PROTO-TYPE SOLAR HOUSING
At this point in time greater and greater emphasis is being placed upon a more efficient use of energy. A major focal point has been the home. Advertising campaigns have directed attention to various ways the homeowner can combat wasteful energy usage; by turning off unused lights; by lowering the temperature in winter and raising it in summer; by weather-stripping windows and doors; by adding insulation to the attic space; etc.

These measures are helpful and are good practices for the existing home. But, what can be done about the homes yet to be built? New housing offers the opportunity to develop and use new techniques of energy efficiency. Still further, with growing concern about energy supplying resources and their availability, the home could take on the added task of producing all or a substantial part of its own energy demands via natural energy systems.

Thus the focus of this thesis project is to develop an energy efficient house incorporated with solar energy systems.

However, one cannot design a particular energy efficient/energy producing element. This project assumes that the energy efficient/energy producer house would become a model for future housing, and that it will replace the conventionally produced/built house of the present.

A major thrust in developing the prototype itself has been to design a system which allows for the growth patterns of the family. This system not only allows for the growth of the unit but for the reduction in size should it be desirable.

The important element of a housing system responsive to the life cycle of a family is not just its growth capabilities but its capabilities in relation to its life style. Therefore, the system must have a great many capabilities for alteration and this can only be achieved through a system which has parts that can be assembled and disassembled at will with a great variety.

The system which meets the demands of family life cycle/style input must also be responsive to demands of energy efficiency and energy production.

Affecting the energy efficiency of the prototype a great deal would be its orientation in the natural environment. The prototype must be able to use or not use the energies of the sun and wind in such a way as to benefit the conservation of energy used in controlling the environment within the prototype.

Materials and their manipulation of great importance in how one deals with such things as heat gain and heat loss and their effects on energy usage. Materials must be selected in terms of their thermal transmission and resistance and their adaptability to the configuration of system components.

Within the prototype the orientation of spaces will play a part in the efficient use of energy. Spaces that use the same services should be in close relation to minimize the supply transmission distance. The services themselves should originate from a centrally located core.

The energy producing aspects of the prototype greatly influence the design.
This chart for the life cycle of a five person family shows the variations that occur in space demands. The prototype housing in this project should show the variations in plan, or the allowance for plan variation, to meet the demands of a family at any stage in this cycle. The problems of plan variation will be compounded due to the demands of energy collection systems.
Attention is given to the regional location to determine the effectiveness of solar space heating/cooling design and to the orientation in the natural environment so as to make maximum use of the sun's energy. Climatic conditions of the region determine the mode and size of the collection and storage systems to give the most efficiency.

A compatible integration of the solar energy system and the housing system is acquired by giving attention to the weight, size, location, and materials of the solar energy system and how they relate to the structure and materials of the housing unit.
Concept

Conceptually the unit is developed in terms of public, family privacy, and personal privacy, and in terms of services dispersal.

The terminology is set up as such:

public: point where entry into unit occurs from pedestrian and/or vehicular circulation exclusive of unit.

family private: areas enjoyed by family as group with some public relationship yet separate.

personal private: areas enjoyed by individual family members.

The relationship of these elements is shown in Figure 1.

Within the family private sector there is a secondary system. In close relation to the public are family private areas (F.P.) with greater activity (i.e., living spaces, family spaces). Somewhat removed from the public yet still included in family private would be food preparation and eating activities (F.P.). (Fig.1.) Movement through this spatial relationship is one of ever increasing privacy with the previous space forming a buffer.

The second level in the conceptual unit deals with dispersal, mechanical and human.

Mechanical services ideally would be located in a core area limiting the distances the services must travel to a given destination and eliminating distribution losses (i.e., heat from long runs of hot water pipes). Efficiency of distribution is the hoped for gain in keeping mechanical serviced elements in close relation to the service origination. (see Fig.2)

Human service dispersal refers to the relation of inter use elements. Figure 3 shows these relationships. The food preparation and dining relation is obvious, but also there is a strong relation between the food prep activities and some activities in the living space (i.e., parties, snacks and T.V.). Personal hygiene is closely associated with the activities associated with before and after sleep, therefore, the relationship shown also in Fig. 3.
The desire for a system of housing that allows maximum manipulation in response to family life cycles/styles means that the enclosure elements must be independent of the structural system. This allows for each enclosing element to be independent of the other so that they can be removed, moved, or added at any time without affecting the structural integrity of the housing unit. Therefore, the structural system becomes a skeleton upon which the skin can be attached.

A second desirable characteristic is that the skeleton/skin system allows for a maximum of volume with which to work in. In addition it is desirable to have a minimum of surface area enclosing this volume total. Various volumetric forms can be maximized but forms with curved surfaces maximize volume but minimize surface area.

Another characteristic which is desirable is a scheme which allows for a simple growth pattern in response to the life cycle of a family. This criteria is met by a scheme which is open-ended so that when expansion or contraction occurs it is homogeneous to the existing or remaining elements.

A scheme which satisfies this criteria well is a linear scheme. With a linear scheme there is a single circulation corridor off which the various spaces of a housing unit occur. There is easy growth within the volume around this corridor which also becomes a good spine for expansion because the corridor can be continuous to the additional spaces.

A second consideration in choosing the linear scheme is that it becomes the spinal column of the volume which is the main line of supply for the various services required for a living unit.
STRUCTURAL ISOMETRIC
The structural system used in enclosing this volume is a series of three-hinged arches placed 12'-6" on center. The arches give a maximum volume in relation to the width of the unit with a greater amount of nearly vertical side area. The desire for near vertical side area is to minimize residual space which would be a product of horizontal surfaces meeting the sides at excessively acute angles. The arched volume is also responsive to the linear scheme.

The enclosing skin is made up of panels (see panel section, opposite page) and various transparent elements set in panels. These enclosing elements are all mechanically attached to the structural skeleton. None are load bearing and are simply curtain walls and they are independent of each other in place and may be removed at any time. (see structural isometric and building section)

Floors above ground level are attached to the arches at the outside and are suspended by cables at the center or interior portions. Cable suspension allows much smaller elements to carry structural loads. They can also be used in a sculptural application still being structural, or in multiple and covered with fabrics to form partitions. (see structural isometric and building section)
**REFLECTING PINS** REDUCE THE AMOUNT OF SUMMER DIRECT SUNLIGHT TO ENCOURAGE SIMPLER CARPETING.

**REFLECTIVE STRUCTURE:** REDUCE THE WINTER RAIN THROUGH AN INCREASED AMOUNT OF PASSING INQUIRING WINTER BLOWING THE ENCLOSURE SIMPLER AN INTENSIVE HAIL.

**INSULATION:** REFLECTIVE GLASS REDUCES THE WINTER RAIN TO ALLOW SUMMER RAIN TO BLOW OVER ENCLOSURE SURFACE HELPING TO COOL THE SURFACE.

**SUMMER SUN**

**WINTER SUN**

**REFLECTING PINS**

**SOLAR COLLECTORS**

**REFLECTING GLASS**

**INFLATABLE WALL FOR TEMPORARY ENCLOSURE**

**CABLE SUSPENSION OF HOUSING STRUCTURE**

**SPAR ROOF**

**SPAR TRANSPARENT EMBOSSED SCULPTURAL PARTITIONS**

**BUILDING SECTION**
Using a design developed for a three or four person house, two bedroom, for explanation, the plans and sections following show the use of the single corridor as the organizing element of the linear scheme. In this particular case the public oriented side is north and the private is south.

The private elements of the unit are also among the most stable spaces (ones which are likely not to change significantly). These elements would include the sleeping spaces, personal hygiene spaces, food preparation, and eating spaces. Add to these elements which share this stable attitude vertical circulation, and utility/mechanical space) and one is able to design a portion of the prototype according to criteria set up in the conceptual analysis of the problem.

In plan the spatial relationships characterized in conceptual form are along the linear corridor so that single spaces related to multiple spaces are centrally located (i.e. bedrooms to bathrooms).

The private and stable elements are all located along the private oriented side of the corridor. This allows the possibly more fluctuating spaces of a more public nature to occur freely along the public oriented side of the corridor.

The corridor is continuous to allow for expansion. Expansion must occur when additional private spaces must be added. This not only maintains the public/private aspects of the house but assures the addition of solar energy collector apparatus necessary to maintain efficient heat producing capabilities to deal with added heating/cooling demands.
SECTION B-B
Sections of the prototype bear out the private/public spatial organization.

The family living spaces occur to the public side of the house where a person would enter from. He then progresses to the spaces which accommodate family activity but are of a more private nature (i.e., eating). Progressing through these and moving to the upper level he would come to the areas of personal privacy which are the farthest removed from the public.

In the plans, the vertical relationship of spaces using the various services predominately was evident. In the sections, the horizontal supply route can be seen to occur above a hung ceiling placed below the second level corridor.

Here also the importance of the near vertical wall area provided by the arch is evident. The spaces at the second level where the curve angle becomes more acute, but is still open enough to minimize the residual space, need a maximum amount of floor space that is usable. Use of the more vertical (perpendicular to the ground level) part of a half circle (if it was a completely rounded arch) allows this to occur.
In respect to the collection of solar energy for space heating and cooling, the arch, due to its web thickness, allows for a collection system independent of the enclosure skin.

Chosen for usage in this project were the Corning Evacuated Solar Collectors. The vacuum tubes are more compact than flat plate collectors, weigh less, and are testing out as being more efficient (in present tests).

The major bulk of the flat plate is in its insulation needs; the vacuum within the tube provides all necessary insulation for the Corning collector. Also the Corning collector collects energy around its entire circumference so that its placement above a surface gives greater use of reflected energy.

With the collectors placed away from the building surface, reflective blinds can be placed between the two. This serves a threefold purpose.

The angle of the blinds is adjusted to block out the majority of the summer sun and reflect it to the collectors. This minimizes the heat gain of the south exposure which would otherwise have to be dealt with by added cooling potential. Since these blinds are not a continuous surface they allow diffuse light in for building interiors and let the summer breezes through to further help cool the southern building surface.

In the winter the solar angle is such that a greater amount of the sun's heating energy strike the building surface providing extra heat as the heat radiates inward to interior spaces. The blinds still act as reflectors as the same surface area is exposed to the sun.

In the winter, through use of these blinds, the effect is that of insulation and in the summer it is insulation.

The arches also provide a good place to connect pipe chases for water supply to and return from the Corning solar collectors.
The mechanical isometric is self explanatory as to the routing of the water from storage to the collector, from the collector to the storage tanks, and from storage to heating/cooling equipment and back.

The equipment itself works with forced air heating and cooling.

In heating, the hot storage water goes through a coil system over which air is blown. Air is the medium of heat transfer to the various spaces. When the stored water temperature drops below the ambient temperature of the spaces, the water is diverted by a valve to a heat pump which extracts any remaining heat, transfers it to the air supply which blows across electric resistance heating equipment, to bring the air to proper temperature before dispersal. Air can also be drawn through the gravel fill around the storage tanks and put through the heat pump to extract heat gained by the gravel by conduction from the storage tanks.

In cooling, a lithium-bromide absorption cooling unit is used. Water again provides the main source of heat with resistance heating being the supplement. (More information at end of booklet of the lithium-bromide unit)

As stated earlier, the heating/cooling supply ducts travel in a space between the upper floor and a hung ceiling, with secondary ducts feeding out from the line of the corridor.
HEAT COLLECTION SUBSYSTEM

ENERGY COLLECTION LOOP

DOMESTIC HOT WATER LOOP

ENERGY MANAGEMENT AND CONTROL SUBSYSTEM

THERMAL ENERGY STORAGE SUBSYSTEM

HOT WATER UNIT

ENVIRONMENTAL CONDITIONING SUBSYSTEM

ENERGY CONVERSION EQUIPMENT

HEAT REJECTION EQUIPMENT

AIR HANDLING AND DISTRIBUTION EQUIPMENT

ELEMENTS OF SOLAR HEATING AND COOLING SYSTEM
The following pages are calculations to
determine solar collector square footage,
storage volume, heating demands, and
cooling demands.

Following this is some additional inform-
lation on the lithium-bromide absorption-
cooling unit.

The Alternate Plans section show the
basic unit for a two person family, and
a larger unit with three bedrooms. These
are to show how growth or arrangement of
spaces may occur. The private side is
the most consistent aspect of the plans
with the public side being much differ-
ent.
QUANTITIES OF SOLAR ENERGY RECEIVED BY DIFFERENT AREAS WHEN THE AVERAGE INTENSITY OF RADIATION IS 1 CAL CM$^2$ MIN$^{-1}$

<table>
<thead>
<tr>
<th>Area</th>
<th>Langleys</th>
<th>kcal min$^{-1}$</th>
<th>kcal day$^{-1}$</th>
<th>BTU hr$^{-1}$</th>
<th>kw (heat)</th>
<th>hp (heat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 cm$^2$</td>
<td>1</td>
<td>0.001</td>
<td>0.990</td>
<td>0.238</td>
<td>7.00 x 10$^{-5}$</td>
<td>9.39 x 10$^{-5}$</td>
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<tr>
<td>1 ft$^2$</td>
<td>929.0</td>
<td>0.929</td>
<td>46.4</td>
<td>221</td>
<td>0.087</td>
<td>0.087</td>
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<tr>
<td>1 m$^2$</td>
<td>10$^4$</td>
<td>10</td>
<td>5.0 x 10$^3$</td>
<td>2.58 x 10$^3$</td>
<td>0.903</td>
<td>0.928</td>
</tr>
<tr>
<td>100 m$^2$ (roof)</td>
<td>10$^4$</td>
<td>10$^3$</td>
<td>5.0 x 10$^5$</td>
<td>2.58 x 10$^5$</td>
<td>70.0</td>
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<tr>
<td>1 acre</td>
<td>4.05 x 10$^7$</td>
<td>4.05 x 10$^4$</td>
<td>2.02 x 10$^7$</td>
<td>2.02 x 10$^7$</td>
<td>2.82 x 10$^3$</td>
<td>2.10 x 10$^3$</td>
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<tr>
<td>1 km$^2$</td>
<td>10$^7$</td>
<td>10$^7$</td>
<td>7 x 10$^9$</td>
<td>7 x 10$^9$</td>
<td>9.00 x 10$^5$</td>
<td>7.30 x 10$^5$</td>
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<td>1 mile$^2$</td>
<td>2.59 x 10$^{10}$</td>
<td>2.59 x 10$^7$</td>
<td>1.2 x 10$^{10}$</td>
<td>6.17 x 10$^{10}$</td>
<td>1.81 x 10$^9$</td>
<td>8.32 x 10$^9$</td>
</tr>
</tbody>
</table>

Conversion factors: 1 kcal = 1000 cal; 1 BTU = 0.252 kcal; 1 kw = 14.3 kcal min$^{-1}$; 1 hp = 0.746 kw;
1 ft$^2$ = 929 cm$^2$; 1 acre = 43,560 ft$^2$.
* Assuming 500 min day$^{-1}$ of solar radiation.

COMPARISONS OF HEAT STORAGE SYSTEMS

<table>
<thead>
<tr>
<th>Substance</th>
<th>Temperature Range</th>
<th>cal g$^{-1}$</th>
<th>Kcal ft$^{-1}$</th>
<th>BTU hr$^{-1}$</th>
<th>BTU ft$^{-2}$</th>
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<tr>
<td>Water</td>
<td>20°C (68°F)</td>
<td>20</td>
<td>35</td>
<td>13,440</td>
<td>4.81 x 10$^{11}$</td>
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<tr>
<td>Pebble bed (rocks with 75% voids)</td>
<td>20°C (68°F)</td>
<td>8.0</td>
<td>2.72</td>
<td>11,048</td>
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<tr>
<td>Na$_2$SO$_4$·10H$_2$O</td>
<td>32.3°C (90°F)</td>
<td>84.5</td>
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<td>9,568</td>
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TABLES FOR USE IN SIZE DETERMINATION
### Building Surface

#### Walls (Curved) A

<table>
<thead>
<tr>
<th>Material</th>
<th>R</th>
<th>U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside Surface</td>
<td>.17</td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
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<td></td>
</tr>
<tr>
<td>6&quot; Polyurethane Form</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>1/2&quot; Plywood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside Surface</td>
<td>.18</td>
<td></td>
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<tr>
<td><strong>Total</strong></td>
<td>.34</td>
<td>.007</td>
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#### Glass

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<tr>
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<tbody>
<tr>
<td>Fixed (F) Airspace</td>
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<td>Single Glass (W) Storm Screen</td>
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#### Doors

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<tr>
<td>Sliding Glass (S4)</td>
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<tr>
<td>Wood (W)</td>
<td>.49</td>
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#### Walls (Flat) B

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</thead>
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</tr>
<tr>
<td>Aluminum</td>
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<td></td>
</tr>
<tr>
<td>4&quot; Polyurethane Form</td>
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<tr>
<td>1/2&quot; Plywood</td>
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<tr>
<td>Inside Surface</td>
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<td>.036</td>
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#### Plastic

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<tr>
<td>Bubbles Double Wall</td>
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#### Floor

<table>
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</thead>
<tbody>
<tr>
<td>2&quot; x 6&quot; Floor Joists</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>1/4&quot; Sub-Floor</td>
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<td></td>
</tr>
<tr>
<td>1/2&quot; Plywood</td>
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<tr>
<td>8&quot; Fiber Glass Insulation</td>
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### Heat Loss BTU/hr

#### North

<table>
<thead>
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<th>Material</th>
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<th>U</th>
<th>AT</th>
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</thead>
<tbody>
<tr>
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<td>Wall A</td>
<td>.027</td>
<td>10</td>
<td>936.50</td>
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<tr>
<td></td>
<td>Wall B</td>
<td>.033</td>
<td>10</td>
<td>1074.94</td>
</tr>
<tr>
<td></td>
<td>B Bubble</td>
<td>.010</td>
<td>10</td>
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<tr>
<td></td>
<td>Glass (W)</td>
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<tr>
<td></td>
<td>Door (W)</td>
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<td>1074.94</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
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#### East

<table>
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<tr>
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<td>.039</td>
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<td>Wall B</td>
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<td></td>
<td>Glass (W)</td>
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<td><strong>Total</strong></td>
<td></td>
<td>-</td>
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#### South

<table>
<thead>
<tr>
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#### West

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<td>Wall A</td>
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<td>Glass (W)</td>
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<td>Glass (F)</td>
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<td>Door (W)</td>
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<td><strong>Total</strong></td>
<td></td>
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<td>3348.50</td>
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#### Floor

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</tr>
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<tbody>
<tr>
<td>156</td>
<td>.025</td>
<td>10</td>
<td>273.0</td>
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#### Infiltration

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<thead>
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<tr>
<td>15960 cu. ft.</td>
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**Total**

<table>
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<tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>40393.6</td>
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</tbody>
</table>

BTU/hr
HEAT LOSS REQUIREMENTS

49,393 BTU-hr⁻¹  118,513 BTU-da⁻¹  35,562 BTU-mo⁻¹

HEAT STORAGE REQ'S.

@ 5 CONSECUTIVE DAYS WITHOUT
COLLECTOR OPERATION = 59,271,600 BTU's

AIR IN BASALT PEBBLES:

TO STORE: 5,927,160 BTU's @ 60° TEMP. RANGE
CAPACITY: 1,068 btu cu.ft⁻¹

5,927,160 ÷ 1,068 = 5,549.8 cu.ft

WATER:

TO STORE: 5,927,160 BTU's @ 150°F (60° TEMP. RANGE)
CAPACITY: 37144 btu cu.ft⁻¹

5,927,160 ÷ 37144 = 1613.4 cu.ft

STORAGE UNITS:

WATER IN STEEL TANK
10' diameter x 20' length
51 diameter x 80' length

9 - 5' diameter x 8' length

COLLECTOR AREA

40° LATITUDE

HIGHEST HEATING DEGREE DAYS = 955 dd
MEAN DAILY SOLAR RADIATION = 144 langley's/day

CONVERSION: 1 langley/min. = 221 btu sq.ft⁻¹ hr⁻¹
144 langley's/day = 18 langley's/hr = 0.3 langley's/min.
(8 hrs/day solar Radiation Ave.)
0.3 langley's/min = 66.3 btu sq.ft⁻¹ hr⁻¹
= 530.4 btu sq.ft⁻¹ da⁻¹

HORIZONTAL RADIATION = 530.4 BTU-sq.ft⁻¹ da⁻¹

RADIATION PERPENDICULAR TO SURFACE = 1858 btu sq.ft⁻¹ da⁻¹
= 3899.8 btu sq.ft⁻¹ da⁻¹

REQUALD. SQUARE FOOTAGE OF COLLECTOR

\[
\text{Heat Loss} \times \text{Efficiency} = \frac{35,562,960 \text{ BTU-mo}^{-1}}{36,198 \text{ BTU sq.ft}^{-1} \text{mo}^{-1} \times 0.5} = 1820, 886 \text{ sq.ft. Flat Plate}
\]

\[
= \frac{35,562,960 \text{ BTU-mo}^{-1}}{36,198 \text{ BTU sq.ft}^{-1} \text{mo}^{-1} \times 1.75} = 1212 \text{ sq.ft. Vacuum Tube (Corning)}
\]
## Heat Gain Calculations:

<table>
<thead>
<tr>
<th>ITEM</th>
<th>HTM</th>
<th>NORTH</th>
<th></th>
<th>SOUTH</th>
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<th>EAST</th>
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<td>A#</td>
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<td>Fixed Operable</td>
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<td>A</td>
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<td>567.0</td>
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<td>TOTAL</td>
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<td>3071.55</td>
<td>40.5</td>
<td>364.5</td>
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</tbody>
</table>

### Infiltration
- P30 W/ft²: 1.6
- People/Equipment: 1.200.0

### Sensible Heat Gain
- 21593.0

### Total BTU Gain (0.4 x 1.3)
- 28090.0 BTU

**Heat Gain:** 2 Tons
REQUIRED HEAT INPUT FOR LITHIUM-BROMIDE ABSORPTION/COOLING UNIT

REFRIGERATION LOAD = 2 TONS
EVAPORATOR TEMP. = 40°F
ABSORBER OUTLET TEMP. = 90°F
CONDENSER TEMP. = 110°F
GENERATOR TEMP. = 192°F

(FROM P. 23, ASHRAE PRINCIPLES MANUAL)

\[ \omega_4 = \frac{24,000}{1079.78} = 22.9 \]
\[ \omega_5 = 1.2 (\omega_4) = 11.2 (22.9) = 257.68 \]
\[ \omega_6 = 12.2 (\omega_4) = 12.2 (22.9) = 279.12 \]

NET HEAT INPUT:

\[ q_s = \omega_4 h_8 + \omega_5 h_9 - \omega_6 h_7 \]
\[ = 257.68 (1147) + 257.68 (-30) - 279.12 (-38.5) \]
\[ = 27413 - 8030 + 11148 = 30551 \text{ BTU/hr} \]

COLLECTOR SQUARE FOOTAGE REQUIRED TO PROVIDE HEAT INPUT

30551 btu/hr : 783224 btu/day \(= 21991720 \text{ btu/mo} \)

\[ \frac{\text{btu/mo}}{\text{BTU/mo}^{-1} \text{sqft}^{-1} \times \text{EFFICIENCY}} = \Phi = \frac{21991720}{38938 \times 0.75} = 750 \text{ ft}^2 \text{ of COLLECTOR} \]
1 **Evaporator and absorber**

Consider two connected, closed tanks with a salt solution (lithium bromide) in one and water in the other. Just as common table salt absorbs water on a damp day, the salt solution in the absorber soaks up some of the water in the evaporator. The water remaining is thereby cooled by evaporation.

2 **Evaporator coil and pump added**

This refrigeration effect is utilized by putting a coil in the evaporator tank. Water from this tank is pumped to a spray header which wets the coil. The spray's evaporation chills water in the coil as it circulates to the refrigeration load. Solution pumped to spray in absorber raises efficiency.

3 **Solution pumps and generator added**

In an actual operating cycle, the salt solution is continuously absorbing water vapor. To keep the salt solution at proper concentration, part of it is pumped directly to a generator where excess water vapor is boiled off. The reconstituted salt solution is returned to the absorber tank where it mixes with the solution sprayed to absorber in step 2.

4 **Condenser and heat exchanger added**

Water vapor boiled off from the weak solution is condensed and returned to the evaporator. A heat exchanger uses the hot, concentrated salt solution leaving the generator to preheat the cooler, weak solution coming from the absorber. Finally, condensing water circulating through the absorber and condenser coils removes the waste heat.
CHARACTERISTICS OF THE REFRIGERANT-ABSORBENT PAIR

The two materials which make up the refrigerant-absorbent pair should meet nearly all of a number of requirements in order to be suitable for absorption refrigeration. Chief among these requirements are:

1. Absence of Solid Phase. The refrigerant-absorbent pair should not form a solid phase over the range of composition and temperature to which it might be subjected. If solid forms it presumably would stop flow and cause a shutdown of the equipment.

2. Volatility Ratio. The refrigerant should be much more volatile than the absorbent in order that the two can be separated easily in the generator. Otherwise the cost of the generator and the heat requirement for separation become large.

3. Affinity. It is commonly considered desirable that the absorbent have a strong affinity for the refrigerant under conditions in which absorption takes place. This affinity causes a negative deviation from Raoult's Law and results in an activity coefficient of less than unity for the refrigerant. It reduces the amount of absorbent which has to be circulated and consequently the waste of thermal energy due to sensible heat effects. Also the size of the liquid heat exchanger which transfers heat from the absorbent to pressurized refrigerant-absorbent solution in practical cycles is reduced. Recently Jacob, Albright, and Tucker have made calculations which indicate that strong affinity does have disadvantages. With this affinity is associated a high heat of dilution, and consequently extra heat is required in the generator to separate the refrigerant from the absorbent.

4. Pressure. It is desirable that operating pressures, largely established by the physical properties of the refrigerant, be moderate. High pressures necessitate the use of heavy-walled equipment. Low pressures (vacuum) necessitate the use of large volume equipment and special means of reducing pressure drop in the flow of refrigerant vapor.

5. Stability. Almost absolute chemical stability is required because the fluids are subjected to rather severe conditions over many years of service. Undesirable results of instability could be the formation of gas, formation of a solid, or formation of a corrosive substance.

6. Corrosion. It is especially important that the fluids themselves or any substance resulting from instability do not corrode the materials used in constructing the equipment.

7. Safety. The fluids must be substantially nontoxic and nonflammable if they are to be in an occupied dwelling.
8. Viscosity. Low viscosity is desirable to promote heat and mass transfer and, to some extent, to reduce pumping problems.

9. Latent Heat. It is desirable for the latent heat of the refrigerant to be high so that the circulation rate of the absorbent can be kept at a minimum.

No known refrigerant-absorbent pair meets all the requirements that have been listed. Two pairs, ammonia-water and water-lithium bromide, are considered to come nearest, and these are the only two which have found extensive commercial use. As has been indicated, the volatility ratio for ammonia-water is smaller than desired. Also ammonia is in ANSI B-1 Safety Code Group 2, and thus its use in residential dwellings is restricted. The pressures encountered with this pair are somewhat high. Other requirements are quite well met.

The main problem with the water-lithium bromide pair is the possibility of solid formation. Since the refrigerant turns to ice at 32 F, the pair cannot be used for low temperature refrigeration. Lithium bromide crystals at moderate concentrations. When the absorber is air cooled, these concentrations tend to be reached, and thus the pair is usually limited to applications in which the absorber is water cooled. There is a possibility that the use of a combination of salts as the absorbent will reduce the crystallizing tendency enough to permit air cooling. Other disadvantages of the water-lithium bromide pair are those associated with low pressure and with the high viscosity of the lithium bromide solution. These latter disadvantages are largely overcome by proper design of equipment. The combination does have the advantages of high safety, high volatility ratio, high affinity, high stability, and high latent heat.

Of the other refrigerant-absorbent pairs which have been investigated, the following types are of some promise:

1. Ammonia-salts.
3. Alcohol-salts.
5. Sulfur dioxide-organic solvents.

Several of these types appear to be suitable for a relatively simple cycle and may not give as much crystallization problem as the water-lithium bromide pair does. However, stability and corrosion information on most of them is very sketchy. Also the refrigerants, except for fluoro-refrigerants in the last type, are somewhat hazardous.

### Thermodynamics and Refrigeration Cycles

#### Table 10 Conditions in Lithium Bromide Cycles

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp, F</th>
<th>Pressure</th>
<th>Weight</th>
<th>Flow</th>
<th>Enthalpy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mm Hg</td>
<td>Fraction</td>
<td>lb/lb Refrigerant</td>
<td>btu/lb</td>
</tr>
<tr>
<td>1</td>
<td>192</td>
<td>66</td>
<td>0.61</td>
<td>11.2</td>
<td>-30</td>
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<tr>
<td>2</td>
<td>100</td>
<td>66</td>
<td>0.61</td>
<td>11.2</td>
<td>-70</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
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<td>0.56</td>
<td>12.2</td>
<td>-75</td>
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<tr>
<td>7</td>
<td>163</td>
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<td>0.56</td>
<td>12.2</td>
<td>-38.3</td>
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<tr>
<td>8</td>
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</tr>
<tr>
<td>11</td>
<td>40</td>
<td>6.3</td>
<td>0.0</td>
<td>1.0</td>
<td>78</td>
</tr>
<tr>
<td>12</td>
<td>40</td>
<td>6.3</td>
<td>0.0</td>
<td>1.0</td>
<td>1079</td>
</tr>
</tbody>
</table>

Table 10 is set up and a start is made at filling in the values. Lower side and high side pressures are the water vapor pressures for the evaporator and condenser temperatures, respectively. Enthalpies for water and steam are found in the steam tables. Concentrations and enthalpies for solutions for which temperatures are known are found in Fig. 49 of Chapter 31.

Relative flow rates are determined from material balances as follows:

\[
\frac{w_s}{w_d} = \frac{x_s}{(x_s - x_b)}
\]

where

\[
\begin{align*}
    w_s &= \text{flow rate of absorbent, lb/hr.} \\
    w_d &= \text{flow rate of refrigerant, lb/hr.} \\
    x_s &= \text{concentration of LiBr in absorbent, lb/lb solution.} \\
    x_b &= \text{concentration of LiBr in refrigerant-absorbent solution, lb/lb solution.}
\end{align*}
\]

\[
\frac{w_b}{w_d} = (\frac{w_s}{w_d}) + 1
\]

where

**HEAT INPUT CALCULATION INFORMATION**
\[ w_0 = \text{flow rate of refrigerant-absorbent solution, lb/hr} \]
\[ \frac{w_0}{w_d} = 11.2 + 1 = 12.2 \]

The enthalpy of the refrigerant-absorbent solution leaving the liquid heat exchanger is calculated from an energy balance as follows:

\[ h_1 = h_1 + [(h_1 - h_2) \times \frac{w_0}{w_d}] \]
\[ = -75 + [(-30 - (-70)) \times 11.2/12.2] = -38.3 \] (62)

The temperature corresponding to this enthalpy is found from Fig. 49 of Chapter 31.

The refrigerant flow rate is calculated from an energy balance as follows:

\[ \frac{w_d}{w_0} = q_e/(h_{11} - h_{10}) \]
\[ = 
\frac{1,200,000}{(1079 - 78)} = 1200 \text{ lb/hr} \] (63)

The absorbent and refrigerant-absorbent solution rates are next calculated as follows:

\[ w_a = 11.2 w_d = 11.2 \times 1200 = 13,400 \text{ lb/hr} \] (64)
\[ w_0 = 12.2 w_d = 12.2 \times 1200 = 14,640 \text{ lb/hr} \] (65)

The net heat input to the generator is calculated from an energy balance as follows:

\[ q_s = w_d h_4 + w_a h_1 - w_0 h_2 \]
\[ = 1200 \times 1147 + 13,400(-30) - 14,640(-38.3) \]
\[ = 1,540,000 \text{ Btu/hr} \] (66)

The coefficient of performance on a net basis is:

\[ \text{(COP)} = \frac{q_s}{q_e} \]
\[ = \frac{1,200,000}{1,540,000} = 0.779 \] (67)

Heat transfer rates for the other components are:

**Liquid heat exchanger**

\[ q_e = w_0 (h_1 - h_2) \]
\[ = 13,400(-30 - (-70)) = 540,000 \text{ Btu/hr} \] (68)

**Condenser**

\[ -q_e = w_d (h_2 - h_3) \]
\[ = 1200(1147 - 78) = 1,280,000 \text{ Btu/hr} \] (69)

**Absorber**

\[ -q_s = q_e + q_e + q_e \]
\[ = 1,540,000 + 1,200,000 - 1,280,000 \]
\[ = 1,460,000 \text{ Btu/hr} \] (70)

In actual practice, somewhat lower concentrations of lithium bromide solutions than those of Example 1 are commonly used in small commercial units to insure against crystallization of the salt, particularly on shutdown. These more typically are 54 percent and 58.5 percent. Higher concentrations, normally about 60 percent and 64.5 percent, are used in large commercial units in order to operate at higher absorber temperatures and thus save on heat exchanger costs. Controls and a shutdown dilution cycle are employed with these large units to prevent crystallization.
In planning a housing development for this prototype, various criteria must be considered.

Most important would be the actual effectiveness of solar space heating, and this would be determined by studying the solar data pertaining to the particular region. If a development is feasible, then there are some restrictive criteria associated with the solar collection equipment.

Obviously, no shadows can be allowed to infringe upon solar collectors between the most effective solar hours, usually 3 or 4 hours each side of the solar noon. To determine what shadows are cast between the hours, a diagram charting the path according to sun inclination, time, and compass direction should be done. Sun shadows for summer and winter need to be charted such as those for the 40° latitude on the opposite page.
• IN PLANNING CONSIDERATION MUST BE GIVEN TO DAILY SHADOW PATHS OF LIVING UNITS.
• CRITICAL SUN HOURS ARE APPROXIMATELY BETWEEN THE HOURS OF 8:00 A.M. AND 4:00 P.M.
• BETWEEN THESE TIMES THE SHADOW CANNOT INFRINGE ON AN ADJACENT UNITS SOLAR COLLECTORS.
In dealing with landscaping, shadows again have to be considered. The main points for consideration are the characteristics of plants that would get tall enough to cast a shadow on the collectors. Therefore, planning is in terms of full growth of plants.

After full growth characteristics are determined, then it must be known if the plants are deciduous or coniferous. If the summer sun angle in relation to the housing unit is diagrammed then it is evident that any plant, deciduous or coniferous, cannot infringe on the space between the critical sun angle and the collectors (see opposite page). In the winter, however, a tree or plant which loses its foliage, deciduous, could be between the sun and the collectors because they would not block the sun’s rays. A conifer, plant which retains its foliage, could not be so placed since it would block the sun. Conifers would have to be below a winter sun critical sun angle. A final major point in planning would deals with the need to allow for the possible expansion of the housing unit. A trade-off to deal with this might be to make lots with adequate dimension in the path of expansion but of lesser overall size and make more of the surrounding land common public ground that cannot be expanded onto.
PLANTING AROUND PROTOTYPE

- Summer sun cannot be blocked by foliage of trees, shrubs, etc.
- Plantings must be on opposite side of critical summer sun line
- Winter sun can penetrate foliage-less plantings
SOLAR/JECTOR ANGLES

Schematic Development
Initial Scheme

Solar Heating Schematic

Diagrams A, B, C represent possible positions of solar heat plate collectors. Position C allows the collector to be tilted in response to seasonal sun angle.

Storage