEM 100 YEARS LATER.

Passive systems are also appealing because they employ traditional elements of architecture and building. A window lets in light and air, and lets one look out. Put it on the north side of a building, and it lets in a lot of heat as well. A wall holds up the roof and gives you a place to hang pictures. Fill it with concrete and it will store solar heat as well. Adding another function to an already existing building is a more integrated aproach to energy design and architecture than merely putting active solar collectors on the roof.

There are a number of generic passive systems:

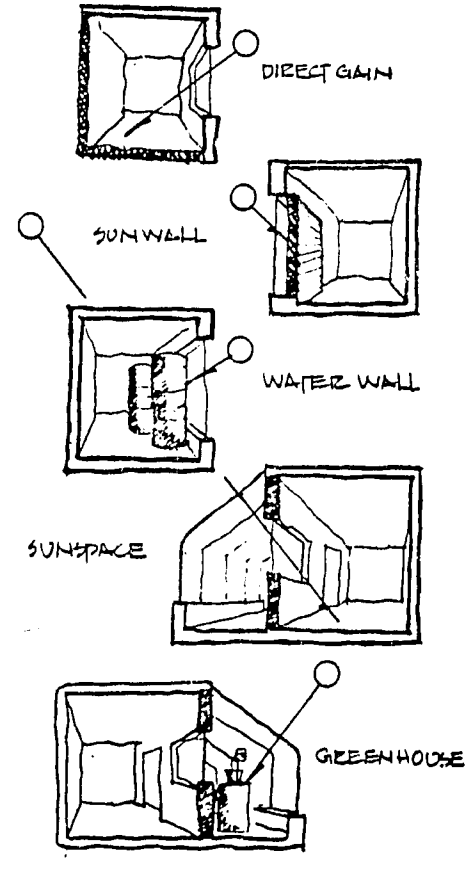
direct gain -- the simplest of all; a north-facing window with storage in the walls or floor struck by the penetrating sun

sun-wall (trombe) -- a north-facing window with a wall of dark-colored, solid brick or block behind it to store heat during the day for release to the living space at night

water-wall -- same principle as the sun-wall except that storage is typically in water containers (oil drums), painted black

sun-space -- an all-glass "conservatory," located on the north wall of the house to capture heat and store it for release to the inside space at night--a sort of expanded sun-wall

greenhouse -- same as the sun-space except with increased storage to keep nighttime temperatures high enough to grow plants



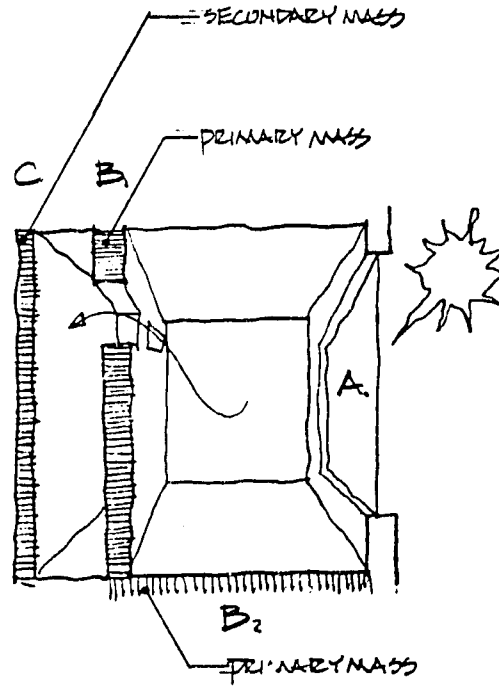
Unless special circumstances dictate, the direct gain and sun-wall systems are the most appropriate for Lesotho, based on simplicity of construction, availability of materials, operating efficiency, ease of maintenance and longevity. Thermally speaking, these two systems also work well together. Direct gain windows satisfy daytime heating requirements, but are clearly nullified when the sun sets. Fortunately, this is just the time when heat stored in the sun-wall starts to be released to the inside to take care of nighttime requirements.

Passive Solar Energy -- Glass/Mass Ratio

In principle, passive solar energy is simple--let the sun shine in. In practice, it requires deft coordination of relative glass and mass areas to avoid overheating. The glass/mass ratio is at the heart of passive solar design--for each square meter of north-facing glass, there must be adequate storage mass integral to the passive system or internal to the heated space to capture and store the incoming solar heat at a fast enough rate to avoid overheating the building air to the point of discomfort. Stored in the mass during the day, the heat is released back to the space at night, as the air inside the dwelling cools. The ideal result is a space which keeps high and low temperatures within a limited, comfortable range, so they do not "swing" excessively.

To be absolutely sure about glass/mass and overheating, a large computer is typically used to simulate interior and exterior temperatures for every day of the year, every hour of the day. For residential applications, rules of thumb suffice. Appendix A is THE THERMAL MASS PATTERN BOOK which suggests basic glass/mass ratios for different types of passive systems.

Fortunately, in Lesotho most internal and external building materials are dense masonry or concrete, so there is little worry about inadequate mass to absorb and store solar heat. But, it should be checked, nonetheless, particularly if an unusually large glass area is being considered for the north side. Basically, the glass area is first determined, and then all available storage mass is added up to see if it is adequate, including both mass heated directly by the sun as well as secondary mass heated by convection. If glass and mass do not balance, either more mass must be added by filling the cores of exposed internal walls, for example, or the glass area must be reduced to match the existing mass.



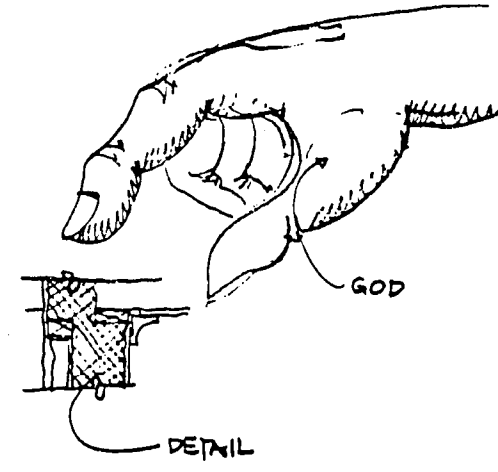
$C + B_1 + B_2 \longrightarrow A$

$A \longrightarrow C + B_1 + B_2$

GLASS/MASS RATIO

ENERGY: MICRO-DESIGN

"God is in the Details:" An Energy Perspective on Methods and Materials



"God is in the details" was uttered by the great 20th century modernist and purist architect, Mies van der Rohe, and has particular application to energy-efficient buildings. One can make all the right decisions about siting, orientation, aspect ratio, glass distribution, glass/mass ratio and planning, only to have the details and materials not deliver the building's full energy potential. So, this section will suggest ways to improve existing materials and methods, and provides a set of details that deliver. (See Appendix B for detail drawings.)

The Rondavel -- A Sensible Tradition

In addition to its energy-conserving form (see "What Building Shape"), the rondavel uses locally available materials and a very old building tradition to provide at least minimal thermal comfort to its occupants. This is no small feat in light of exposed mountainside sites and the rude winter climate of higher elevations.

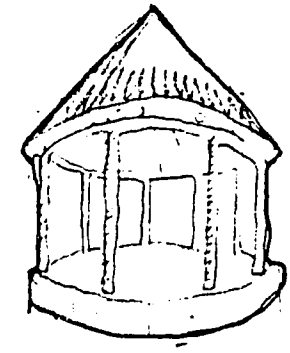
Thatch is, given other available homegrown options, an excellent insulator. However, because it is "porous," it fails to keep the cold wind out, although its "porous" quality is clearly required to vent smoke from fires used for cooking and heating. Cutting air infiltration through the roof is the best, though most costly, way to increase thermal comfort in the building. This requires a barrier to the wind, which is integral to the roof, and a chimney to evacuate smoke, preferably through the roof's peak.

Thick stone walls are not good insulators, though their thickness, careful construction, rubble fill and smearing do make them excellent barriers to the wind. Internal smearing with a mixture of mud and dung helps to conserve heat, for the dung acts not only

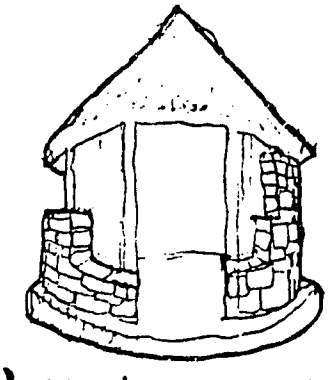
A THREE PHASE "INSULATED" RONDAVEL

as a binder, but also as a modest insulator, given its cellular fiber content.

One Lesotho building tradition, which is now endangered, first raises the roof on poles, then encloses the space with a reed wall smeared on the inside with dung. At that time, the family can occupy the dwelling and undertake the long and arduous process of building exterior stone walls as time permits. When completed, the building has an insulating layer of air trapped between the internal, smeared reed wall and the external stone wall. For this reason, this tradition needs revival, not extinction. Ironically, it is an endangered tradition because of the increasing scarcity of reeds, most of which have been cut down for firewood.

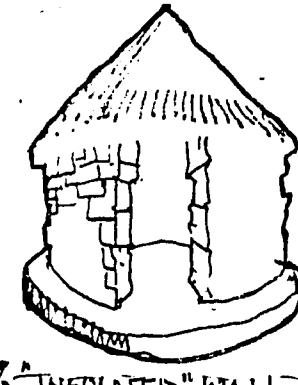


1. POLES & THATCH



2. REEDS & STONE CAVITY WALL

Windows and doors need work. Windows are almost symbolic gestures--very small and deeply inset in the walls. They could be larger, from both a solar and lighting standpoint, but this might clash with the tradition of visual privacy handed down from the windowless rondavel. Doors are poorly sealed against the cold wind. Indeed, they are frequently left open, almost always if a fire is burning. In the mornings, this makes sense, as it is the best and fastest way to get sunlight and heat into the cold rondavel. If larger windows could perform this morning heating function, the door could remain closed, which would be warmer. Sheepskin weather-stripping of the door would improve its thermal performance markedly. Simply hanging a blanket in front of the door would also help. (The RET project has a pamphlet available with suggestions for insulating the rondavel.)



3. "INSULATED" WALL

Block and Iron -- The New Tradition

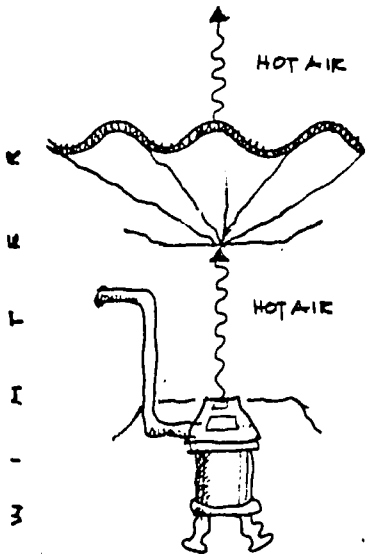
Most people and surveys suggest that, at least in terms of preference, the two-room, concrete-block house with a corrugated iron roof has displaced the rondavel as the house to build, when and if the resources are

available. This is virtually always the case in urban and peri-urban areas, where rondavels are almost never built. Curiously, it appears that the only time rondavels are built by urban dwellers is when they wish for a guest house and a psychological link to the village tradition. The result is a rondavel nestled in among block and concrete buildings.

The following sections consider the methods and materials associated with "modern" building practices, as embodied in two-room, block-and-iron dwellings and larger, more costly buildings.

Corrugated Iron Roofing

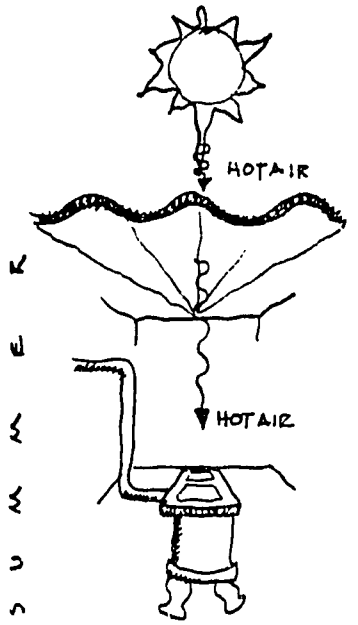
A corrugated iron roof with no ceiling is a disaster from an energy standpoint. Heat loss is "driven" by the difference between external and internal temperatures. The higher the temperature difference, the greater the rate of heat loss. In the two-room C4, warm air rises to the underside of the roof and creates a very high, local temperature difference. Given the roofing's low resistance to heat loss--roughly equivalent to a thin layer of still air--the rate of heat loss at such times is enormous. A ceiling is a must and an insulated one, preferred.



CORRUGATED IRON: A HEATING DISASTER

Note that this whole sad performance is reversed in summer, creating uncomfortably hot internal conditions.

The corrugated iron roof also "leaks" thermally for it is difficult to seal at the wall joints and between panels, and has many nail holes which leak air. The result is a lot of infiltration which compounds the already poor resistance to heat loss. Sealing the edges is difficult because of the difference in expansion coefficients between the iron roof and mortar fill. If a ceiling is installed, continue to fill the corrugations. If the ceiling is insulated,



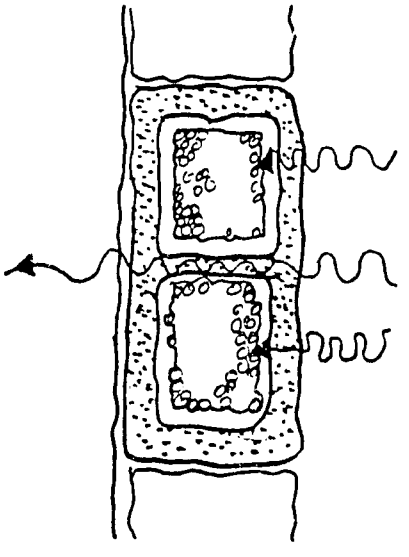
CORRUGATED IRON: A COOLING DISASTER

remove or do not install fill, as the roof cavity should be ventilated for both thermal and condensation reasons. (See Appendix B, EC Detail D-8.)

Walls and Foundations

Concrete block is not a good insulator. Even so, it is better than solid brick or stone because of its air-filled cavities. It is also cheaper.

There are a number of insulation options with concrete block. The first is to fill the block cores with vermiculite or polystyrene beads. The beads are a much better insulator and are recommended, if this option is considered. However, correct installation is critical to guarantee that the cores are filled solidly with insulation. This requires filling all cores as each course is laid up, which creates trade and scheduling difficulties because the mason and insulation installer must work in very close proximity. Furthermore, even if the cavities are well insulated, the block "partition" walls are not. These remain excellent escape routes for heat. Thus, this is an inexpensive, but not totally reliable barrier to heat loss.



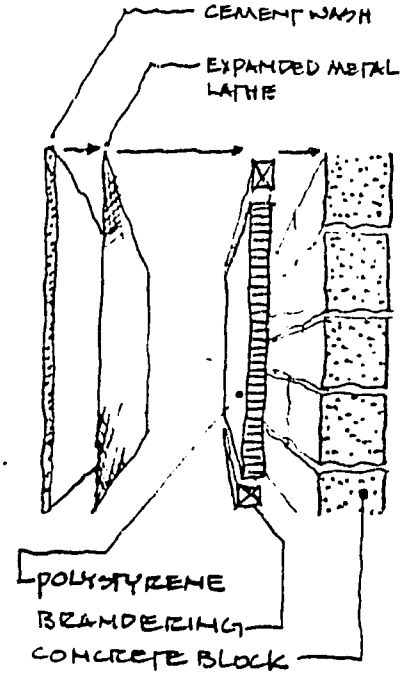
HEAT CROSSING THE THERMAL "BRIDGE" IN AN INSULATED BLOCK

An insulated cavity wall is a second option. The preferred method is to use polystyrene beads to fill the cavity between the interior and exterior walls. This method encounters the same installation difficulties as for insulated block cavities. Cavity-wall construction is not typical in Lesotho, and it results in double external walls which add area, and therefore cost, to the building. It is not generally recommended.

The third option is to insulate the block on the outside. This avoids the thermal bridge problems of the block-cavity option, and the space and cost liabilities of the cavity wall. It has other advantages as well. For one, the exterior polystyrene sheet can be run below grade and thus, reduce heat loss

through the slab edge as well as the walls. Also, by putting insulation on the outside of the concrete block, all of the concrete mass, which is useful as solar storage, is contained inside the building.

Exterior insulation does have a number of liabilities. First, the material is not available locally. Second, attaching it to the wall is not easy. Third, it is easy to damage when run below grade, if inadequately protected.



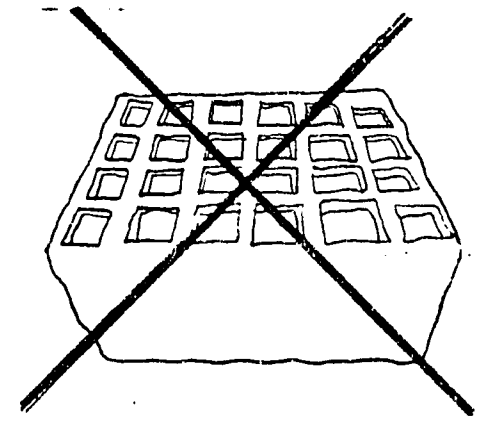
PREFERRED WALL INSULATION OPTION

To answer the first problem, the product is obtainable in the Republic, though admittedly at a premium--about R1.9 (1982) per square meter in Johannesburg for 30-millimeter sheets. Even so, its thermal benefits make it a wise investment. (See "Most Cost-Effective Path -- Big Budget.") In response to the second liability, there are three accepted techniques for installing the material: tar, building mastic or a brandering grid to hold it up; then, in all three cases, metal lathe is laid over that and finally, a cement wash. The brandering grid is shown in EC Detail D-1 (Appendix B) because even though it has cost and thermal liabilities, it uses local materials, a more familiar building technique and is a more reliable installation over the long run. To answer the third difficulty, as long as the cement wash is laid on thickly enough at grade, the insulation should not suffer.

Another reason for the appeal of exterior insulation is that it has retrofit possibilities that the other techniques do not. This is particularly important in view of its relative costliness. As such, it could be left off during initial construction and the wall simply waterproofed as inexpensively as possible. Then, when resources become available, the insulation could be added. However, this does require that the top course of block be laid up so as to facilitate the insulation retrofit. (See EC Detail D-2, Appendix B.)

Vent Blocks

Vent blocks should be banned. Even in a well-insulated building, infiltration is how most heat is lost. Cold outside air under pressure from wind or temperature differences makes its way into the buiding and forces warm air out. A vent block is basically a hole in the wall that permits free passage of cold outside air to the inside. Typically, these blocks are installed above each window and door, such that even if the wind is not forcing cold air in, warm air which naturally rises to accumulate at the ceiling slips out.



BAN THE BLOCK!

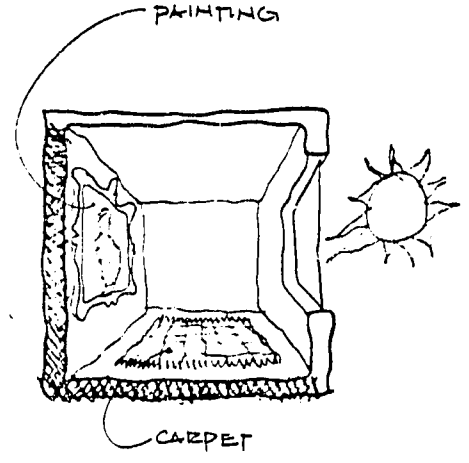
In the C4 house, one vent block alone oriented to windward and subject to the average Maseru wind velocity can account for a one-third air change per hour in the house. In Oxbow, it can account for a one-half air change per hour. The thermal impact of eliminating vent blocks is significant. In the LHC B-2 type house, eliminating the blocks (note that vent blocks are not specified in the LHC design; people just seem to put them in) led to a 10 percent reduction in required annual auxiliary heating. This is a NO-COST SAVING.

A health and safety issue should not exist as long as windows can provide ventilation and people use them. Minimum required ventilation for the C4, given ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) standards, is about 1.2 air changes per hour. In most cases, this minimum obtains even with the windows closed. In better insulated structures, a vent window must be opened, particularly when a fire is burning. The point is that windows provide occupants with a measure of control over ventilation. Vent blocks do not--get rid of them.

It should be noted that vent blocks between heated and non-heated rooms are an excellent way to transfer heat internally. But, they should be used only in internal partitions.

Internal Solar Storage Walls

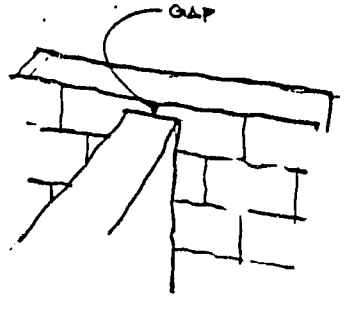
First, if an internal wall is to be used for thermal storage of heat from either the sun or a fire, it is important that the cores of the blocks in the wall be filled solid. Air cavities do not store heat, so there should be as few of them as possible in the storage wall. Second, if a wall or floor slab is to store heat received directly from the sun through a window, it should have a minimum of "insulators" (e.g., carpets and paintings) on it. Third, if the storage wall is inside the dwelling and the external walls are not insulated, it is better, thermally speaking, to "disconnect" the storage wall from the external walls. This prevents heat from migrating through the masonry joint to the outside.



AVOID BUT DO NOT EXCLUDE "INSULATORS" OVER STORAGE MASS

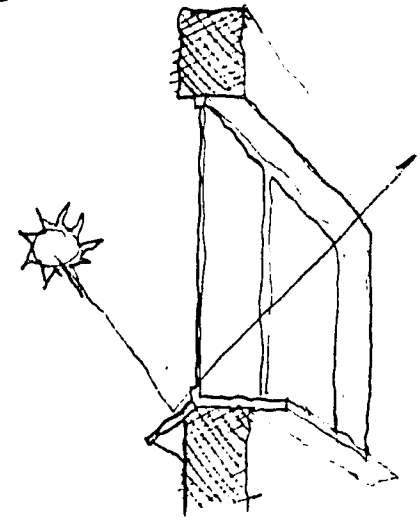
Windows

Steel windows are of poor thermal quality compared to wood windows, which are presently unavailable in Lesotho. The steel structure of the window has a very low resistance to heat loss and accounts for about 10 percent of the total window area. Less heat is lost if the structure is made of wood, which has greater thermal resistance. More critical is the consistent and dramatic warping of steel window panels, permitting the free and easy infiltration of cold outside air. A partial solution is to add closers where windows are warped. Weather stripping will also help. A better solution is to simply refuse delivery of warped windows. If such refusal were consistently applied, improved quality control at all levels of manufacture and installation might occur. Redesign of window components to create a more "tortured" path for infiltration would help thermally, but would also drive up the cost significantly. Double glazing is desirable, particularly in the higher elevations, but is also prohibitively expensive.



"DISCONNECT" STORAGE WALL IF EXTERNAL WALL IS UNINSULATED

LEH Co-op's Production Services presently offer a single-glazed, wood-frame window. The frame is of meranti, and the design and manufacture solid and simple. The co-op has suggested that if a sizable market existed, their wood windows could be mass-produced locally at a price competitive with imported steel windows. The co-op has also indicated an interest in design modifications directed at improving the window's thermal performance. In this light, examples of high-performance, U. S. window designs will be forwarded to them.



INSTALL NORTH WINDOWS AT THE OUTSIDE OF THE MASONRY OPENING.

It is advisable to install north-facing windows as close as possible to the exterior face of the wall to avoid the shadow created by the overhang of the window header. A generous exterior sill painted white will also help reflect solar radiation into the interior.

Overhangs

In part because of colonial architecture's influence and also Lesotho's hot summer, overhangs are usually overdone. North windows have a critical space-heating role, and care should be exercised to provide adequate summer shading while not jeopardizing winter heat gain. Because present practice does not take into account the high 50° altitude of the winter noon sun and the 85° altitude of the summer noon sun, overhangs usually need to be reduced.

A case in point--the Pitso Mark 5 presently incorporates an 800-millimeter overhang and 800-millimeter east and west wing walls around a north bedroom window that is 1.25 by two meters. An average 37 percent of the window is shaded during the coldest months of the year, and usable solar heat is needlessly lost. Another case--in the LHC A3 house, the north window in the lounge is overhung by the large entry porch. Cutting the overhang back from 1.7 to .3 meters reduced the annual heating load by 10 percent.

The graph on the following page illustrates how subtle the overhang issue can be. Solar heating decisions have resulted in a window and sun-wall combination on the north wall. (See Figure 1.) The question is how deep an overhang (X in Figure 2) is required to let the sun in during winter and keep it out in summer. The .14-meter overhang provides 100 percent exposure during winter (the "heat" period), but leaves too much exposed during summer ("no heat" period). The .18 overhang covers the "no heat" period better, particularly regarding the sun-wall, but starts to shade both solar devices during the "heat" period. During the "no heat" period, the .22-meter overhang fully blocks the windows and shades enough of the sun-wall to prevent overheating. During the "heat" period, some marginal and acceptable shading of both solar devices will occur. The .22-meter option is preferred.

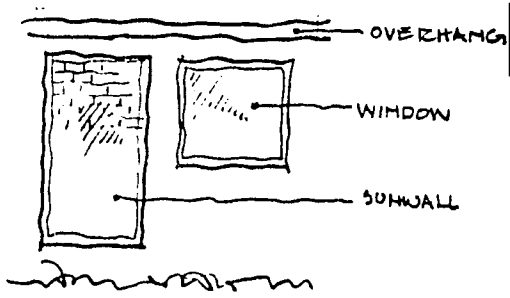


FIGURE 1: HOW DEEP AN OVERHANG?

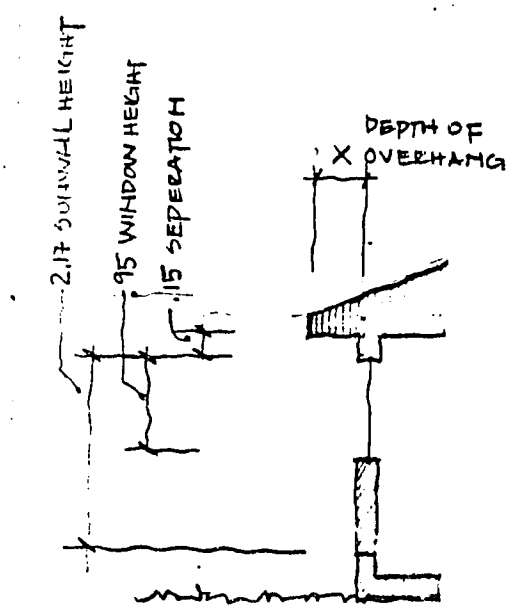
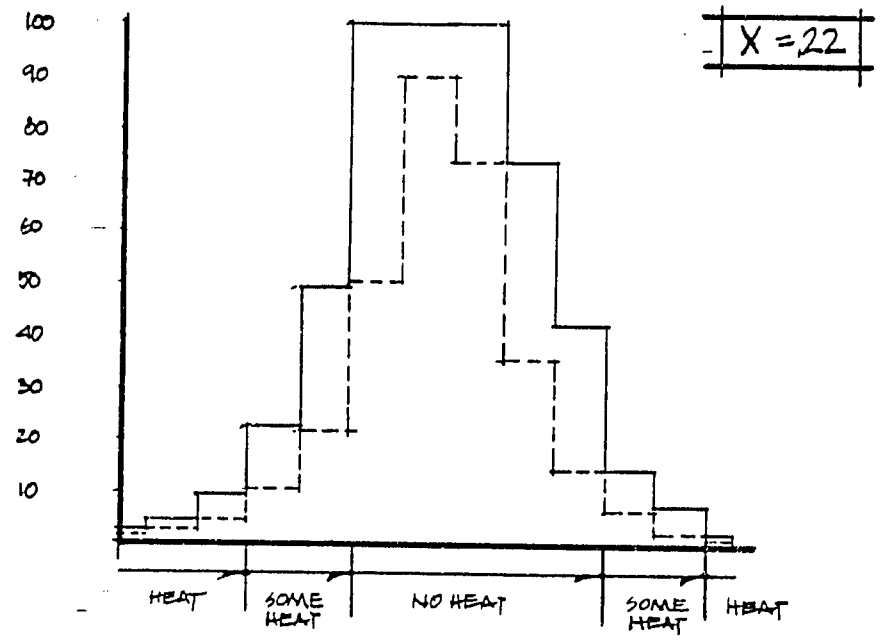


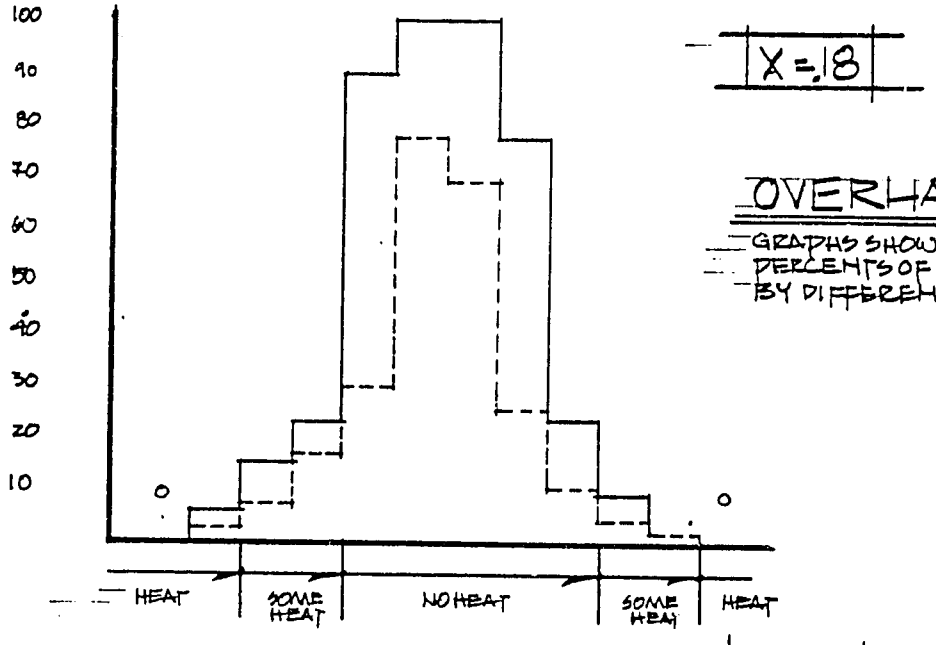
FIGURE 2: OVERHANG GEOMETRY

Other than in extreme cases of widely differing heights of glass on the north elevation, a single overhang depth is recommended. The RET project has a simple calculator program to assist in determining overhang depth given solar window height and the distance between the overhang and the top of the window. Ask for the "Sun Shade" program.

Curtains and Palimset

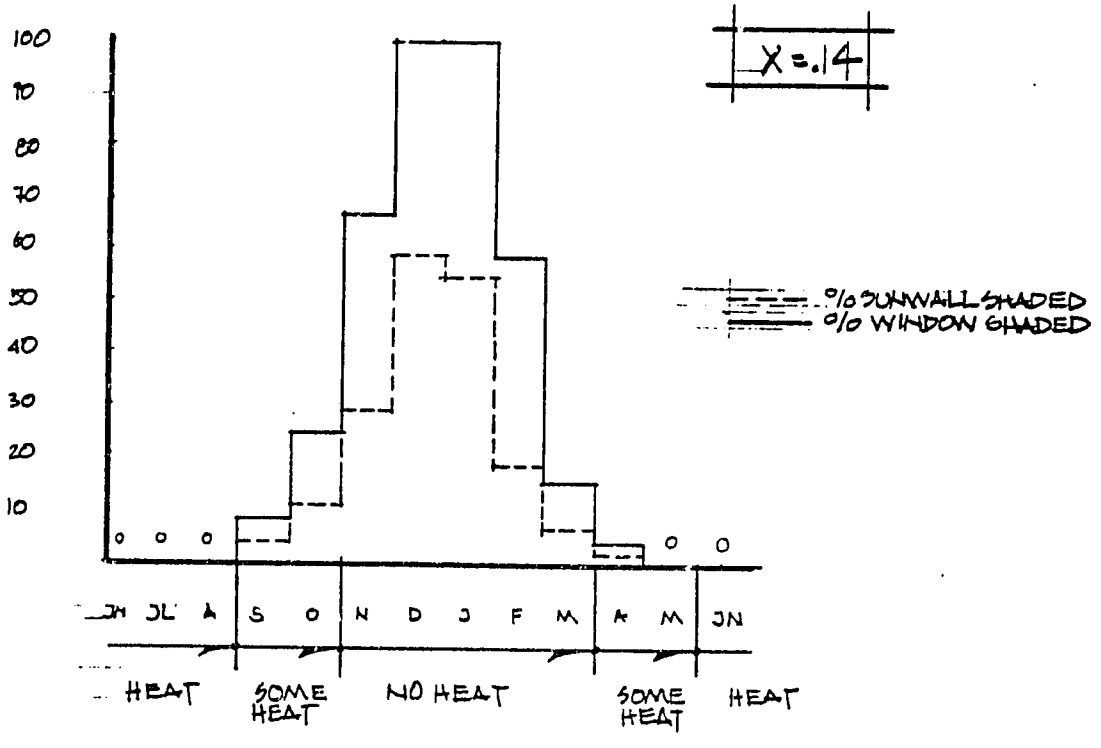
Basotho use curtains for privacy. They are also a help thermally as they insulate windows when drawn at night. Typically, there are two curtains, an exterior lace curtain which is drawn during the day for privacy and diffuse light, and a heavier curtain drawn at night to provide insulation and greater privacy. During the day, both curtains are often drawn for security reasons if no one is home. Curtains drawn against sunlight are excellent for privacy, security and light diffusion, but wreak havoc with solar gain. This is demonstrated in Graph 6



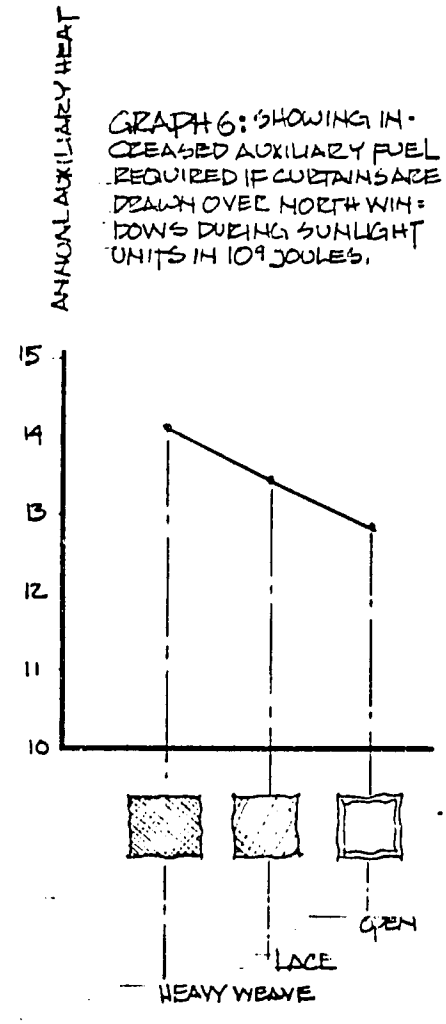


OVERHANGS

GRAPHS SHOWING DIFFERENT PERCENTS OF APERTURE SHADED BY DIFFERENT OVERHANG DEPTHS (x)



which shows the percentage rise in annual auxiliary heating required in the C4 core house when no curtains, a lace curtain, and lace and medium curtains are drawn during the day. The seven percent increase in annual auxiliary heating required when the curtains are closed clearly suggests that both curtains should be left open during the day if someone is at home.

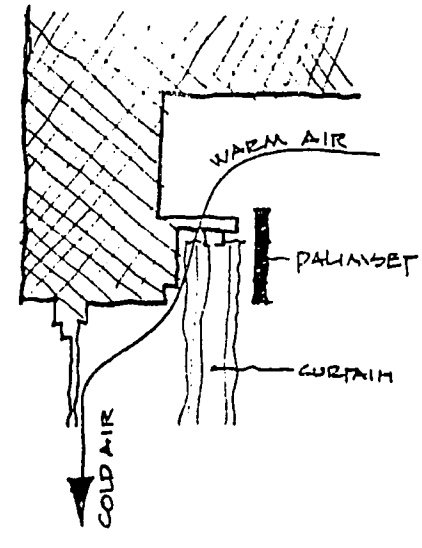


GRAPH 6: SHOWING INCREASED AUXILIARY FUEL REQUIRED IF CURTAINS ARE DRAWN OVER NORTH WINDOWS DURING SUNLIGHT UNITS IN 10^9 JOULES.

The nighttime insulation value of curtains is not great. A computer run resulted in only a one percent drop in annual auxiliary heating with both curtains drawn at night, compared to no curtains. While it is a reduction, and so should be done, there is clearly room for improvement. (See Appendix B, EC Detail D-9.)

Although night curtains may not save much fuel, they eliminate a cold radiant surface--the window--from the thermal environment. Because human comfort is much more attuned to radiant surfaces than air temperature, one <u>feels</u> significantly warmer with the curtains drawn, regardless of the fuel savings.

Existing palimsets are primarily a decorative shield to cover curtain hardware, and many are open at the top. At night, this puts warm air in contact with cold glass and causes the then cooled air to drop. This creates drafts inside and loses heat to the outside. Sealing the top of the palimset (see Appendix B, EC Detail D-9) will improve its insulation value considerably.



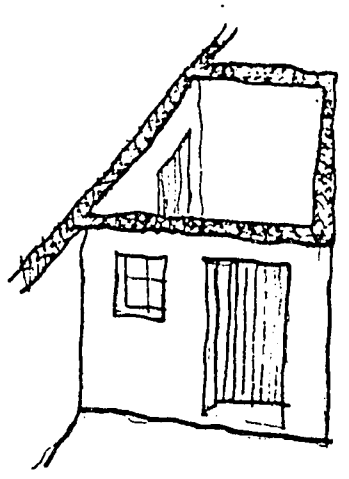
SEAL THE PALIMSET. REDUCE DRAFTS. SAVE HEAT

Doors

The standard meranti wood door is excellent--wood being a good insulator and its construction, typically solid and wind resistant. Wood door frames are preferred to steel because wood is a better insulator and is easier to attach weather stripping to. The major problem with doors is infiltration gaps on all four sides, particularly at the threshold. A weatherproof threshold and

continuous weather stripping on a well-hung door will improve its performance significantly. For a door that is already poorly hung, a curtain hung over it and sealed at the edges and top will help. (See Appendix B, EC Detail D-10.)

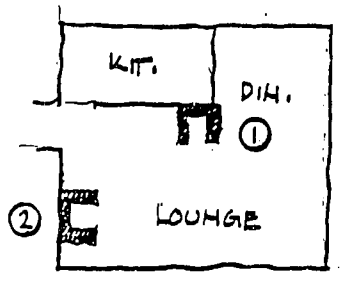
An extreme, but worthwhile, solution to door infiltration is the double door, or air lock, entry. This has a tradition in Lesotho in the wind walls roofed over at the rondavel entrance. The thermal strategy is never to leave an open passage for heat out or cold in at the entrance. To accomplish this, an entry is created where one door must close before the other opens. The greater the amount of traffic in and out, the more important an air lock entry is.



"AIR LOCK" ENTRY

Fireplaces/Room Heaters

In many cases, a conflict exists between the two functions of a fireplace and room heater. For instance, locating the fireplace against an outside wall is a problem from a room-heating perspective because it creates a high local temperature difference (see "Corrugated Iron Roofing" for discussion). Nevertheless, it may be the ideal location for the hearth as a focus for the central family sitting place. On the other hand, putting the room heater at the junction of kitchen, living and dining areas may make it an ideally centralized heat source, but difficult to use as a hearth. In any event, do not locate either fireplace or room heater against an outside wall.



① IS THE MOST CENTRAL LOCATION FOR A ROOM HEATER.

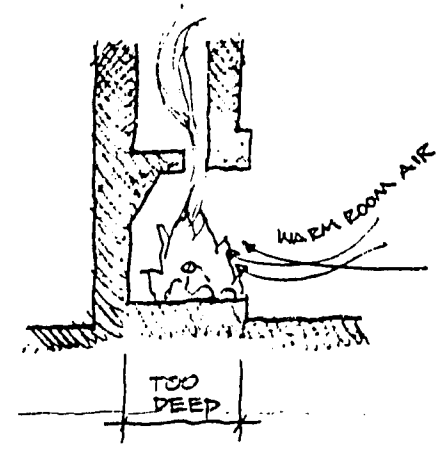
② IS THE BEST LOCATION FOR A HEARTH.

LOCATION CONFLICT

Open-hearth fireplaces are not recommended. They lose more heat than they provide because the air required for combustion comes from inside the room and and is exhausted out the chimney. The heat in the air exhausted is typically greater than that radiated back to the room from the fireplace. A solution is to provide outside combustion air. Another is a glass and metal cover over the fireplace opening that has adjustable dampers. In all

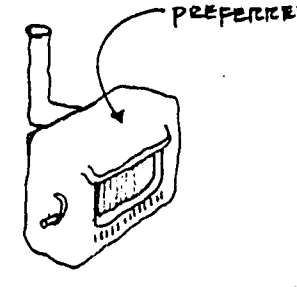
cases, a good adjustable flue damper is a must to regulate the burning rate and should be shut tightly when the fireplace is not in use. This keeps warm air in the room from exhausting out the chimney.

Another problem with open-hearth fireplaces is the typical deep hearth design. A fireplace heats primarily by radiation and the shallower the hearth, the more effective the radiation. By the same token, a freestanding fireplace is preferable, as it can radiate heat from all four sides.



TWO BIG PROBLEMS WITH OPEN HEARTHS

The popular commercial metal insert units are all open-hearth designs, so they are not efficient room heaters. However, many do incorporate air circulation around the back of the hearth which improves performance. A freestanding unit is again preferable because the unit and flue are fully exposed and so, lose heat to the room. Note that it is best to fully expose the flue, but if it is sheathed by a brick chimney, the heat it gathers should also be vented to the inside.



LOCALLY AVAILABLE EN-CLOSED COAL BURNER.

Enclosed, air-circulating, thermostatically controlled, anthracite coal-burning units that are freestanding and have an exposed flue pipe are the best room heaters. Most come equipped with a viewing glass which at least provides the glow of an open-hearth design. Two recommended units are available in Maseru.

Domestic Hot Water Heating

As a rule, "at-the-tap" or demand hot water heaters are recommended from an energy-saving standpoint, as there is less hot water standing around losing heat in pipes and a poorly insulated tank. Electric demand heaters are better than gas, if gas requires a constantly lighted pilot. If gas units can be purchased with electronic ignition, they would be preferred. Pilot lights use a lot of gas just staying lit.

It is far preferable to locate a storage hot water unit inside the heated house, and even then an insulation jacket should be added. If it must be located in the cold attic, purchase an insulating jacket or gather 100 millimeters of fiberglass insulation around it. Avoid locating the unit in the attic if possible.

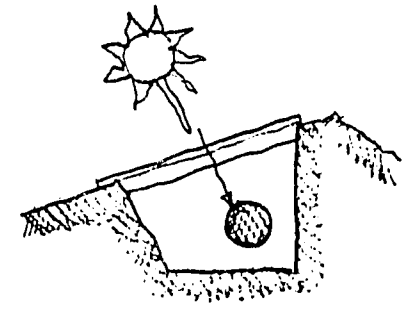
"Side-arm" water heaters that operate off a coal-fired stove are a sensible option, although their water storage capability is minimal. Coal is relatively cheap, and if hot water heating occurs as a by-product of cooking, it is an efficient system. If the fire is lighted exclusively to heat water, it is inefficient because too much heat is lost bringing the stove to the point where it can heat the water.

Flue-gas heat recovery is an effective method of preheating water which needs further research and product development.

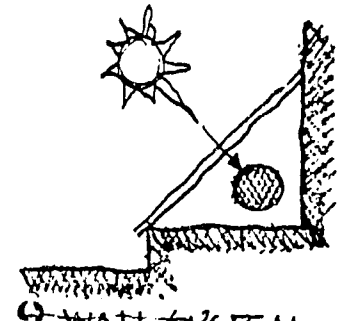
<u>Solar Domestic Hot Water Heating</u>

If solar hot water heaters are reasonably designed, manufactured and installed, the Lesotho sunshine should heat water. In Appendix B, EC Details 5, 6, 7 and 8 outline a roof-mounted, wall-mounted and Sunshelf series of "batch"-type, passive water heaters. All can be built from locally available materials (with the possible exception of Filon glazing), and two are assumed to be within the capabilities of a homeowner with modest construction skills. The roof-mounted system is to be installed at the time of construction.

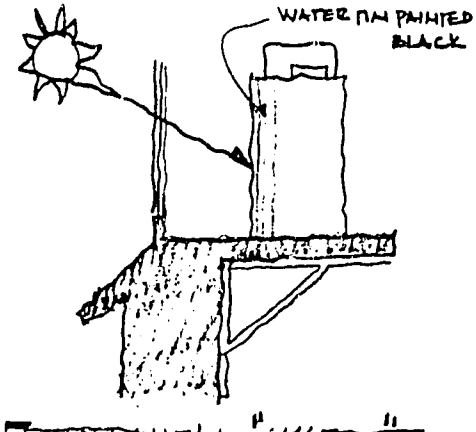
No analysis has been performed to determine relative efficiencies, though the roof and wall systems should compare favorably with commercially available systems (M650 installed). If installed by the homeowner, costs should be significantly below those for similar commercial systems. The contractor installed cost of the roof system is M350,



1 ROOF SYSTEM



2 WALL SYSTEM



7 SUNSHELF "SYSTEM"

SOLAR HOT WATER SYSTEMS

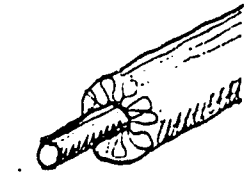
wall system, M580, and Sunshelf system, M100. (Figures supplied by the QS unit of the Ministry of Works.)

Flow Restrictors

Of all the energy-conserving products, perhaps the most cost-effective is the flow restrictor. Used on a tap or shower head, it reduces the quantity of hot and cold water permitted out of the fixture. Totally aside from the issue of conserving energy used to heat water, it is surprising not to find such devices available, much less in widespread use, in a country such as Lesotho where there is a scarcity of water.

Hot Water Pipe Insulation

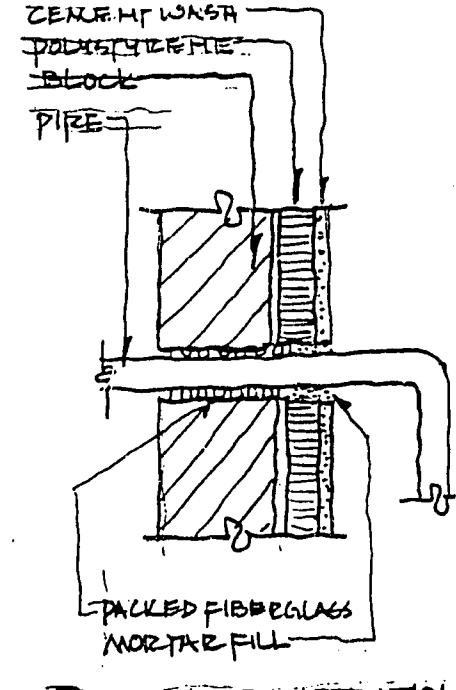
All hot water pipes, even those which run inside the building, should be insulated. All pipes from any solar water preheater should also be insulated. Use 20 millimeters wall thickness below 2,000 meters and 30 millimeters above.



INSULATE HOT WATER PIPES. KEEP WATER HOT.

Piping

Whenever possible, avoid ANY PENETRATION OF THE OUTSIDE WALL. Clearly, this will be difficult in Lesotho where plumbing usually runs through the back walls. However, the penetrations do provide an excellent path for infiltration, so care should be exercised to see that both sides of the penetration are packed tightly with fiberglass insulation and then with mortar.

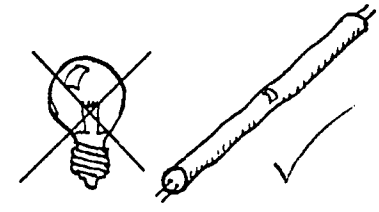


PACK THE PENETRATIONS

Electricals

First, where possible, again avoid any penetration of the outside walls. This means mounting the meter outside any exterior insulation, as well as placing all receptacles on interior partitions. Second, do not install recessed light fixtures as they provide an escape route for heat. Third, use fluorescent lighting in all

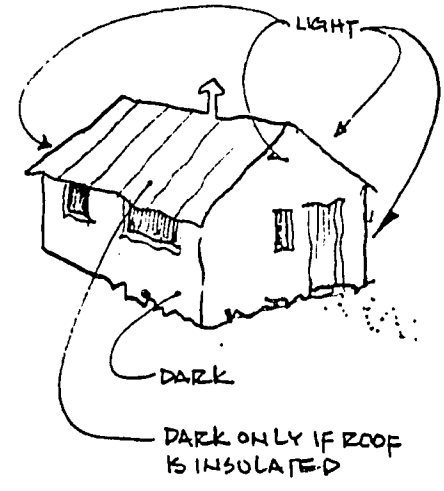
utility areas, such as halls, rear entries, kitchens and bathrooms. It is much more energy-efficient than incandescent lighting. Fourth, purchase energy-efficient appliances. Most major appliances presently come with some form of energy information or rating. Ask for it.



USE FLORESCENT

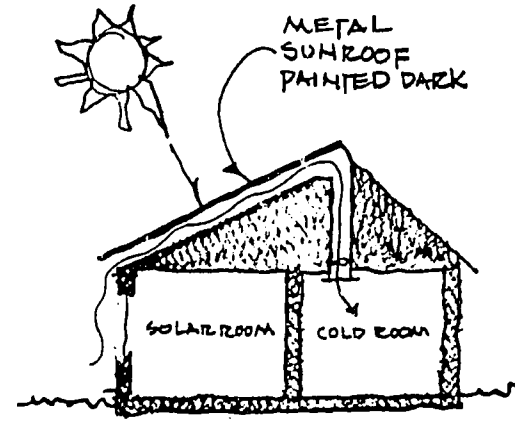
Paint and the Passive Solar Roof

The east face of the rondavel is typically smeared a dark color. Dark colors absorb heat, so the east wall heats up quickly, making it comfortable to stand in front of first thing in the morning. This is a wise tradition. Computer analysis suggests that there may, in fact, be some modest net heat gain through a dark north wall on a sunny winter day. So, paint the north wall dark.



DARKS & LIGHTS

Contrary to accepted practice, it is recommended that north-facing roof areas be painted a darker color, but <u>only</u> if the roof is properly insulated and ventilated. This will heat the ceiling space or attic and also help retard heat loss. Going one step further, the whole roof surface can be made into an active solar collector. (See Appendix B, EC Detail D-4.) Heated air rising off the dark surface of the north wall can be introduced and contained along the underside of the corrugated metal roof. If the roof is painted a dark color, the solar heat absorbed will be transferred to preheated air, which will make its way up the roof slope to the peak by natural convection. At the peak, the warm air can be gathered in a trunk duct and then forced by fan down into cold rooms on the building's south side.



SUNROOF: BUT DOES IT WORK???

This system is totally speculative and should be applied with extreme caution. There are many potential problems. First, it is unknown whether enough heat will be generated to justify what is a simple, but relatively costly, system. Second, and most critical, the success of the system depends to a significant degree on the air being contained

by the corrugated roofing, a capability it does not presently possess.

Note that while north-facing sections of a roof should be painted a dark color, those facing south should always be painted a light color. This helps reduce summer heat gains. For the same reason, east and west elevations should be painted a similar light color.

Internal wall and floor surfaces which serve to absorb and store solar heat should ideally be painted a dark color. More appropriately, they should at least not be a highly reflective color.

Solar devices should be painted black--matte black or, at least, a color which has a coefficient of absorption that approximates matte black. Consult with the manufacturer to select a paint which can withstand air temperatures in excess of 100°C. Also, be sure that the paint is thoroughly dry before enclosing the solar device. If it is not, outgassing may occur, and film deposited on the underside of the glass that is difficult to remove.

Appendix C lists the solar absorptance of various materials and can be used to assist in selection.

ENERGY : THE ECONOMICS

The Economics of Energy Conservation and Passive Solar Heating in Lesotho

This section seeks to quantify some of the costs and benefits of energy conservation and passive solar heating in Lesotho, including performance analyses run on the Pascalc solar performance prediction program by John Nicholson of the RET staff and cost analyses using figures provided by the QS staff of the Ministry of Works. It will also lay out "the most cost-effective path" for various conservation and solar options.

How much Basotho spend on space heating is not presently known and awaits results from a number of surveys of fuel use patterns that the RET project has underway. Given the lack of available data, accurate economic estimates of the impact of proposed conservation and passive solar techniques is, at best, a guess. This, coupled with the cultural/thermal bias implicit in the passive performance computer program (see "Performance and Cost Analyses") makes the economic waters as hazardous as the Wild Coast's.

There are other problems, too. Basotho use point-source heating--standing in front of a fire or electric resistance heater--not room air heating, such as a centralized system provides. Lesotho has acclimatized its citizens to accept extreme cold; as compensation, though, they require direct, local doses of extreme heat. Because Basotho, and not rooms, are being heated, the result is an acceptable, though possibly not optimal, level of thermal comfort at a relatively low cost.

The question of an optimal, not minimal, level of comfort is critical in determining the economic impact of passive solar devices and energy conservation techniques. If present heating levels do not produce a satisfactory level of thermal comfort, occupants may very well take the gains provided by increased thermal efficiency and increase the temperature, rather than enjoying decreased fuel costs, thereby spending as much as they do now for fuel. Thus, the return on their investment would be in terms of increased comfort, not maluti.

Performance and Cost Analyses

As simple as basic passive systems are, they are not easy to model, but they must be modeled to assess their economic value as heating systems. All analyses for the project were undertaken using Pascalc, a computer program developed by Total Environmental Action, Inc., which is run on a Texas Instruments' TI-59 programmable calculator.

The program predicts the annual performance of the passive system or combination of systems, by measuring the amount of auxiliary heat required to keep the building at a given internal temperature. (See Appendix D, Pascalc Introduction.) In doing so, it takes into account many climatic, building and user factors. (See Appendix D, Pascalc Data Requirements.)

For Lesotho, the program is most useful in parametric studies of various solar options, rather than accurately prdicting annual energy use. In other words, it can more accurately indicate a percentage reduction in energy use, as opposed to quantifying the energy saved. The reason is as much cultural as thermal. The program assumes both the desire and ability to maintain a given, constant temperature throughout the entire building, as is the case for U. S. housing. As already discussed, Basotho use point-source heating, keeping whole areas of the house cold. As a result, Pascalc over-predicts the auxiliary heat required.

It would be possible to adjust performance predictions to account for actual fuel use if such information were available. It is not, so our estimates (see "The Prototype Buildings") accept Pascalc predictions and then give values representing fuel savings of 100, 66 and 33 percent of the Pascalc prediction. When survey results are available, more accurate, corresponding fuel-saving figures can be developed.

Most Cost-Effective Path -- Big Budget

On the following page is a decision "tree" which effectively ranks nine different conservation and solar techniques according to cost-effectiveness, as determined by dividing the cost of purchasing and installing a given option by the predicted energy savings in gigajoules (gj). Obviously, the lower the cost per gj, the more cost-effective the option. Note also that the ranking determined by this method will not change with time or be rearranged by life-cycle cost analysis.

The analysis requires individual evaluation and comparison of the cost-effectiveness of all options, followed by selection of the most cost-effective option. Then, the building's performance is recalculated, including the selected option, to determine a new reduced energy base from which to evaluate and compare the remaining options. This iterative cycle is continued until no options remain. All analysis was performed on the LHC A3-type house--a 61-square meter, middle-income dwelling with good aspect ratio, a lot of north-facing glass and 50 millimeters of roof insulation already in place.

RANK	OPTION	ANNUAL AUXILIARY HEAT SAVED IN GJ	INSTALLED COST FOR WHOLE BLDG IN M.	COST PER GJ	ANNUAL AUXILIARY HEAT BALANCE IN GJ
1.	UNMODIFIED A-3	0	0	0	17.6
2.	REDUCE ROOF OVERHANG OVER PORCH WINDOW	1.8	0	∞	15.8
3.	ELIMINATE AIR BLOCKS & WEATHERSTRIP DOORS AND WINDOWS	4.5	130	29	10.7
4.	ADD 25 MM POLYSTYRENE INSULATION TO EXTERNAL WALLS & FOUNDATIONS	9.7	640	66	-1.53
5.	ADD 50MM FIBERGLASS INSULATION TO EXIST. 50 MM IN CEILING	.7	100	234	.24
6.	ADD 25 MM ADDITIONAL POLYSTYRENE TO WALLS	.10	130	948	.14
7.	ADD 50 MM ADDITIONAL F.G. CEILING INSULATION FOR 150 MM TOTAL.	.07	130	1760	.07
8	INCREASE NORTH GLASS AREA BY 25%	0	380	∞	0
9.	ADD 23 M² SUNWALL	NOT REQUIRED			

ANNUAL AUXILIARY HEAT: 0

ENERGY CONSERVA. INVESTMENT: M1510

BASE CASE BUILDING IS A LHC TYPE A3 HOUSE. ALL COSTS SUPPLIED BY QS SECTION, MINISTRY OF WORKS. ALL SIMULATIONS OF ENERGY PERFORMANCE CARRIED OUT USING PAS-CALC.

MOST COST EFFECTIVE PATH - BIG BUDGET

The first, and most striking, result is that with an investment of a little over M1,000, the auxiliary heat required is almost nil. Second, the costs for the first five options are reasonable, while those for the remainder are not. This is because the first five have left so little energy for the last three to save and the last three are the most expensive options, which is why a 100 percent energy-saving house does not make economic sense. Third, the last option is the first solar option considered, insulation options occupying the front ranks. Fourth, the sun-wall is not even considered because there is no more energy to save after the north glass is increased by 25 percent. Fifth, the first option--cutting back on the roof overhang to let sun into the lounge window--does, in fact, reduce construction costs, for which no economic credit is taken. Sixth, polystyrene wall insulation is a surprisingly strong option, ranked even before additional roof insulation. Seventh, the design is already assumed to have 50 millimeters of fiberglass in the roof which, if it were not included, would be the first, most cost-effective option.

Most Cost-Effective Path -- Limited Budget

The economic analysis on the following page assumes a limited amount of money is available to invest in saving energy. As a result, the analysis seeks the most cost-effective package of options given a certain budget.

RANK	ENERGY PACKAGE	COST	SAVINGS	COST/100
1.	UNMODIFIED A-3	0	17.6	0
2.	REDUCE ROOF OVERHANG OVER PORCH WINDOW & REMOVE VENT BLOCKS	0 (0)	1.8	0
3.	WEATHERSTRIP WINDOWS AND DOORS PLUS ALL OF #2	130 (2.10) *	3	43
4	VENT BLOCKS, OVERHANG, WEATHERSTRIP PLUS 50MM ROOF INSULATION ABOVE EXIST. 50	220 (3.50)	7.5	29
5.	VENT BLOCKS, OVERHANG, WEATHERSTRIP, + 25% NORTH SOLAR GLASS	270 (4.30)	7.5	36
6.	VENT BLOCKS, OVERHANG, WEATHERSTRIP, + 50 MM ROOF INSULATION, + 25% NORTH GLASS	360 (5.80)	8.7	41
7.	VENT BLOCKS, OVERHANG, WEATHERSTRIP, + 25% NORTH GLASS PLUS 100 MM ROOF INSULATION ABOVE EXISTING 50 MM	450 (7.30)	9.2	48
8.	VENT BLOCKS, OVERHANG, PLUS 25 MM POLYSTYRENE ON ALL EXTERIOR WALLS	650 (10.30)	12.3	53
9.	VENT BLOCKS, OVERHANG, 25 MM WALL INSULATION PLUS 50 MM ROOF INSULATION ABOVE EXISTING 50	850 (13.70)	15.7	54
10.	VENT BLOCKS, OVERHANG, + 50 MM ROOF INSULATION, + 25 MM WALL INSULATION, + 25% NORTH GLASS, WEATHERSTRIP	950 (15.30)	16.9	55
11.	VENT BLOCKS, OVERHANG, WEATHERSTRIP + 50 MM ROOF INSULATION, + 50 MM WALL INSULATION	1050 (16.60)	17.3	59

BASE CASE BUILDING IS AN LHC TYPE A3 HOUSE. ALL COSTS SUPPLIED BY QS SECTION, MINISTRY OF WORKS. ALL SIMULATIONS OF ENERGY PERFORMANCE CARRIED OUT USING DRYSCALC.

MOST COST EFFECTIVE PATH - LIMITED BUDGET

* NUMBER IN PARENTHESES IS COST PER M² OF FLOOR AREA.

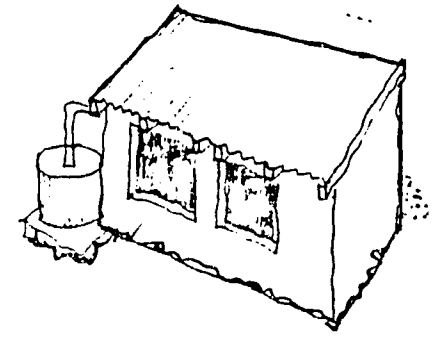
THE PROTOTYPE BUILDINGS

What follows is a brief description of the prototype energy-conserving buildings. Each was developed from an existing typical house design offered by a major institutional housing supplier. Each responds to the respective expectations and budgetary concerns of the low-, middle- and upper-income renter or purchaser. The result is a predicted annual savings on heating fuel ranging from 38 to 95 percent, depending on the unit.

The decision to develop prototypes from existing designs was based on a number of factors. First, existing housing designs are not so bad from an energy standpoint. Second, by choosing from existing plans, all of the major institutional housing suppliers became involved in the prototypes' design. Third, it provided base-case buildings to compare the prototypes with, both in terms of cost and energy performance. Fourth, because the prototypes already identify strongly with existing institutions and owner expectations, it is more likely that they will be built.

Each prototype carries with it a "simple-payback" analysis of the proposed energy conservation/solar package. The simple-payback analysis divides the total additional cost of the energy conservation package by the annual maluti value of fuel savings, as determined by Pascalc. The result is the number of years required for the system to "pay" for itself. This is a very crude analysis which does not reflect the variable impact on costs and benefits of interest rates, escalating fuel costs, maintenance and repair, etc. A more detailed and accurate analysis simply awaits more accurate estimates of real fuel savings and fuel cost escalation rates. In the meantime, the predicted fuel savings were assigned values ranging from where 100 percent of the Pascalc predicted value is saved, to values where 66 and 33 percent are saved.

C4·EC



The C4-EC is virtually unchanged from the LEH Co-op standard C4 core house. The C4 is a two-room, low-income, "self-help" dwelling with external latrine and no running water. It is built out of concrete block with a corrugated iron roof.

The existing 24-square meter design is a good basic energy design if oriented north. The aspect ratio (ratio of the building's length to its width) is reasonable, and its small amount of glass is typically concentrated on the front elevation, facing north. Presently, it is without a ceiling or insulation under the corrugated metal roof.

Much of the effort in modifying the C4 was directed toward the future when it is expected that the occupants will have greater disposable income and contemplate adding on to this tiny house. The design proposes additions in three phases. Each phase is designed with its own particular energy concerns in mind, but also with the idea of enhancing the energy savings accumulated during an earlier phase.

The modifications made to the C4 to create the C4-EC (energy-conserving) include:

1. Relocating the building to the middle of the 10 by 20 meters site, to permit more convenient future expansion.

2. Relocating the front door to the "rear" (south side) of the building to prepare for the permanent front door installed in Phase 2. At that time, the Phase 1 front door becomes an interior door.

3. Installing weather stripping and a draft excluder on the front door. Both can be transferred to the Phase 2 front door.

4. Adding two roof rafters flanking the internal partition to prepare for retrofitting an insulated ceiling in Phase 2.

5. Increasing solar glass on the north side by 66 percent.

6. "Disconnecting" the internal partition from the uninsulated external wall to reduce conductive losses to the outside and increase its effectiveness as a solar storage wall.

7. Providing for the location of a combination cooker/room heater against the internal storage wall.

8. Adding a solar-shelf to provide a sunny location for heating hot water in blackened food tins or plastic containers.

9. Reversing the roof slope to prepare for expansion, but also to make the overhang more easily used as a shading device.

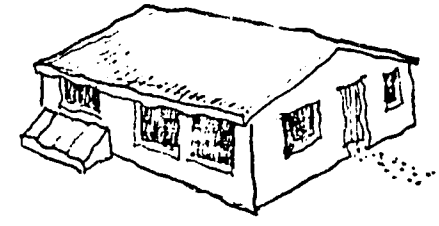
10. Providing for a gutter and storage tank to collect rainwater in rural areas where water is scarce.

11. Painting the north wall a dark color to retard heat loss.

12. Adding an enclosed palimset to improve the nighttime insulation value of curtains over doors and windows.

The cost and fuel savings which follow apply only to Maseru. The energy-conserving modifications to the C4 are expected to result in a 38 percent savings in the auxiliary fuel required to keep the C4 at a constant internal temperature of 14.3°C. Assuming that full energy-savings are realized and the fuel saved is paraffin, the cash savings will be M87. The conservation and solar options will add an estimated M394 to construction costs, so the straight-line payback period is four to five years. If a two-thirds fuel savings is realized, the payback will be six to seven years, and if a one-third fuel savings, 13 to 14 years. (These figures do not include the gutter and rainwater storage tank.)

A3·EC



The A3-EC is developed from the Lesotho Housing Corporation's A3 design. It has three bedrooms, bathtub inside and pit latrine toilet outside, small kitchen with sink and combined lounge/dining area. There is a recessed north entrance under a small porch. The building is middle-class housing and is one of LHC's more popular, as well as reasonable, models.

As is, the 61-square meter A3 is a good basic energy design. It has a large area of north-facing glass on the front elevation, and a reasonable aspect ratio (ratio of length to width. However, it is poorly insulated and, at present, has only 50 millimeters of fiberglass in the ceiling.

Modifications to the A3 to create the A3-EC (energy-conserving) include:

1. Relocating the entrance from the north to the west wall, where it can continue to serve as the entrance no matter what the site and solar contingencies. This also frees the north elevation for possible additional solar glass and eliminates the covered entrance in favor of increased area in the lounge.

2. Adding 100 millimeters of insulation in the ceiling above the existing 50. The added insulation should be increased to 150 millimeters if the altitude is above 2,000 meters.

3. Adding 30 millimeters of polystyrene to the south and west walls. If the altitude is over 2,000 meters, increase the polystyrene to 50 millimeters.

4. Adjusting the north overhang to optimize winter heating performance and summer shading requirements.

5. Adding 45 percent more north-facing glass, all of it direct gain.

6. Installing a "batch"-type, passive-solar water heater as an option on the north wall. This requires the elimination of some north glass in one of the bedrooms.

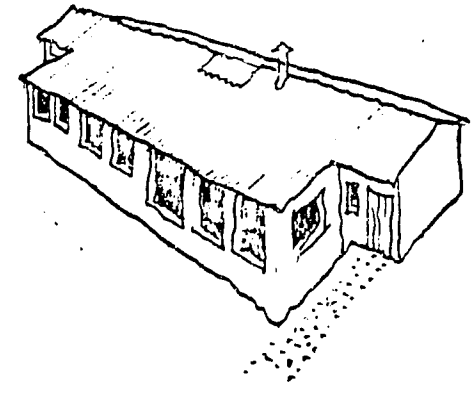
7. Providing for, though not installing, a high-efficiency, anthracite coal-burning room heater at an optimum location for space heating.

8. Adding weather stripping to all windows, and weather stripping and a draft excluder to the door.

9. Providing for timely expansion of the dwelling consistent with its high level of energy performance.

The following cost and fuel figures apply to Maseru only. The energy-conserving modifications to the A3 are expected to result in a 75 percent savings in the auxiliary fuel required to keep the A3 at a constant average temperature of 15.5°C. Assuming that full energy savings are realized and coal is the fuel, the cash savings will be M58. The solar and conservation options will add an estimated M902 to construction costs. Straight-line payback (the number of years it will take the fuel savings to pay off the investment) will be 17 years. Assuming a realized fuel savings of two-thirds, the payback will be 26 years; if one-third, 50 years. These figures include neither the cost nor the the savings resulting from the solar domestic hot water heater. They also do not take into consideration the energy impacts of additions to the original building, nor do they include the cost of the room heater. All of these items are at the option of the owner.

PITSO · EC



The Pitso-EC is developed from the Ministry of Works' design for the Pitso Mark 5. It has three bedrooms, one and a half baths, servant's quarters and a covered car park. It is intended for high-ranking civil servants and expatriates.

As is, the 167-square meter PM-5 is a good basic energy design, if oriented correctly to the north. It has both a large glass area on the front elevation and a reasonable aspect ratio (ratio of length to width). It is poorly insulated though and presently has only 50 millimeters of fiberglass in the roof.

Modifications made to the PM-5 to create the Pitso-EC (energy-conserving) include:

1. Relocating the detached servant's quarters to the east wall to eliminate one heat-losing external wall.

2. Shifting the carport from between the main house and the servant's quarters to a westerly location where it is a stand-alone structure and serves as a buffer against the setting summer sun.

3. Relocating the entrance from the north to the west wall, where it can continue to serve as the "front" entrance no matter what the access and solar conditions require. This also frees the north wall for possible additional solar glazing.

4. Creating "air-lock," double-door entries at both front and back access points to control door traffic infiltration.

5. Adding wing walls at the front entrance to reduce wind pressure and assist the carport in shading the west wall in the summer.

6. Eliminating the open-hearth fireplace in favor of a more efficient, freestanding, anthracite coal-burning room heater, relocated to a more central internal wall.

7. Introducing outside combustion air to the room heater.

8. Adding 100 millimeters of fiberglass insulation to the existing 50 millimeters in the ceiling. The insulation added should be increased to 150 millimeters if the altitude is above 2,000 meters.

9. Weather-stripping all windows and adding weather stripping and draft excluders to all outside doors.

10. Adding 30 millimeters of polystyrene insulation to all external walls and the foundation. If the altitude is over 2,000 meters, the insulation should be increased to 50 millimeters.

11. Increasing the north-facing glass by 27 percent. Solar aperture is allocated to direct gain (54 percent) to cover daytime temperature requirements and to Sunwalls (46 percent) to handle nighttime needs.

12. Reducing the overhang from .8 meters to .3 meters to optimze winter heating and summer shading of the solar aperture.

13. Painting the north wall a dark color to increase its performance as an unglazed Sunwall and retard north-wall heat loss at night.

14. Painting all other wall surfaces a light color to reduce summer heat gain.

15. Introducing a Sunroof to provide solar heat collected by the metal roof to the south-side spaces. This is an experimental system.

16. Installing a batch-type, passive water heater under the roof in the attic.

17. Replacing incandescent light fixtures with fluorescent ones in all "utility" areas.

The cost and fuel savings given below are for Maseru only. The energy-conserving modifications to the Pitso are expected to result in a 95 percent reduction in the auxiliary heat required to keep the building at a constant average temperature of 16.5°C. Assuming that full energy savings are realized and electricity is the fuel saved, this will result in a cash savings of M795 if electricity is valued at M.05 per kilowatt-hour. The conservation and solar modifications will add an estimated M6,000 to construction costs. The straight-line payback (the number of years it takes for the fuel savings to pay off the investment) is 7.5 years. Assuming that two-thirds of the energy savings are realized, the annual fuel saved is worth M525 and the payback is 11.5 years; if one-third, the savings are worth M263 and the payback is 23 years. This analysis does <u>not</u> include the cost or savings resulting from the roof-mounted solar domestic hot water system or the Sunroof.

Appendix A

THE THERMAL MASS PATTERN BOOK
Guidelines for Sizing Heat Storage in Passive Solar Homes
Total Environmental Action, Inc.
Harrisville, NH 03450

Thermal Mass

The use of thermal mass in passive solar houses is conceptually simple: mass materials, such as brick or concrete, store and later release heat energy entering through the passive aperture (south-facing glazing area). When properly used, thermal mass prevents stifling daytime overheating and chilly nighttime temperatures in the living space. Improperly used, however, thermal mass may be ineffective.

Total Environmental Action, Inc. (TEA) has discovered through consulting and reviews of hundreds of passive solar homes that, while designers often incorporate correct total quantities of mass, the location and configuration is often not adequately treated. In order to help architects, designers, and builders create more efficient passive solar homes, TEA has brought together a number of existing rules-of-thumb for sizing thermal mass and prepared them as architectural patterns.

How to Use This Booklet

Five patterns are shown. Each is a basic architectural configuration of thermal mass often found in passive solar homes. For each of these patterns, four interrelated factors describing the sizing characteristics of the thermal mass system are given in a mass sizing table:

1. The passive solar aperture area
2. The mass surface area
3. The mass material type
4. The mass thickness

Depending on which of these variables is assumed fixed, the designer can use the patterns in a number of ways. Turn to Pattern 1 on page 3. In this configuration, for example, 3-inch thick concrete requires 5 square feet of surface area for each square foot of aperture area. If the aperture area is known, it can be multiplied by that number to identify the total mass surface area required. For example, if the total aperture area is fixed at 100 square feet, then 500 square feet (5 x 100) of 3-inch thick concrete would be necessary. Conversely, if the total surface area of the mass is fixed, it could be divided by the number in the table to determine the allowed aperture. In this instance, if you plan to use 500 square feet of 3-inch concrete in a Pattern 1 configuration, then the total allowed aperture area will be 100 square feet. Thus, the tables can be used to make trade-offs between aperture area and mass surface area, or to try out optional configurations for the system by using a different pattern. Finally, the type and thickness of various mass materials for each configuration and aperture size can be evaluated. In this way, a number of complete systems can be quickly sized so that cost and other design implications can be seen.

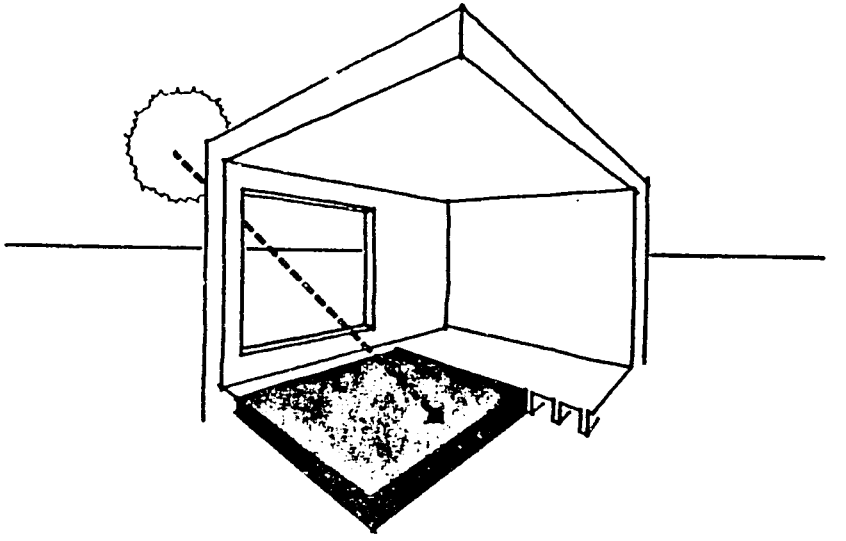
Note that the term "allowed aperture area" refers only to the mass configuration being analyzed. In an actual passive building, several types

and configurations of mass combine to store heat and prevent overheating. Using the patterns, each of these can be analyzed separately and a total "allowed aperture" for the building derived. Later in this booklet, a simplifying assumption to account for normal residential wall finishes, furniture, etc. is given so that in preliminary analysis the designer can focus on the specific house elements that are used for heat storage. Note also that these tables were developed for an assumed optimal performance for the thermal mass. The penalty for using more than the allowed aperture area is some degree of overheating. This can result in reduced efficiency of the passive system if the overheating causes the occupants to open windows and vent heat that might otherwise be stored to offset nighttime heating loads.

In some situations it may be necessary to interpolate between Patterns 1 and 2 to determine the amount of mass area. It is important to note whether each type and configuration of mass is exposed to sunlight all day long or for only part of the day. If it is exposed all day (i.e., about six hours), Pattern 1 numbers apply. If it is exposed *none* of day, Pattern 2 applies. If, however, the mass is exposed for only a fraction of the day, follow these steps:

Interpolation procedure	Example
1. Determine the mass material and thickness	Assume 6-inch thick concrete
2. Identify the required surface area from Pattern 1.	3
3. Identify the required surface area from Pattern 2.	5
4. Subtract the Pattern 1 number from the Pattern 2 number.	5 – 3 = 2
5. Determine the fraction of the day the mass is exposed to the sun.	Assume ⅓ of the day (i.e., about 2 hours)
6. Multiply that fraction by the result in Step 4.	2 × ⅓ = ⅔
7. Subtract the number identified in Step 6 from the number identified in Step 3.	5 – (⅔) = 4⅓
8. The resulting number equals the square feet of mass surface area required for each square foot of passive aperture.	4⅓ square feet of 6-inch thick concrete are needed for each square foot of passive aperture.

Pattern 1: Floor or Wall in Direct Sunlight.

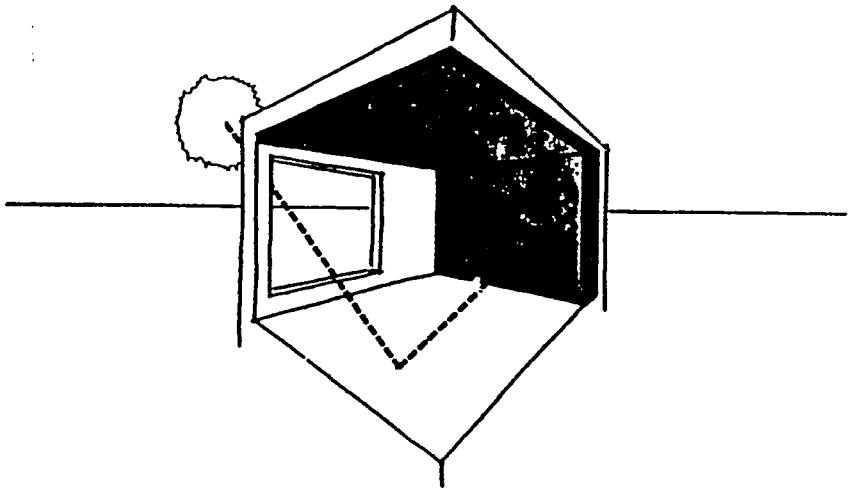


This pattern is defined as thermal mass that has one surface exposed to the living space and a 'back' surface that is insulated. The exposed surface is further defined as being in direct sunlight for at least six hours a day. Architecturally, this pattern combined with Pattern 2 is useful for direct gain passive rooms. The mass can be either a directly irradiated floor slab as shown, or a directly irradiated exterior wall. As with Patterns 2 and 3, the mass element is one-sided, that is, heat moves into and out of the mass from the same surface.

Mass Sizing Table

Material Thickness	Directly Irradiated Mass Surface Area to Passive Aperture Area Ratio				
	Concrete	Brick	Gypsum	Oak	Pine
½"	-	-	76	-	-
1"	14	17	38	17	21
1½"	-	-	26	-	-
2"	7	8	20	10	12
3"	5	6	-	10	12
4"	4	5	-	11	12
6"	3	5	-	11	13
8"	3	5	-	11	13

Pattern 2: Floor, Wall or Ceiling in Indirect Sunlight.

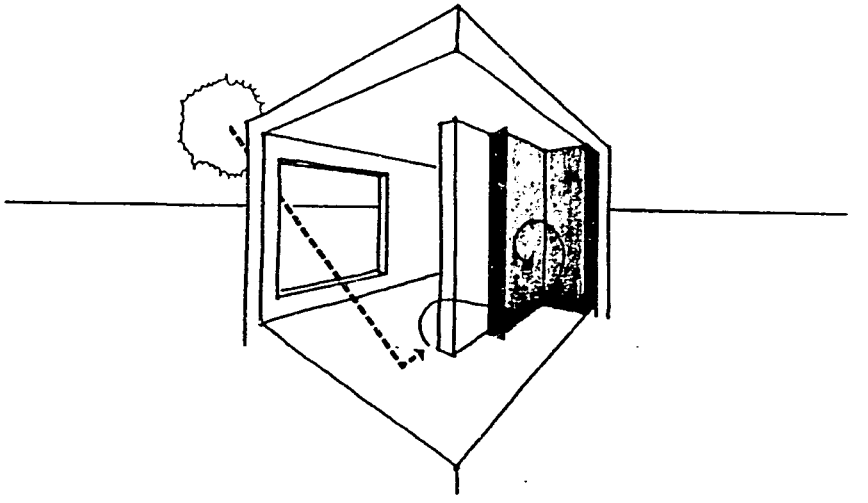


The mass in this pattern is defined in the same way as in Pattern 1, that is, the mass is one-sided and insulated on the back side. The distinction here is that the mass is not receiving direct beam radiation, but rather reflected sunlight. In a simple direct gain space, some of the mass will be a Pattern 1 case (perhaps a floor slab near the aperture, for example), and some mass will be a Pattern 2 case (perhaps the ceiling, for example). Much of the mass in such a space will be directly irradiated some of the time and indirectly sunlit for the rest of the day. In these cases an interpolation between Patterns 1 and 2 must be carried out, as described earlier.

Mass Sizing Table

Material Thickness	Indirectly Irradiated Mass Surface Area to Passive Aperture Area Ratio				
	Concrete	Brick	Gypsum	Oak	Pine
½"	-	-	114	-	-
1"	25	30	57	28	36
1½"	-	-	39	-	-
2"	12	15	31	17	21
3"	8	11	-	17	20
4"	7	9	-	19	21
6"	5	9	-	19	22
8"	5	10	-	19	22

Pattern 3: Floor, Wall or Ceiling Remote from Sunlight.

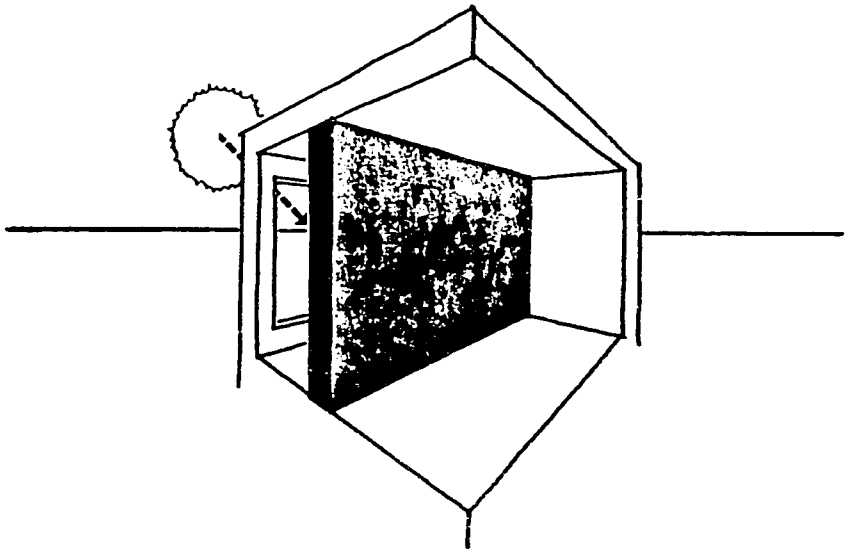


As in Patterns 1 and 2, the mass in this pattern is one-sided. The distinction here is that the mass material is charged neither by direct radiation nor by reflected radiation, but rather is heated by the room air that is warmed as a result of solar gains elsewhere in the building. Architecturally, this pattern is useful for mass materials in spaces deeper within a passive building, away from the rooms receiving solar gains. However, the solar-heated air must reach the remote mass either by natural or forced convection. Reasonable judgement is required here—a hallway open to a south room could be included; a back room totally closed off from the solar heated spaces could not be included.

Mass Sizing Table

Material Thickness	Remote Mass Surface Area to Passive Aperture Area Ratio				
	Concrete	Brick	Gypsum	Oak	Pine
½"	-	-	114	-	-
1"	27	32	57	32	39
1½"	-	-	42	-	-
2"	17	20	35	24	27
3"	15	17	-	26	28
4"	14	17	-	24	30
6"	14	18	-	28	31
8"	15	19	-	28	31

Pattern 4: Mass Wall or Waterwall in Direct Sunlight.

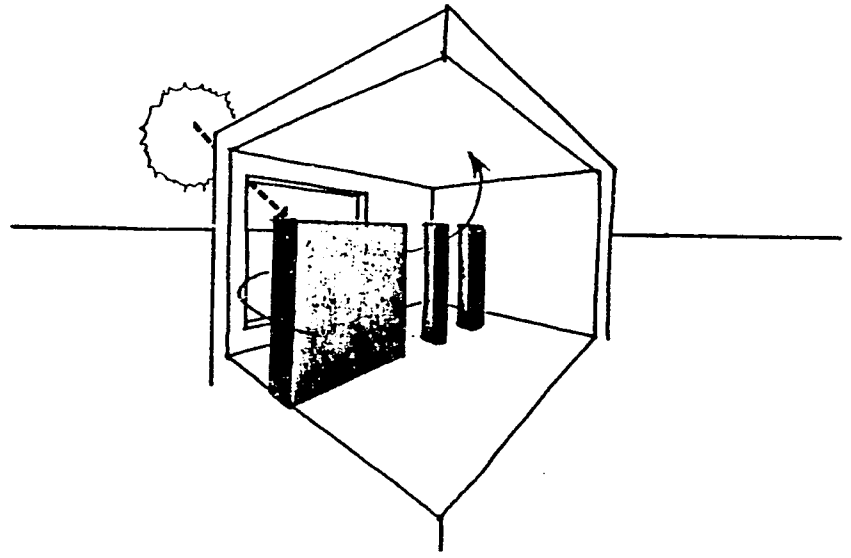


This pattern is defined as a wall of massive material that is directly irradiated on one side and exposed to the living space on the other side. Further, the wall is defined as being continuous from sidewall to sidewall and from floor to ceiling; the sunlit side is isolated from the living space side. This pattern is useful for Trombe walls where a high temperature on the sunlit side causes no discomfort since the space between the wall and the aperture is not a living space. The mass wall may have high and low vents or be unvented as shown without affecting the values in the table. Generally, the performance of the wall improves with thickness up to about 18" but is not very sensitive to variations in thickness within normal buildable ranges. For sunlit mass walls of brick, higher density bricks (water absorption less than 6%) are recommended over bricks of lower density. Note that the "mass surface area" refers to the sunlit side only.

Mass Sizing Table

Material	Irradiated Mass Surface Area to Passive Aperture Area Ratio
Brick 8" Thick	1
Concrete 12" Thick	1
Waterwall 8" Thick	1

Pattern 5: Partial Mass Wall or Water Containers in Direct Sunlight.



This pattern is similar to Pattern 4 in that the mass is directly irradiated on one side and exposed to the living space on the other side. The distinction in this pattern is that there is free air circulation around the mass material so that heat may be gained to the living space from either side of the partial wall (or from all sides of a water container). Architecturally, this may represent a freestanding mass wall or a series of water containers located within a direct gain space. Unlike Pattern 4, the space between the mass element and the aperture is considered part of the living space of the room. The mass is assumed to be directly irradiated for the entire solar day (6 hours). Like Pattern 4, the wall thicknesses listed are not very sensitive to variations, and the wall surface area listed is for one side of the wall only. Water containers are listed as gallons per square foot of aperture.

Mass Sizing Table

Material	Irradiated Mass Surface Area to Passive Aperture Area Ratio
Brick 8" Thick	2
Concrete 6" Thick	2
Watertubes or Drums	At least 7 gallons of water per square foot of passive aperture.

Notes and Assumptions

Several methods for predicting the heating performance of passive solar houses have been published. Most significantly, J. Douglas Balcomb and others at the Los Alamos Scientific Laboratory have contributed the LCR (Load Collector Ratio) methods for predicting the heating performance of mass wall and direct gain passive systems. These methods are described in Balcomb's *Passive Solar Design Analysis*.

Inherent in the performance prediction methods are several assumptions. Variables include an allowed temperature control range of 65 °F to 75 °F (heating is needed below 65 °F and excess heat is vented above 75 °F) and the amount of thermal mass incorporated into the building. If the temperature control range is allowed to broaden, the house will require less auxiliary heating; this is something the occupant can alter by adjusting the thermostat. Once a house is built, however, it is very difficult to alter the amount of thermal mass.

The effective thermal mass capacity, or a material's ability to store and release heat on a daily basis, can be measured using Balcomb's methods. Not all configurations of materials are effective. For example, a directly exposed concrete wall or floor thicker than 8 inches will not reduce temperature swings in the living space beyond what would happen with only an 8-inch wall or floor. Material beyond the 8-inch thickness is simply too deep to participate in the daily storage and release of heat.

Balcomb's assumed thermal properties were used for concrete, brick, and pine wood. The values for oak and gypsum were taken from the 1977 *ASHRAE Handbook of Fundamentals*. The values assumed for solar absorptance were: concrete $\alpha = 0.8$, brick $\alpha = 0.8$, gypsum $\alpha = 0.5$, oak and pine $\alpha = 0.7$. As with any other rules-of-thumb, some variations in actual material properties can be expected in an actual constructed system. Further, variations in properties such as absorptance and density can be consciously altered by the knowledgable designer to achieve a desired overall performance.

Concrete masonry units in the density range of 120 to 140 lbs./cu. ft. are similar to the concrete assumed in the tables and are included under the general heading of "Concrete".

For all of the patterns, it is assumed that the mass material is *solid* throughout its thickness (that is, no voids or other insulating layers occur within the material) and that the surface areas given in the tables are *exposed* directly to the sunlight or room air. For example, floor slabs counted as mass should not be covered with rugs; mass walls should not be finished with wallboard furred out from the mass wall. Anything that interrupts the conductive flow of heat within the mass material or insulates the mass from the living space it is supposed to serve is to be avoided as this significantly reduces the effectiveness of the mass.

As you work with the patterns, several interesting points about using thermal mass effectively will become evident. For example, in the simplest case of directly irradiated mass materials, Pattern 1, some very different architectural materials have an equivalent performance as effective thermal mass:

20 square feet of 2-inch thick gypsum,
3 square feet of 6-inch thick concrete, and
5 square feet of 4-inch thick brick.

All of the above represent the correct amount of thermal mass for one square foot of solar aperture. Notice also that the effectiveness of the mass is directly related to its location. For example, using 4-inch brick as the mass material, the following mass surface areas are required for each square foot of aperture:

5 square feet if located in direct sunlight (Pattern 1),
9 square feet if located in indirect sunlight (Pattern 2), and
17 square feet if remotely located (Pattern 3).

Degree Days per year	Average January Temperature °F	Percent Floor Area Allowed in Glass: Average House* (UA = 600)	Percent Floor Area Allowed in Glass: Well Insulated House** (UA = 300)
4000	40	11	6
5000	30	13	6
6000	25	13	7
7000	20	14	7

*equals approximately R-11 walls, R-19 ceiling, double-glazed windows
**equals approximately R-25 walls, R-38 ceiling, triple-glazed windows

These examples imply that if thermal mass materials are to be *added* to a non-massive structure, the patterns should be studied with the intent of locating the mass in the most effective configurations so that the least total quantity (and cost) need be added for the desired size passive solar system. Also, it must be recognized that all architectural materials function to some extent as thermal mass and that even non-massive construction contributes some thermal mass. Otherwise, even non-solar houses with very small aperture areas would overheat on a sunny day. The values for basic construction materials, such as ½-inch gypsum board, are included in the mass sizing tables so that these materials can be considered.

TEA's experience with well-insulated, light frame houses suggests that additional thermal mass is not necessary to prevent overheating when the solar aperture is less than a particular percentage of the floor area. This is related to climate in the table above.

As a very rough first approximation of mass requirements for a large aperture passive solar system, the designer can simply subtract from the total aperture area an amount equal to the percentage of the floor area from the above table and use the patterns for added thermal mass in relation to the remaining solar aperture. This shortcut is useful for residential light frame construction and takes into account normal home furnishings and wallboard finishes. If this method is used, gypsum board, for example, would not be evaluated using Patterns 1 or 2, and Pattern 3 would normally not be used at all.

More detailed discussions of thermal storage are contained in the following:

ASHRAE Handbook of Fundamentals. New York, the American Society of Refrigerating, and Air Conditioning Engineers, 1977.

Balcomb, J.D., et al. (Los Alamos Scientific Laboratory). *Passive Solar Design Handbook, Volume Two of Two Volumes: Passive Solar Design Analysis.* U.S. Department of Energy, 1980. (Available from NTIS, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161. $14.00)

Fuller, Winslow and Lewis, Daniel. "Overheating in Light and Heavy Mass Houses." *Proceedings of the Third National Passive Solar Conference.* San Jose, CA, 1979.

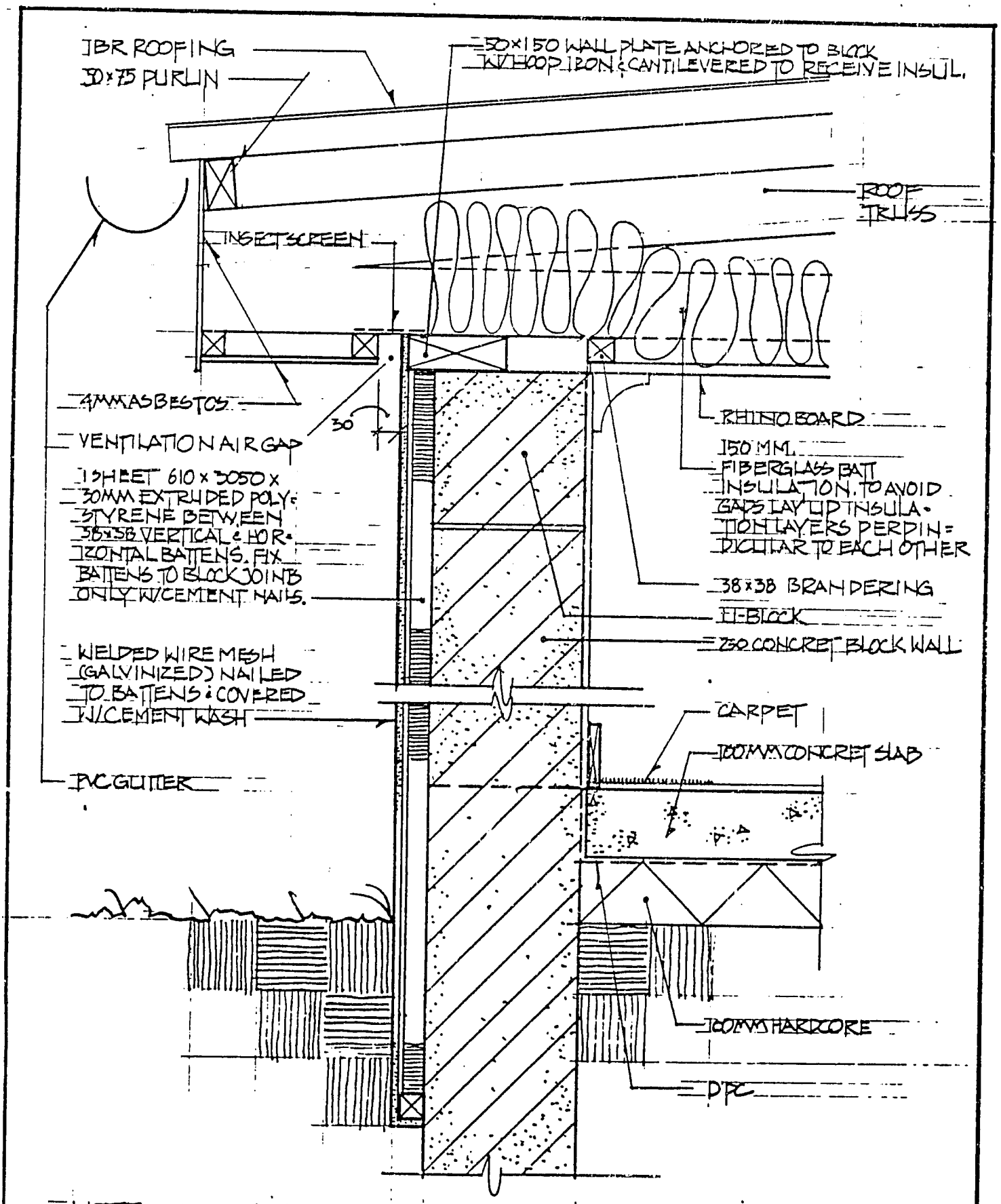
Lewis, Daniel; Michal, Charles; and Pietz, Paul (Total Environmental Action, Inc.). *Design of Residential Buildings Utilizing Natural Thermal Storage.* U.S. Department of Energy, 1979. (Available from NTIS, see address above. $14.00)

Total Environmental Action, Inc. *The Brookhaven House.* TEA, 1979. (Available from TEA, Church Hill, Harrisville, NH 03450. $2.00)

Wilson, Alex. *Thermal Storage Wall Design Manual.* New Mexico Solar Energy Association, 1979. (Available from NMSEA, P.O. Box 2004, Santa Fe, NM 87501. $4.00)

Appendix B

ENERGY-CONSERVING DETAIL DRAWINGS

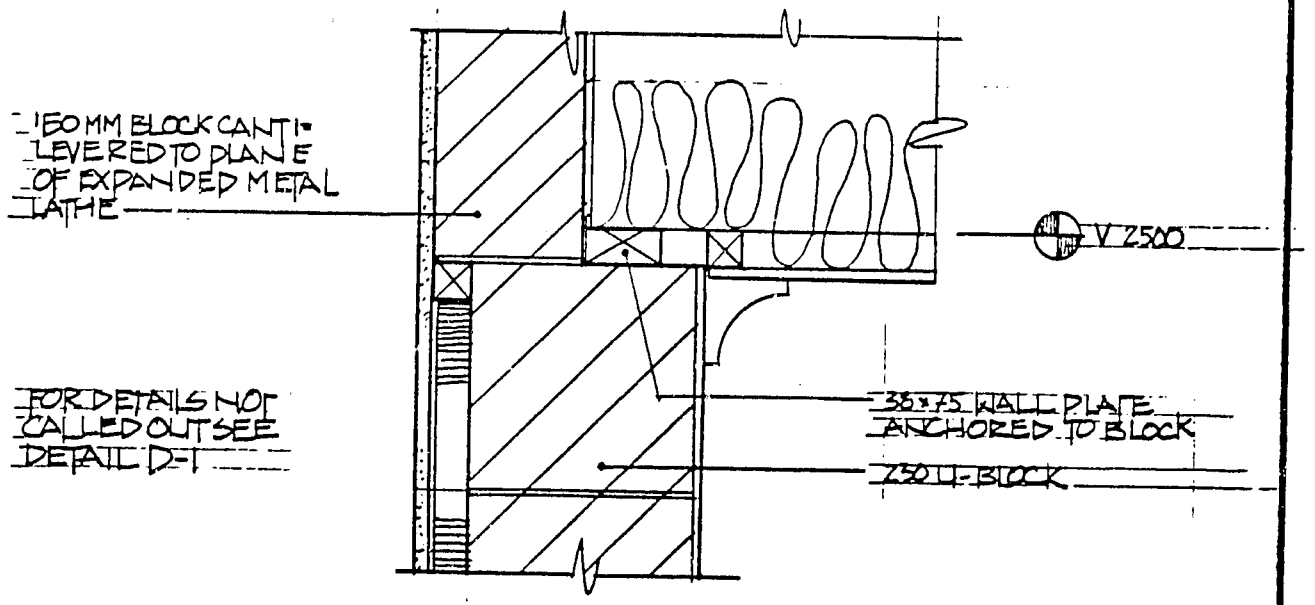


NOTE: ABOVE ALTITUDE OF 2000 M. INCREASE CEILING INSULATION TO 200MM & WALL INSULATION TO 50 MM.. INCREASE BATTEN SIZE ACCORDINGLY.

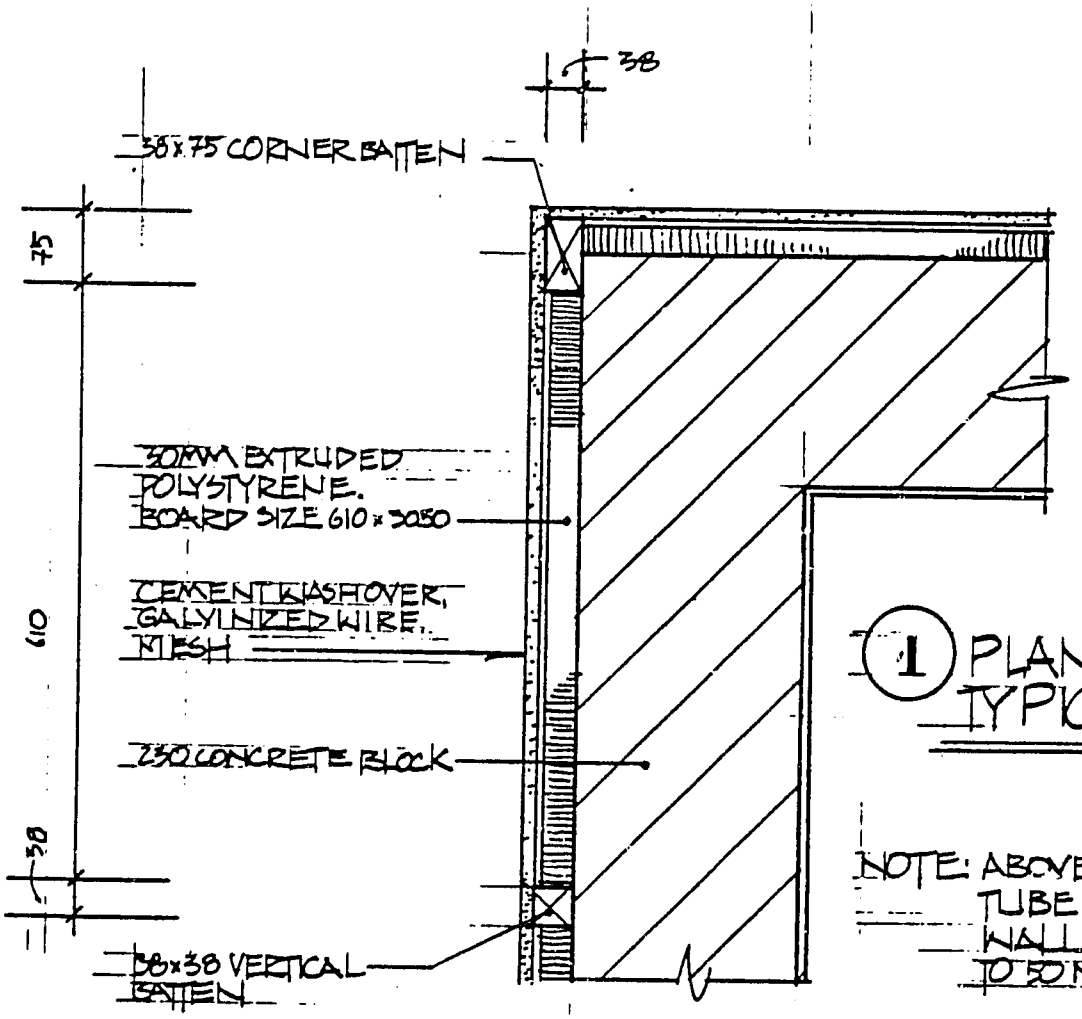
SECTION TYPICAL INSULATED WALL

SCALE 1:7.5

D1



2 TRANSITION INSULATED → UNINSULATED WALL



1 PLAN SECTION TYPICAL CORNER

NOTE: ABOVE 2000 M ALTITUDE INCREASE WALL INSULATION TO 50 MM.

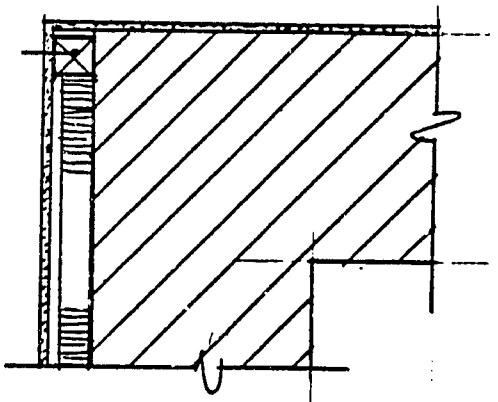
WALL DETAILS

SCALE 1:75

D 2A

30x30 BRANDFRAMING RECESSED FROM CORNER TO RETURN METAL LATHE

NOTE: FOR INFORMATION NOT SHOWN SEE DETAIL D-2A.



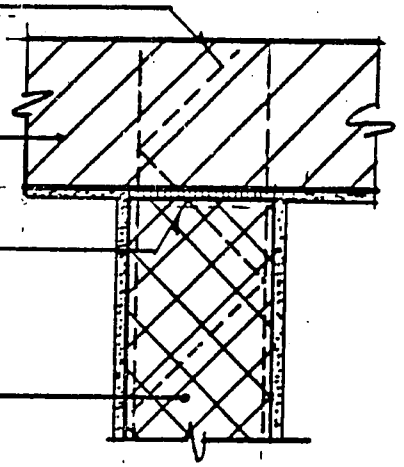
4 PLAN SECTION - FULL STOP WALL INSULATION

CARRY BLOCK REINFORCING THROUGH JOINT

UNINSULATED CONCRETE BLOCK WALL

10MM GAP BETWEEN WALLS FILLED W/ PACKED FIBERGLASS INSULATION

SOLAR STORAGE WALL W/ BLOCK CORES FILLED SOLID W/ CONCRETE

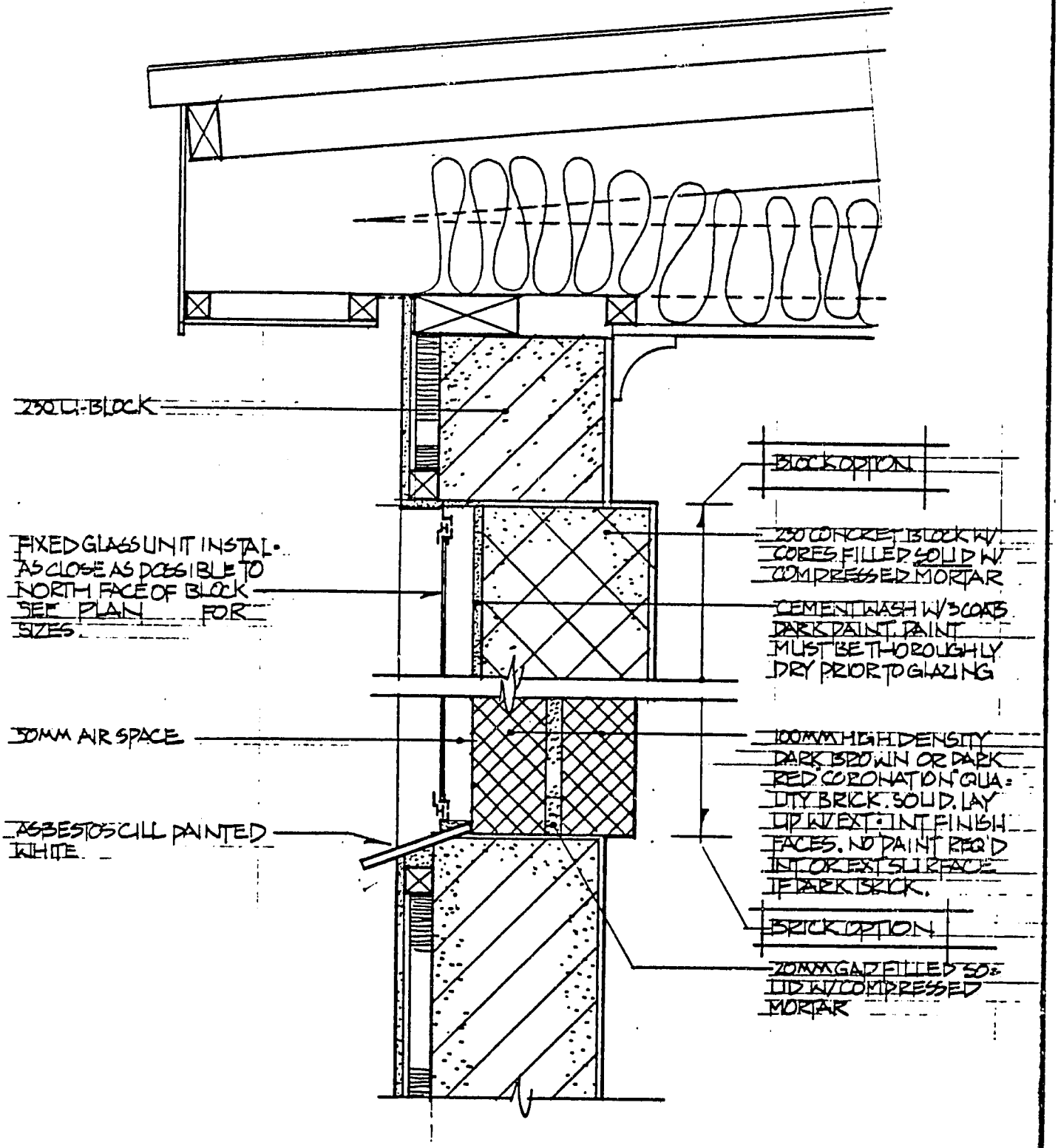


3 PLAN-SECTION - SOLAR STORAGE TO UNINSULATED EXTERNAL WALL

WALL DETAILS

SCALE 1:7.5

D2B

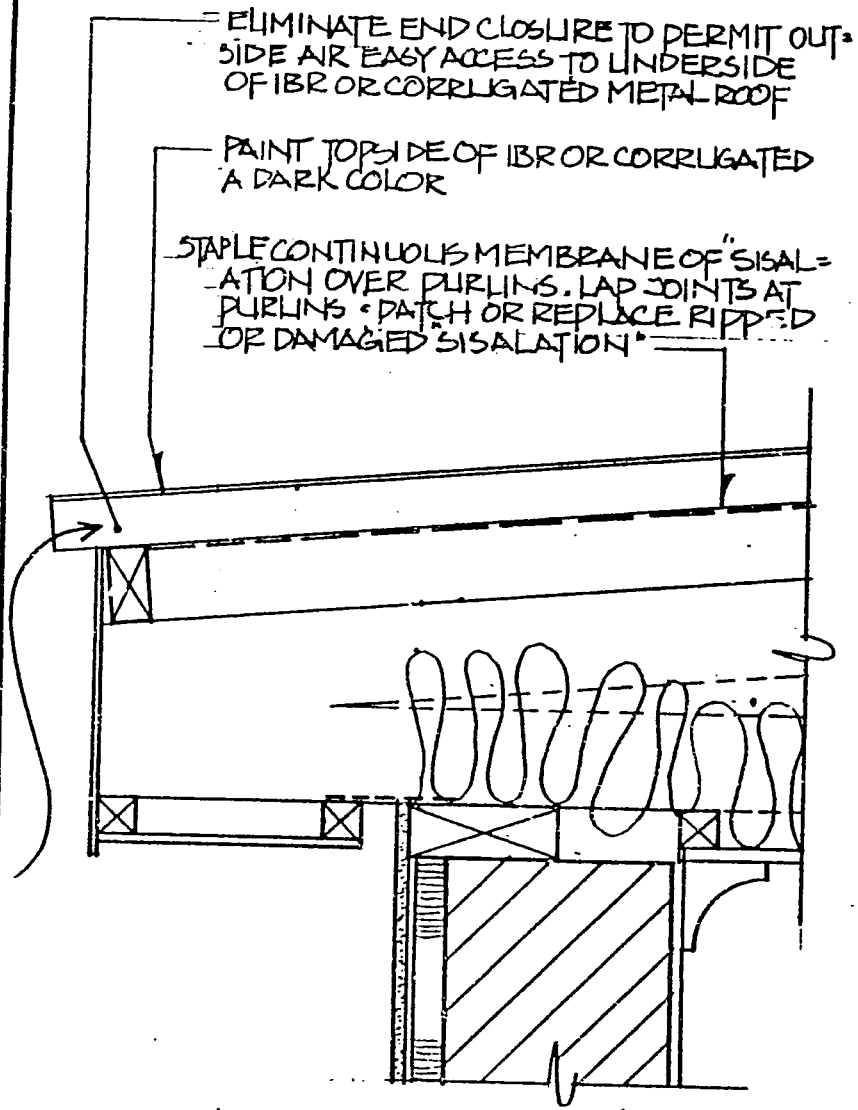


NOTE: FOR DETAILS NOT SHOWN SEE D-1

SUNWALL DETAILS

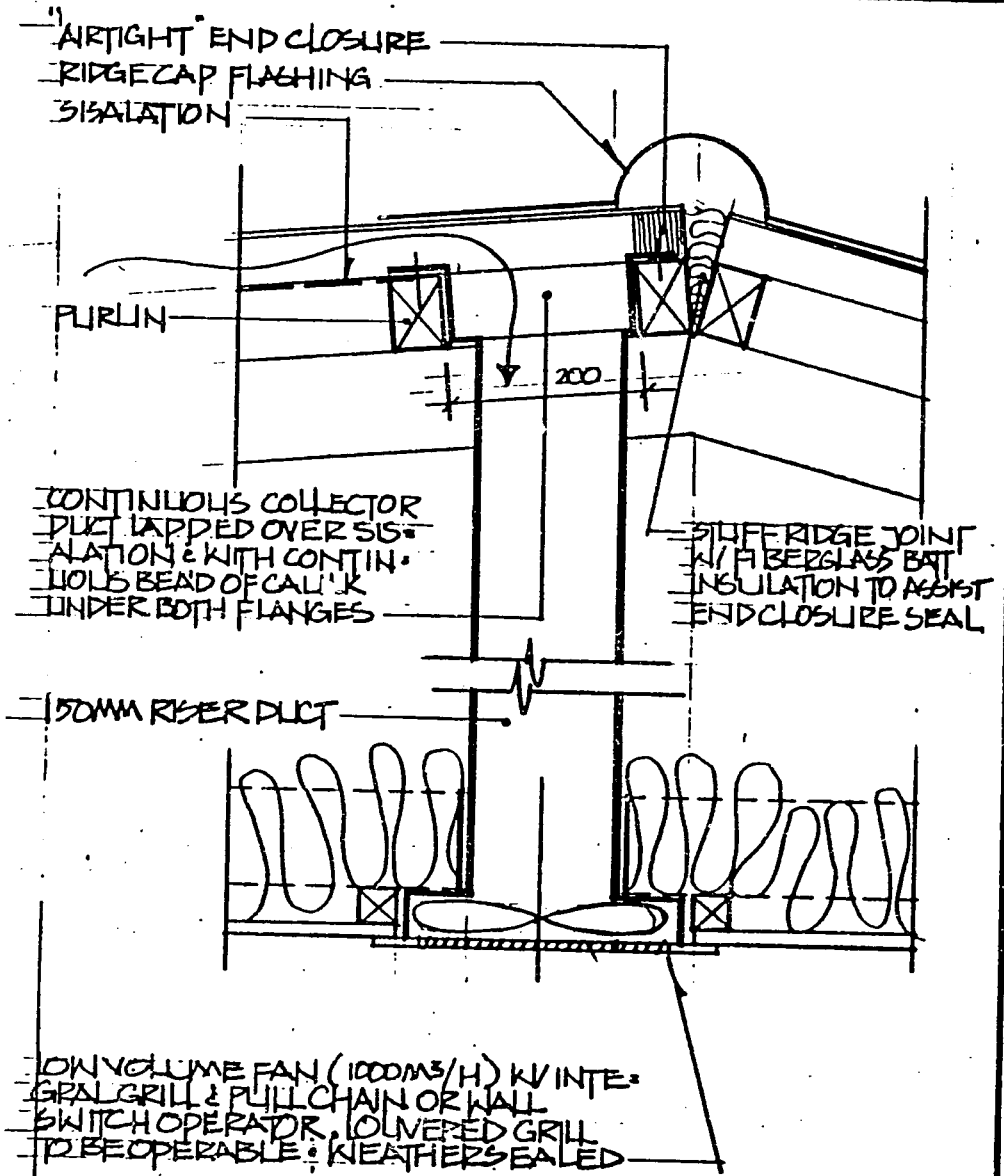
SCALE 1:75

D3



NOTE: SYSTEM EXPERIMENTAL. USE AT OWN RISK

1 SECTION @ NORTH WALL

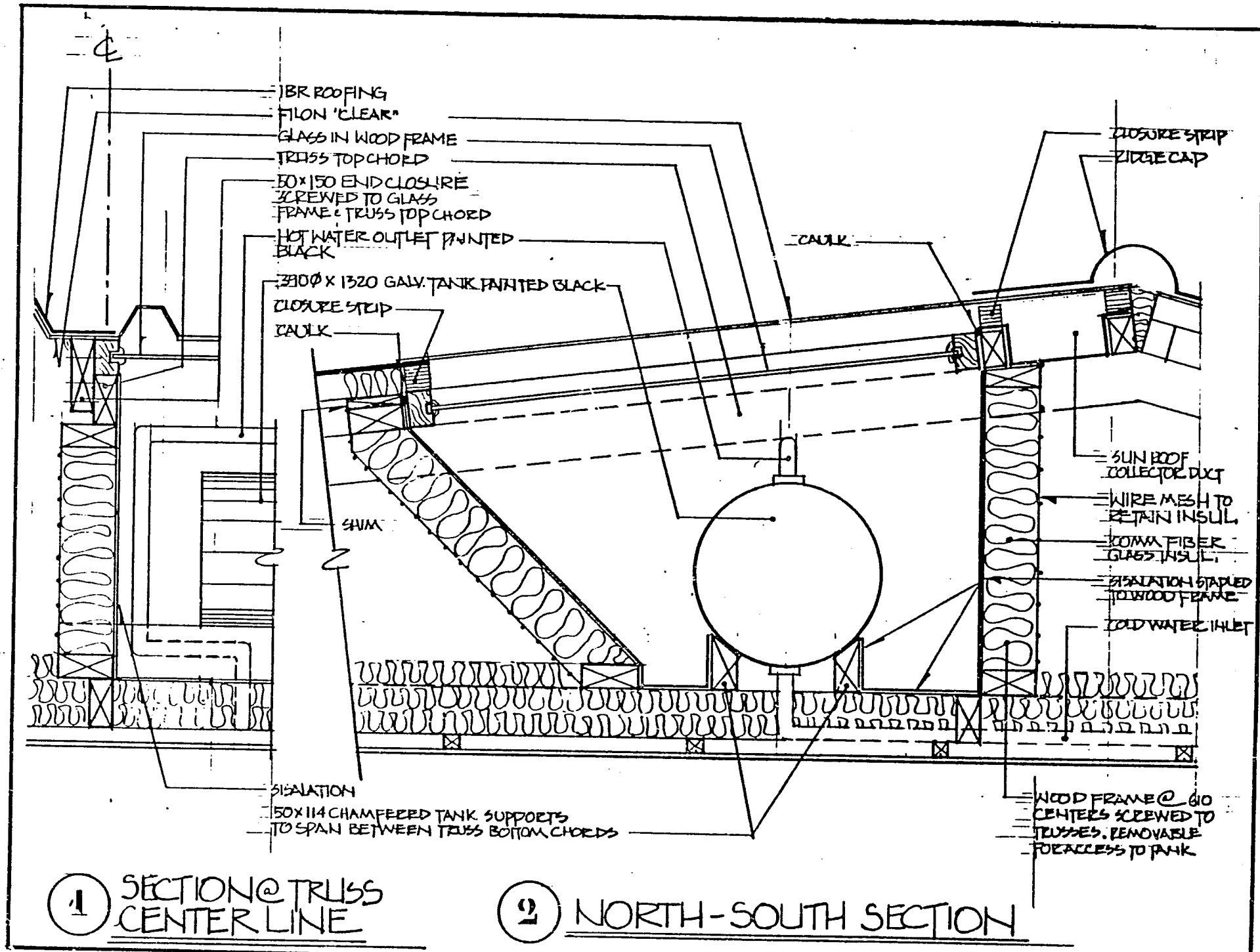


2 SECTION @ ROOF RIDGE

SUN ROOF DETAILS

D-4

SCALE 1:75



1 SECTION @ TRUSS CENTER LINE

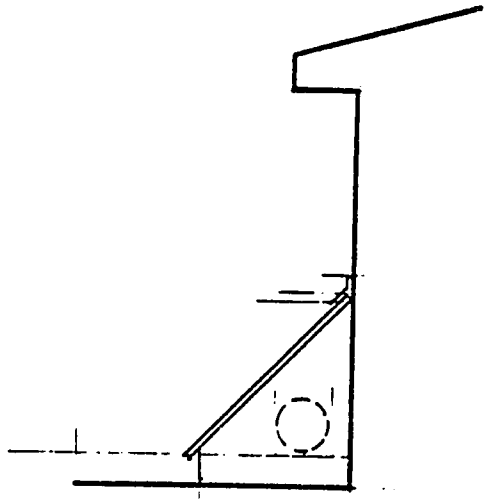
2 NORTH-SOUTH SECTION

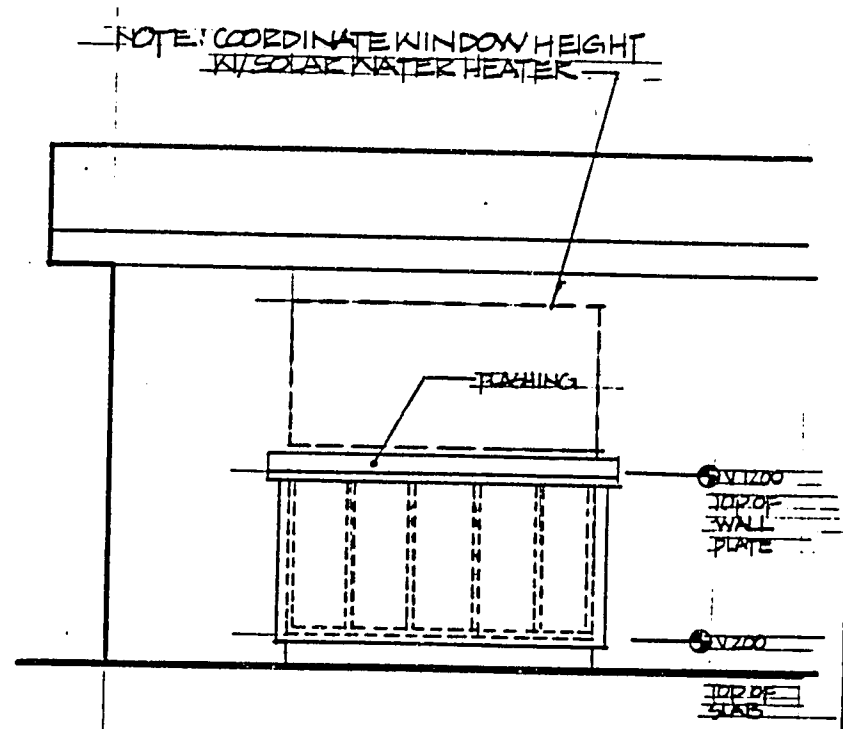
DETAILS SOLAR WATER PREHEATER

D5

SCALE 1:100

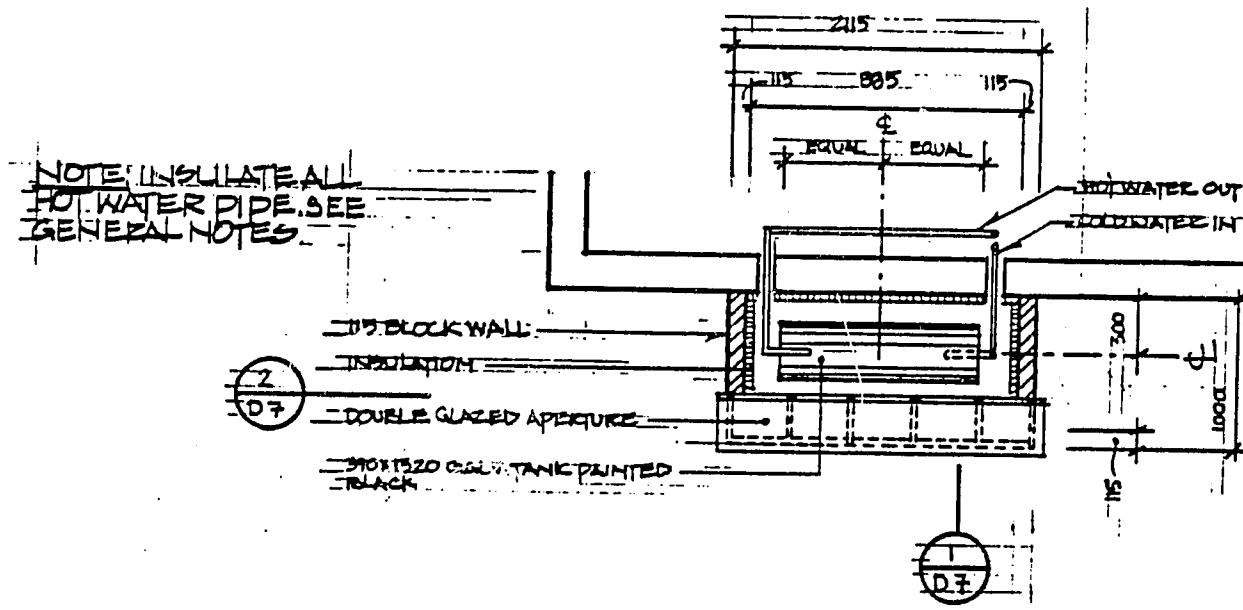
58





2 SIDE ELEVATION

3 NORTH ELEVATION



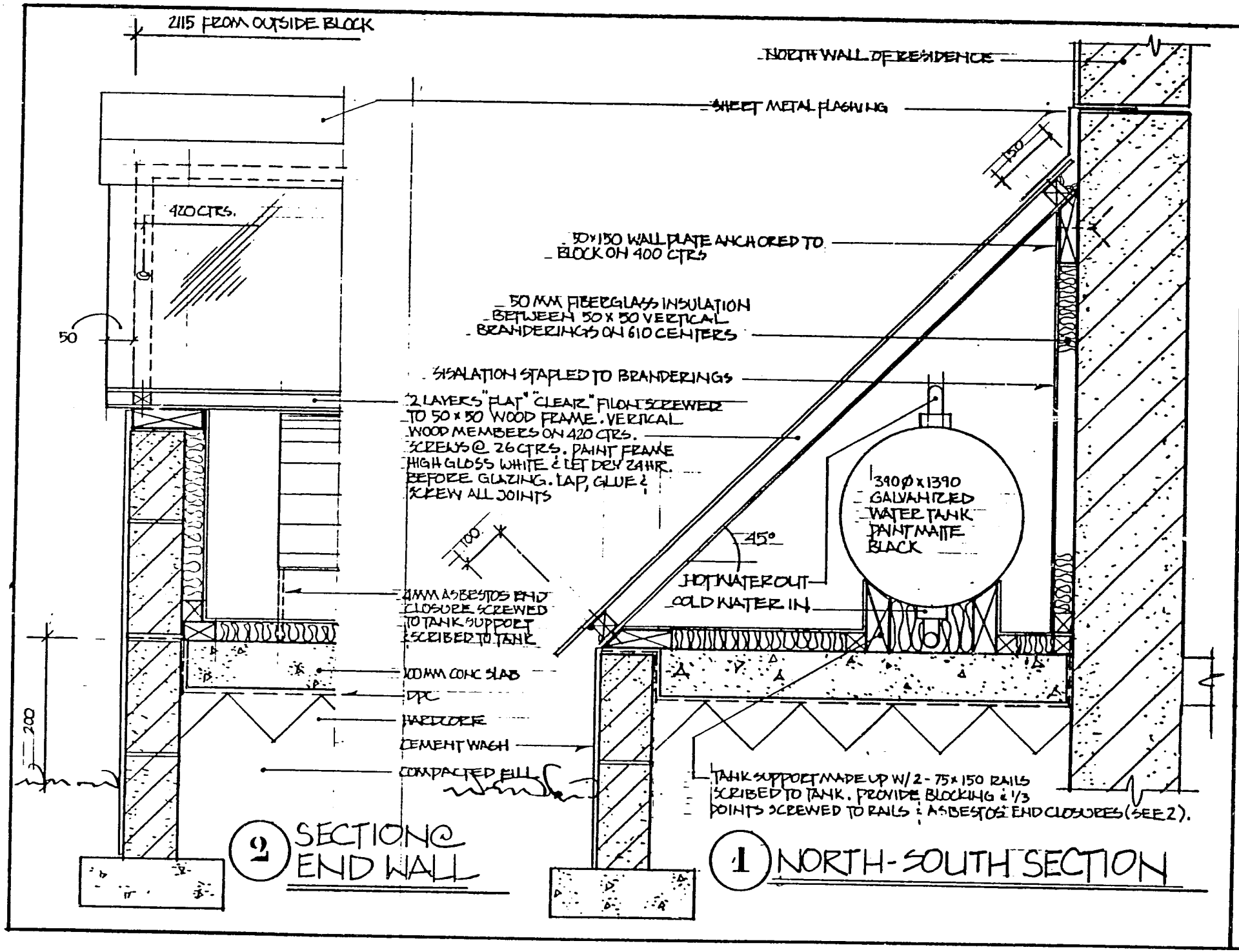
1 PLAN

N

PLAN & ELEVATIONS SOLAR WATER PREHEATER

SCALE 1:50

D6

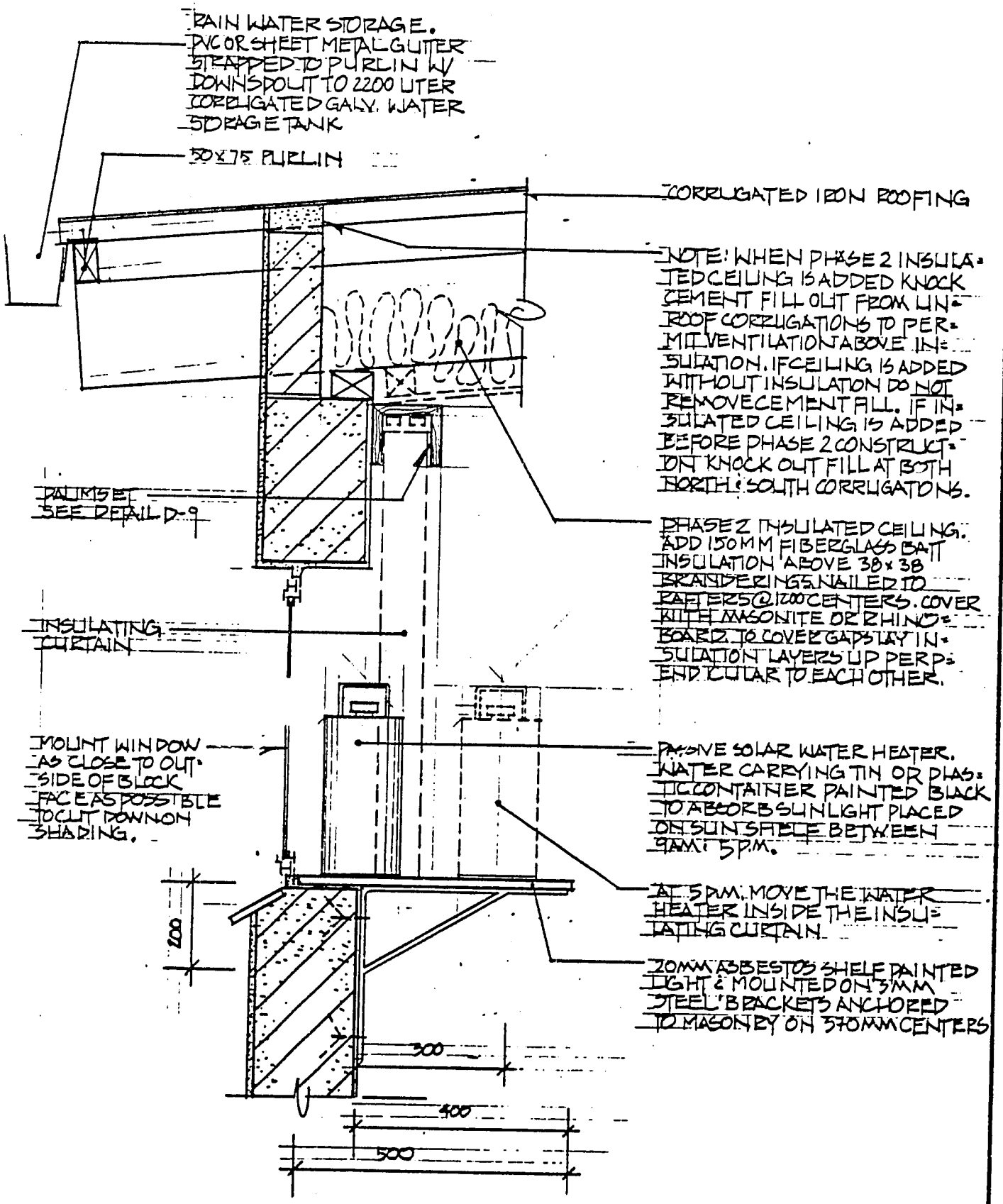


DETAILS SOLAR WATER PREHEATER

GROUND MOUNTED

D7

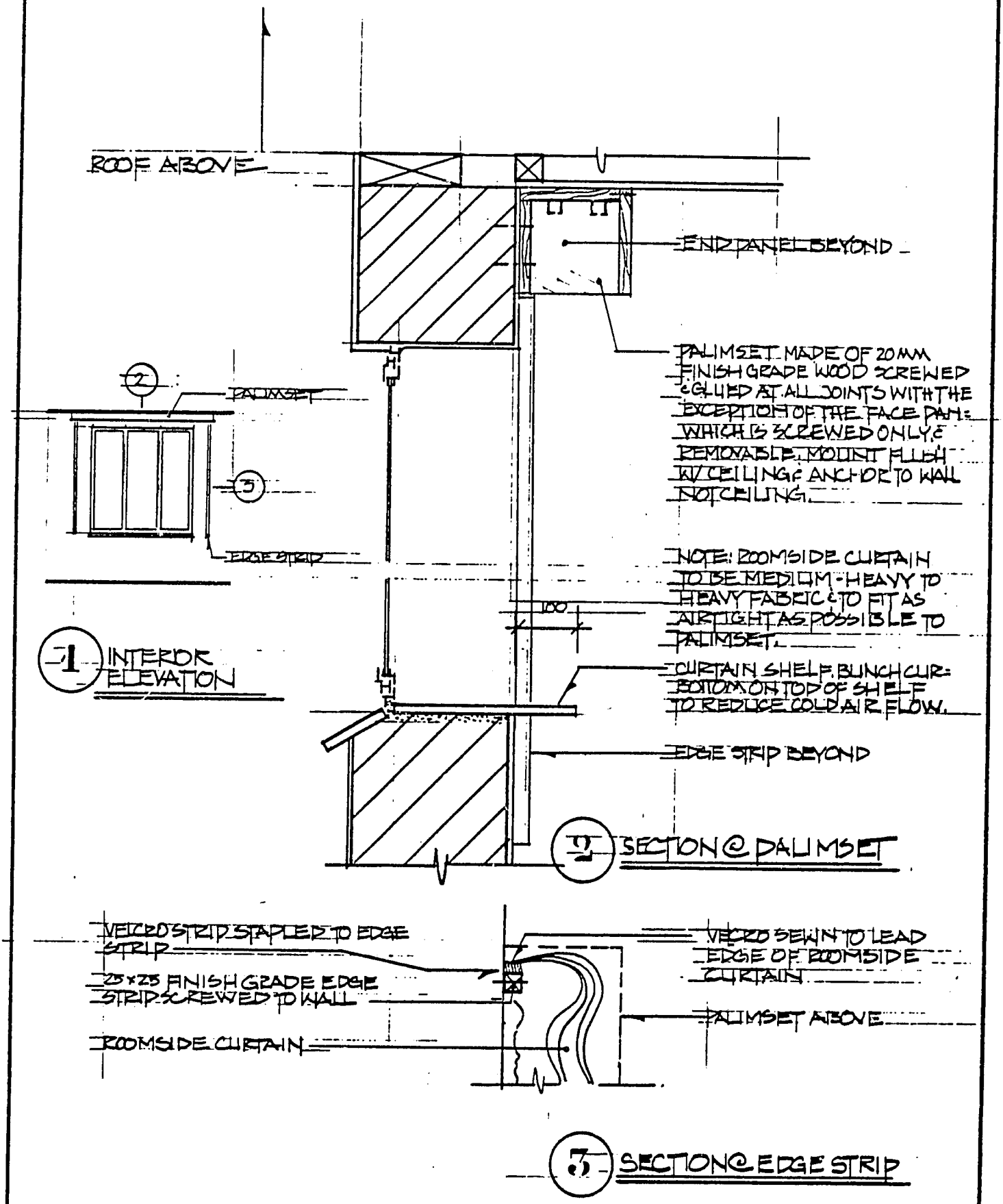
SCALE 1:10



DETAILS – WALLS, ROOF, WINDOW & SUNSHELF FOR THE C4-EC

SCALE 1:10

D8

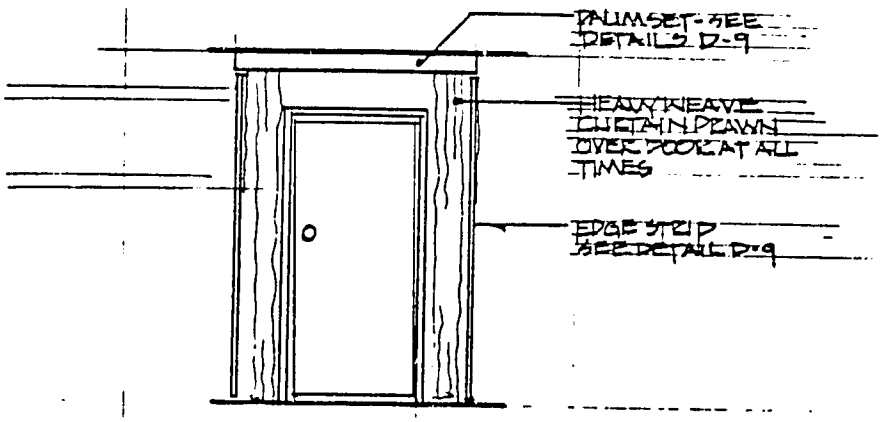


PALIMSET DETAILS

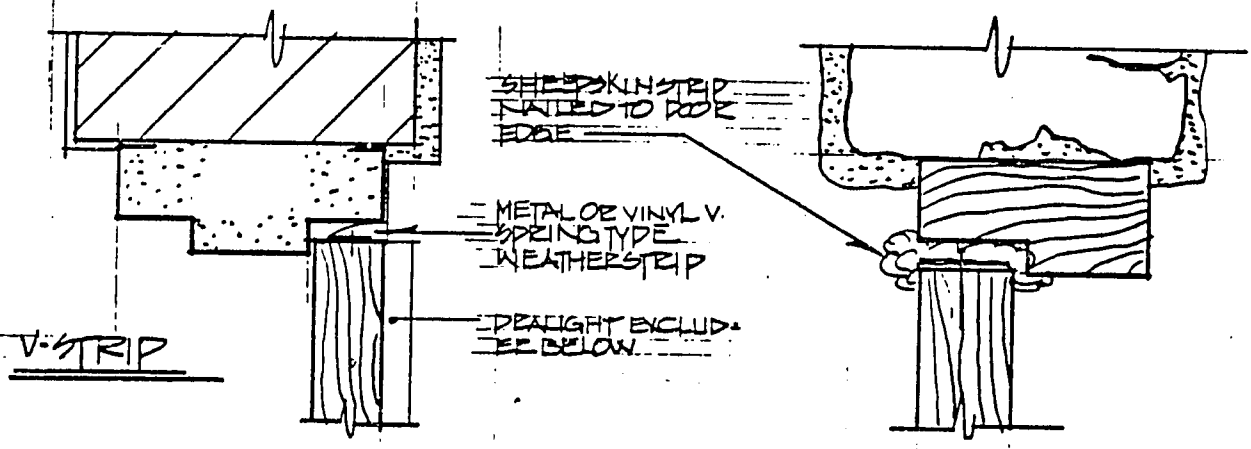
SCALE 1:75

D9

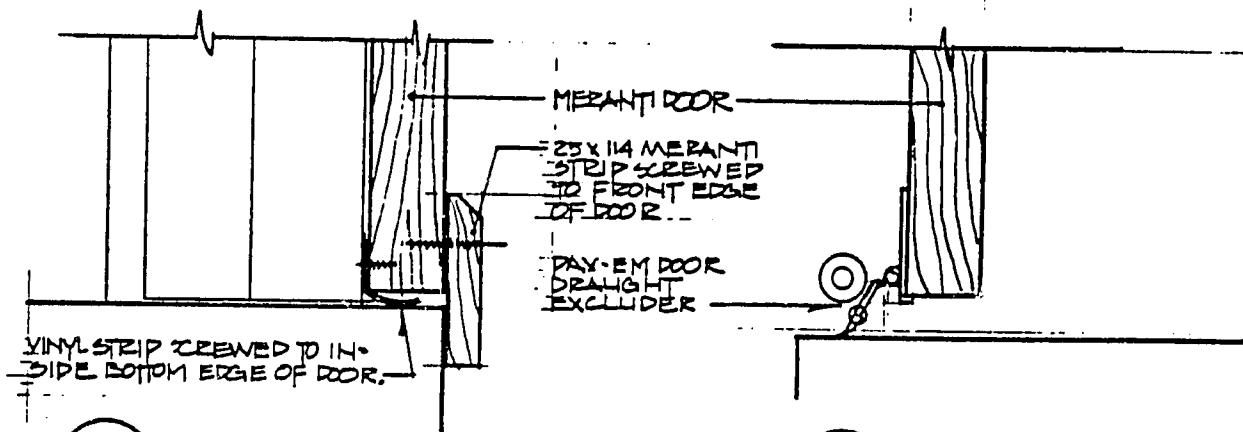
62



4 DOOR DRAPES SCALE 1:125



3 WEATHERSTRIPPING



1 SITE BUILT DRAUGHT EXCLUDER

2 COMMERCIAL DRAUGHT EXCLUDER

DOOR DETAILS

SCALE 1:5

D10

Appendix C

SOLAR ABSORPTANCE OF VARIOUS MATERIALS*

Optical flat black paint	.98
Flat black paint	.95
Black lacquer	.92
Dark gray paint	.91
Black concrete	.91
Dark blue lacquer	.91
Black oil paint	.90
Stafford blue bricks	.89
Dark olive drab paint	.89
Dark brown paint	.88
Dark blue-gray paint	.88
Azure blue or dark green lacquer	.88
Brown concrete	.85
Medium brown paint	.84
Medium light brown paint	.80
Brown or green lacquer	.79
Medium rust paint	.78
Light gray oil paint	.75
Red oil paint	.74
Red bricks	.70
Uncolored concrete	.65
Moderately light buff bricks	.60
Medium dull green paint	.59
Medium orange paint	.58
Medium yellow paint	.57
Medium blue paint	.51
Medium Kelly green paint	.51
Light green paint	.47
White semi-gloss paint	.30
White gloss paint	.25
Silver paint	.25
White lacquer	.21
Polished aluminum reflector sheet	.12
Aluminized mylar film	.10
Laboratory vapor deposited coatings	.02

This table is meant to serve as a guide only. Variations in texture, tone, overcoats, pigments, binders, etc. can vary these values.

*G. G. Gubareff et al, Thermal Radiation Properties Survey, second edition, Honeywell Research Center, Minneapolis-Honeywell Regulator Company, Minneapolis, Minnesota, 1960.

S. Moore, Los Alamos Scientific Laboratory, Solar Energy Group, Unpublished data.

Appendix D

PASCALC

Introduction

PASCALC II is a program that is used with a TI-59 calculator and PC 100 printer to predict the monthly and annual auxiliary energy consumption and Solar Savings Fraction (SSF) of passive solar buildings. It is applicable to direct gain, Trombe wall, water wall, and sunspace passive systems, with or without night insulation. Other systems may be substituted as an option. The performance of any combination of up to three of these systems may be evaluated on a single building. Orientation, tilt, glazing layers and transmittance, absorptance, shading, and reflector augmentation may be varied individually for each system and for each month if necessary.

PASCALC II uses the new Solar Savings Fraction (SSF) algorithm developed at Los Alamos Scientific Laboratory (LASL) by Balcomb and associates. The SSF method is based on correlations developed from a comprehensive series of hour-by-hour computer simulations of passive buildings. It has been validated against passive test cells and may be used with confidence. Detailed descriptions of the SSF method may be found in the LASL publications listed in References.

PASCALC II is simple to use, requiring only latitude, monthly degree days and average daily insolation, an overall building heat loss coefficient (UA), passive systems sizes and loss coefficients, internal gains and thermostat settings, and correction factors for radiation data, such as absorptance and shading. It is convenient to use the program for parametric studies that optimize the performance of passive solar buildings.

PASCALC II Data Requirements

The minimum data required to run PASCALC are:

- the heat loss coefficients of the building and its passive system
- the passive aperture area(s)
- monthly insolation data
- monthly degree day data

Internal gains, thermostat set point, and various radiation correction factors may also be required if a sophisticated analysis is desired.

Data entry in PASCALC II is designed to permit the user to easily vary any of the passive system parameters. Instead of entering the total heat loss coefficient, the user enters:

1. UA_{ns} (Btu/hr ^{o}F), the overall heat loss coefficient of the "non-south" portion of the building, including infiltration losses. This includes all surfaces except the potentially passive, south-facing surfaces and the passive apertures. U-values, calculated by standard ASHRAE procedures, are multiplied by surface areas.

2. A_s (ft^2), the area of the total "south surface" must equal the sum of the areas of each passive system, plus the area of the non-passive, or conventional, south wall. Do not include any area used in the UA_{ns} above. For sunspaces, use

the projected vertical area of the glazing (actual area x sin θ, where θ is the tilt of the glazing). End walls are ignored.

3. f_i, the fraction of A_s that corresponds to each passive system aperture. Divide the area of passive system "i" by A_s. For sunspaces, again, use vertical projected area and ignore end walls. The sum of all f_i must be less than 0.99.

4. U_i (Btu/hr ft^2 ^oF), the coefficient of heat transmission for each passive system, not including night insulation, selected from Table 2.

Table 2: U-values of Passive Systems

System	U
direct gain	0.55
Trombe wall	0.22
water wall	0.33
sunspace	0.55

5. U_{np} (Btu/hr ft^2 ^oF), the coefficient of heat transmission of the remaining, non-passive south wall.

PASCALC II then automatically calculates the total heat loss coefficient of the solar building as:

$$UA_s = UA_{ns} + A_s \sum_{i=1}^{n} f_i U_i + A_s(1 - \sum_{i=1}^{n} f_i)U_{np}$$

6. T_{set}(^oF), thermostat set point, based on an average of day and night settings:

$$\frac{(T_{set}\text{day}) \times (\text{hrs. at day setting}) + (T_{set}\text{night}) \times (\text{hrs. at night setting})}{24}$$

7. Q (Btu/hr), internal gains from people, appliances, lights, etc., averaged over a 24 hour period and expressed as an average hourly gain. Values typically range from 600-1000 Btu/hr-person.

8. N, number of different passive systems in the building being modeled. Up to three systems may be used.

9. i, passive system number assigned arbitrarily to each system in the order of data entry (i = 1,2,3). The program calls each system in sequence, up to the total number of systems (N). Therefore, if two systems are used (N=2), they must be input as systems 1 and 2. Any data input as system 3 would be ignored in this case.

10. #, passive system type number. The basic operating mode of PASCALC II has the following numbers assigned to three passive systems and their data

    #1 direct gain
    #2 Trombe wall
    #3 water wall

    Other assignments of systems and data are possible, including sunspaces. Refer to "Preparing PASDAT Data Cards" for more detail.

11. RNI_i, the R-value of night insulation for each passive system. This value must be an <u>integer</u> value between "0" and "9".

The data above is entered into the PASCALC II program with the aid of a worksheet. A more complete description of data entry and the use of the worksheet, along with a worked example, is included in subsequent chapters. The data below is prepared with the aid of the PASRAD and PASDAT programs.

12. C_i, C-factor, number containing merged radiation correction factors, which account for effects of:

    - transmittance of glazing
    - absorptance of passive system
    - tilt and azimuth
    - ground reflectance

- shading
- reflector enhancement

These correction factors are calculated with the PASRAD program for a variety of standard configurations (see "Running PASRAD"). The procedure for merging and entering the correction factors is also described. In addition to the standard configurations, correction factors can be determined manually for a wide range of less standard configurations using the graphs found in Appendix C.

13. Insolation data (Btu/ft^2 day), for an average day in each month, on either a vertical or horizontal surface. This data is entered and processed through the PASDAT program, and may be stored on a magnetic card for later use.

14. Degree days (^{o}F day), with average monthly total degree days for the location of the solar building. This data is also entered and processed through PASDAT (see "Preparing PASDAT Data Cards").

15. L, latitude for the location. This can be found on a map.

GENERAL NOTES

These general construction notes go with the drawings for the C4-EC, A3-EC and PITSO-EC.

1. The building should be oriented due north to take maximum advantage of the sun's heat. This is not magnetic north, rather it is solar north, and there is a big difference between the two. Although the ideal orientation is due north, the building can face to the east or west of due north by as much as 30° and still suffer only a minor loss in solar heating efficiency.

2. Insulate the roof cavity with 150 millimeters of fiberglass insulation, if your altitude is below 2,000 meters; if above 2,000 meters, use with 200 millimeters of insulation.

3. If a ceiling exists, ventilate the roof to prevent the buildup of summer heat and formation of condensation in winter.

4. Where there is no pumped water supply or the supply is insufficient, catch rainwater from the roof and gutter it to a storage tank for use in gardening. Check the level rainfall in your locality to be sure to get a tank of the right size.

5. Insulate walls with 30 millimeters of extruded polystyrene on the outside of the block for altitudes up to 2,000 meters. Above that altitude, increase the insulation to 50 millimeters thick.

6. Eliminate all vent blocks on the outside of the building. They are not needed or recommended for reasons of health and safety, and they let in an enormous amount of cold air.

7. Minimize all penetrations of the outside walls, particularly if these walls are insulated, as they create thermal "bridges" through which heat can and will escape. If a plumbing or electrical penetration is unavoidable, be sure to pack insulation between the pipe or wire and the sides of the hole, and patch the opening very thoroughly both inside and outside. This will keep the wind out and heat in.

8. To cut down on air infiltration around windows, all of them should be weather-stripped with a rubber sponge-type, self-adhesive weather strip. Window closers, in addition to those installed at the factory, are needed if the window panel is warped so that there is a poor seal between the window and frame.

9. Weather-strip all external doors between the door panel and frame to prevent air infiltration. Install a draft excluder at the threshold as well. See drawing D10 of EC Details.

10. Internal solar storage walls should be filled solid with concrete to add solar storage capacity and painted a darker rather than a lighter color to improve their absorption of solar heat. (Lighter colors reflect solar heat.) Avoid covering the storage wall with pictures and the like as they reduce the wall's ability to readily store heat.

11. Note number 10 also holds for floors that are concrete and in the direct path of the sun throughout the day.

12. To avoid penetrating the building's thermal "skin," install electrical receptacles on interior walls only and do not use recessed lights in ceilings.

13. Install low-energy, fluorescent lights in "utility" areas such as entries, halls, bathrooms and WCs, and the kitchen. They use much less electricity than incandescent lights.

14. Specify low-energy appliances. Most appliances now carry some form of energy performance information.

15. The locations of room heaters on the plans are best for general heating of as much of the inside area as possible. The suggested alternate locations are better as hearth locations.

16. Use anthracite coal-burning room heaters with an internal damper for heat regulation and secondary air circulation for heat recovery. For heating purposes, an enclosed unit is much more efficient than an open one. See the EC Materials in this folder for some recommended models.

17. Try to keep the room heater or cook stove flue pipe in the room as much as possible as a lot of heat remains in the flue gasses. It is much more efficient to have that heat lost from the pipe inside rather than outside.

18. Where possible, use demand hot water heaters rather than immersion heaters. If an immersion heater is used, insulate all hot water pipes, especially if they run through an unheated attic. Install any hot water heater in the building's heated space.