

A BUILT FORM EXPLORATION OF SOLAR ENERGY

by

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ABSTRACT

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JOHN C. KAUFFMAN

This thesis deals with some of the form considerations in designing with flat plate collectors and heat storage facilities. It is especially concerned with small scale residential aspects of this problem and explores some built form alternatives. The focus is upon the process of designing with technically proven components using simple production/capacity/support relationships as guiding principles.

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## INTRODUCTION AND PROCESS

My original thesis proposal was:

A thesis project which explores some built form possibilities for a housing cluster employing solar energy for heating purposes with special emphasis on form/organization/context considerations and on the extent to which/manner in which these considerations affect/are affected by various technical parameters/exigencies/apparatuses (and their attendant forms). In particular, with respect to these forms, i.e., collectors, storage facilities, delivery elements, the object of the exercise is to build with them rather than to apply them a la "inclined billboards" -- in the case of collectors -- or, as with storage facilities, relegating them to a basement, never to be seen/used again. While my principal interest is the form/organization/context issue of solar energy, I recognize at the onset that mechanical "solutions" should be technically reasonable and apropos the built form. Further my intention is not to look for new engineering techniques, but rather to make use of those already proven. The design program call for 6+ units of housing totalling approximately 8000 square feet.

My interest in such a thesis derives from an actual project begun in January, 1975 to design and build a single family solar heated residence on land adjacent to the site

used herein. For various reasons the actual project could not be used as a thesis subject, the most important being that due to local site conditions, solar collectors must be removed some 75 feet from the actual dwelling, which presents a problem not of integrating but of segregating house form and technology.

What follows is an attempt to document the process I have experienced in thinking about the problem. The beginnings of this had largely to do with developing, nearly from scratch, some technical sense concerning solar energy, especially as it applies to domestic heating, with a bias toward the current/past state of the art, and purposely excluding "high-tech" possibilities. In particular I was initially interested in finding rules of thumb which would allow me to make more or less reasonable decisions with respect to what solar components meant in physical terms and how they might be thought about in beginning to design a solar supported structure of any sort. At this state Tremmie, my advisor, was faced with relying almost entirely on my information, or misinformation, as it was presented to him. For this blind faith I thank him, but additionally for the along-the-way comments, criticism, and encouragement (on three occasions) and general direction which often seemed pretty tangential to what I had imagined I was after.

Armed with what I considered to be sufficient information, my next endeavor was to look for a physical relationship or connection between solar components which went beyond simple performance/capacity descriptions and would suggest some sort of organizing principle. Seemingly, what always was in my mind and which remained elusive, was the notion of designing some "piece of stuff" which would be additive, associative, etc., but which simultaneously fulfilled perfectly the technical requirements central to the exercise. The small scale and geographic/social context of the problem did not help in this regard as I found myself continually thinking in terms of integrating solar components with those building systems with which I was familiar and comfortable -- frame/post and beam systems -- which happened to coincide rather nicely with program and context. Perhaps the most important upshot of my midterm review was a general interest in the problem of size/context, the consensus being that the number of units, which had been pushed to about 24, was inappropriate and that perhaps looking at a smaller number -- the originally intended #6, for instance, -- might prove more fruitful.

My own conclusion just before the midterm review was that to escape the "inclined billboard" solar form it was necessary to design collectors which were not necessarily physically connected with the space they supported. In

other words to build collectors per se, perhaps, in order to free some enclosed inhabitable space from the otherwise ubiquitous roof collector which produces nothing but extruded sections. Extruded sections do, however, insure that no shadowing of one collector piece will occur as a result of an adjacent collector or other building element built in a different plane. Indeed, beyond the simple fact of building and transmission efficiency, by keeping collectors in the same plane, the problem of shadowing of collection surfaces is the most significant determinant of solar forms I have encountered. Knowledge of sun angles for the critical underheated time of the year is of little help if forms are very complex, i.e., are built in many planes and have many shadow casting possibilities. This problem is discussed in Robert Knowles's book Energy and Form.<sup>1</sup>

About midway through this project the "piece of stuff" which might serve as a building part toward larger organizations still remained elusive and the decision was made, especially after my midterm review, to concentrate on more singular prototypical forms, rather than on clusters built up out of the repetition of some piece. The information which follows is organized in approximately the chronological order of the process. The design explorations are clearly not meant to stand as solutions but rather as graphic projections of my thoughts on the process.

## PROGRAM AND SYSTEM

The original program called for six housing units totalling approximately 8000 square feet (including various outbuildings) to be designed for a rural Colorado site of approximately ten acres. These units would be organized in a cluster and range in size from 400 to 2000 square feet. The projected number of units was later amended to 24 and still later back down to six. This was an attempt to examine a larger organization of units, which proved to be inappropriate to the site.

The building system is wood frame, post and beam, and masonry construction. Solar collectors are of a type currently available, and storage elements are designed to be easily fabricated from common materials.

## SOLAR COMPONENTS, ASSUMPTIONS AND TECHNICAL BACKGROUND

The following information is intended to provide a basic knowledge of solar heating components, their forms, sizes, and interrelationships. It is hoped that through this discussion a background sufficient to make some assumptions or rules of thumb will emerge, and that these can be employed in making form decisions apropos the technical requirements and constraints.

Basically, a simple domestic solar heating system can be broken down into constituent parts which include radiation collectors, heat storage elements, transmission equipment connecting these first two, and a variety of heat delivery elements not unlike those associated with conventional heating systems (ducts and registers, heated slabs, walls, etc.). Of course various regulating controls are another category, but are of little concern to a form consideration.<sup>2</sup>

Collectors are the most convenient starting point since it is with these elements that the process of utilizing solar energy for heating purposes begins. These are, first of all, a variety of types, the most common of which I have chosen to consider, since this type, the "flat plate" collector, has been most responsible for the forms associated with solar energy in general. Basically, when used

as a sloping roof collector, a typical collector section is dimensionally not unlike the average roof section: it collects the sun's energy, keeps out the weather, and provides insulation between shelter and the exterior world. The variety of individual type is ever-increasing and ranges from homemade sorts to those produced commercially, the major difference being in technology employed within a particular application.<sup>3</sup>

If for the moment it is accepted that flat plate roof collectors behave physically as roofs do -- keep out weather, insulate, and are opaque -- then the most important form considerations are clearly the slope, associated with efficient use of the sun's altitude, and the size of collector required to make a solar application worthwhile in the first place. The slope of collector has principally to do with efficiency, and assuming that the slope of the collector does not change as the sun's altitude does, it is wise to design collector slopes such that the most underheated time of the year receives radiation at as close to normal an angle as possible. This is the first principal restraint as regards collectors since this angle necessitates a sloping "roof" of up to  $60^{\circ}$ , although  $45^{\circ}$  appears to be a good compromise and is employed later in design projections.<sup>4</sup>

The second principal restraint is the sheer size of

collector required to support a dwelling. The best, recurrent guide, based on FHA insulation values, which are the norm, indicates a 2:1 ratio between floor area supported and collector area required for such support. More than anything else, it is this enormous area, coupled with shadowing problems, which has determined such solar forms as have been built.<sup>5</sup>

Associated with collectors and heat storage is the question of what collection medium should be used. From the standpoint of form, this is not of major consequence, except in that the medium will be either a liquid or a gas, and clearly one requires plumbing components for transmission from collection to storage, while the other employs ducting. The most common media within each category are water and air. While water is subject to freezing and thus requires anti-freeze, air presents no such problem and has the additional benefit of being "free." Also to be considered is the possibility of medium leakage, which obviously would be of greater consequence if the medium were a liquid. Indeed it has been stated that all liquid systems are subject to leakage caused essentially by mechanical action on circulation fittings, which experience temperature differentials of several hundred degrees F in the course of a day. The bias here, for reasons of cost and leakage, is clearly in favor of air collection and

transmission systems.

Having been collected, heat must be stored in some way to allow for later use on demand. Heat can be stored in a variety of ways, the principal consideration being which of three basic media is used. This decision has special importance to this study since the physical form of a storage facility is determined, at least in terms of volume, rather directly by the heat storage capacity of the particular medium. A second form determinant appears, as of this writing at least, to be the desirability of enclosing heat storage elements as deeply within the interior of a total built form as possible. This insures that any heat lost from a storage element is used toward heating the enclosure rather than the out-of-doors. Hence, storage elements ideally should not be associated with external edges, but rather should act as internal parts with strong ground association due to their mass.

As with collector size, rules of thumb have been established for storage volumes, these being related to which of three principal media are used.<sup>6</sup> As stated, heat can be stored in a wide variety of ways, although most appear to be permutations of the three basic media -- rock, water, and eutectic salts.<sup>7</sup> If floor area supported, hence collector size, is held constant, the following ratios for storage volume may be used: rock, one cubic foot per

square foot of collector area; water, one cubic foot per square foot of collector area; and eutectic salts, one cubic foot per 20 square feet of collector area.<sup>6</sup>

There are advantages and disadvantages associated with each of these media. Rock is inexpensive, perhaps free, works well with hot air systems and presents virtually no maintenance problems. About 30 BTU's can be stored per cubic foot of rock per degree increase in temperature. A comparatively large storage volume is required, but this is not necessarily a disadvantage.<sup>7</sup>

Water is inexpensive, but is likely to require the addition of anti-freeze in the event that the system is ever shut down long enough to allow the freezing of storage elements. The storage of water can require large, expensive tanks or other receptacles which may need repair or replacement. Here, access can present a major problem. In its favor is the fact that an equal volume of water stores more than twice as many BTU's as does rock.

Controversy continues to surround the use of salts, and centers on the physical characteristic of this medium which makes it attractive for heat storage in the first place. An enormous amount of heat may be stored at the solid-to-liquid phase change which occurs at approximately 90°F. When heat is withdrawn, however, the salt exhibits unpredictable characteristics, namely stratification, or

incomplete, irregular change of phase, and the possibility of "supercooling," i.e., the change from liquid to solid not occurring until as low as 55°F. Assuming a proper phase change in both directions, salts store about seven times more heat than water at 90°F and require about one cubic foot per 20 square feet of collector area. The use of additives has been suggested as a means of correcting these phase change problems. I have chosen not to consider the use of salts, not only because the phase change problem remains unresolved, but also because the sizes of storage elements used are small enough to be of little value to a form exploration.<sup>10</sup>

## SIZES OF COMPONENTS

In seeking an organizing principle of use in designing with solar components, it appears necessary to establish some catalog of size relationships between square footages to be supported and the components themselves. If the 2:1 ratio of collector-to-square footage is accepted, then this size issue is determinate. So too, then, is the storage facility issue, due to the basic interrelationship. However, there remains at least the possibility of size/configuration options based on which storage medium -- rock or water -- is selected. Almost any physical form is possible if it somehow contains the material used, allows for insulation of the heated mass, and solves the problem of transmitting heat in and out. The following is an attempt to develop a set of form types which are certain to satisfy the above, and which hopefully can be additive and have some association beyond the purely technical requirements.

In beginning, I took as the smallest size to be supported a piece of 400 square feet, which also represented the smallest unit size I imagined designing. The collector area for this size would be half its square footage, or 200 square feet. From the information above, it is clear that storage facilities would vary between 80 cubic feet --

if water were used as the storage medium -- to 200 cubic feet if rock were used.

Water storage elements have traditionally been large tanks, which, as previously mentioned, are expensive. More importantly, they provide a fairly limited use form. Containerized water, or better, a water/anti-freeze mix, presents the advantage of greater form flexibility, given less cumbersome sizes and the additive quality which this implies. A water/anti-freeze mix can be held in small recycled containers, for instance, and arranged in a "wall" having the required cubic footage.<sup>11</sup> To provide some "wall-like" dimensions, 80 cubic feet factors into 1' x 8' x 10'. Obviously, insulation increases these dimensions, possibly as much as four to eight inches in each direction. Obvious, too, is the fact that an assemblage of this sort has no structural integrity in and of itself, and that such a large building element ought to contribute structurally to the larger form of which it is a constituent part. Hence the necessity of "wrapping" the container/insulation combination with some structural skin. Clearly this might be as simple as a stud wall around the whole. An alternative would be to use three- or four-inch thick concrete block which could be more successfully used either as a ground form, especially if the "wall" were very low, or as a major support wall with lateral stabilization, if the

"wall" were built high enough that this became necessary.

A storage facility using rock as a medium suggests containment in some form which is very much ground associated, perhaps bin- or crib-like. A volume of 200 cubic feet factors roughly into 4' x 8' x 8' (this is somewhat large). Obviously, other dimensions are possible, and in any case it is not necessary that the volume required be a single unit, as implied here. Diagrammatic studies of this follow, showing the importance of the two sorts of storage facilities on a 400 square foot area.

One other approach to the 400 square foot piece is via Olgyay's "basic forms and building shapes" for different regions. Given what information I have so far, there is, perhaps, insufficient reason to expect that a 400 square foot piece will ever add up to any larger scale organization. Nevertheless, it seems worthwhile to keep Olgyay's work in mind, at least as a beginning reference. Olgyay gives optimum width-to-length ratios for "temperate" climate as 1:1.6, and for "hot-arid" as 1:1.3.<sup>12</sup> Since the climate under discussion lies somewhere between the two, I chose to use 1:1.5 as a width/length ratio. Applied to a 400 square foot piece, this gives dimensions, roughly, of 16' x 24'. Again, I am not certain that a larger organization can be generated by this smaller piece, but the Olgyay ratio would be built into the larger, at least to

the extent that the smaller size was used repetitively.

The 4' x 8' x 8' rock storage might be associated with a change in level, and in any case would be meant to produce a use surface of a size between smallest -- for instance, the top surface of a heat storage "wall" -- and largest -- the entire 400 square foot floor area. As this organizing size grew or divided, so too would storage sizes, although, of course, a 1:1 correspondence between unit and storage element, or for that matter, between unit and collector, would not be sought in reality. At this stage the assumption of this correspondence is entirely for organizational purposes in trying to understand a possible relationship between solar components and square footages of floor area.

HEAT STORAGE UNIT DIAGRAMS

Using a 1:1.5 configuration ratio from Olgyay,  
a 400 square foot area factors into

$$x \cdot 1.5x = 400$$

$$1.5x^2 = 400$$

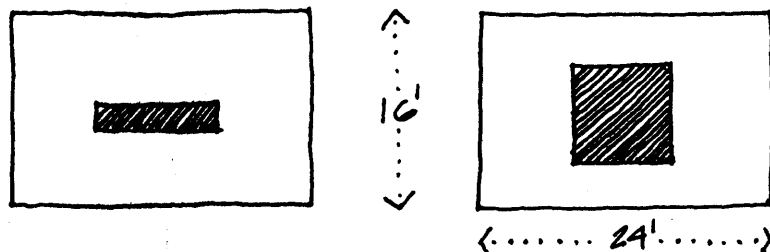
$$x^2 \cong 266$$

$$x = 16$$

$$\text{thus, } 1.5x = 24$$

$$16' \times 24' = 384 \text{ s.f.} \cong 400 \text{ s.f.}$$

Assuming, then, a 400 square foot area, two heat storage types, as previously described, might be employed. One would use a water wall (2' x 8' x 10') and the second would use a rock "bin" (4' x 8' x 8'). Given the required volume for the respective media, these sets of dimensions represent two out of many possibilities. If the absolutely simplest plan is used (16' x 24'), two possible configurations are shown. Both examples generate surrounding dimensions of dubious use. An obvious solution, of course, is to not center the storage elements. The diagrams are intended simply to show a size relationship between square footage supported and storage size required.



## THE CONTEXT

Essentially the context of the larger region of west central Colorado has much to do with the landscape. The overall impression which an outsider carries away is of super-human scale landforms which totally diminish any man-built additions. It is difficult to describe this to someone who has not experienced the American Southwest. Words, maps and color slides are insufficient to the task.

Running generally east-west, the Colorado River Valley establishes the direction of the larger landscape and determines the route of the major highway and railroad lines which connect this region to Denver, 200 miles to the east, and the Utah line, about 75 miles to the west. Settlement is organized in this direction also, with the nearest "city" of 20,000+ lying about 50 miles to the west, and the next largest, of 5,000+, being approximately 40 miles to the east. Between the two are numerous towns, ranging in population from fewer than 200 to 2500. Enclaves of still fewer people are found mainly on secondary roads paralleling the river and at distances of one to five miles to its south. These settlements tend to be quite close to the road and at most number 20 families. In general, the river elevation is +5200 feet, although settlements can be found as high as +6200 feet. The

climate is severe in both winter and summer, with temperatures ranging from sub-zero nearly every winter night to 100°F during summer days. Clear skys at night make for cool summer nights, however. My best guess at Degree Days per year is 6500, although local conditions vary greatly in the mountains, so that this is an extrapolation from an average of measuring points, and I suspect that, if anything, it is conservative.

Nearly all of the inhabitants of the area within five miles of the site are engaged in some form of agriculture, although possibly thirty per cent also commute to the two larger population centers mentioned above, where their occupations vary widely, or to the most proximate town of 2500, some 12 miles distant, which has the nearest secondary schools, hospital, retail sales, etc.

Within the settlement nearest the site, with which I am fairly familiar, there is a strong sense of community through the sharing of tools, various implements, time, expertise, and even land. A distinct barter economy exists, founded primarily on agricultural products, but including just about anything of use. Much of it appears to find its way into various piles of material, spare parts, etc., which particularize individual settlements, but also run throughout as a constant theme. A discernible pattern in the creation of outdoor space is particularly apparent

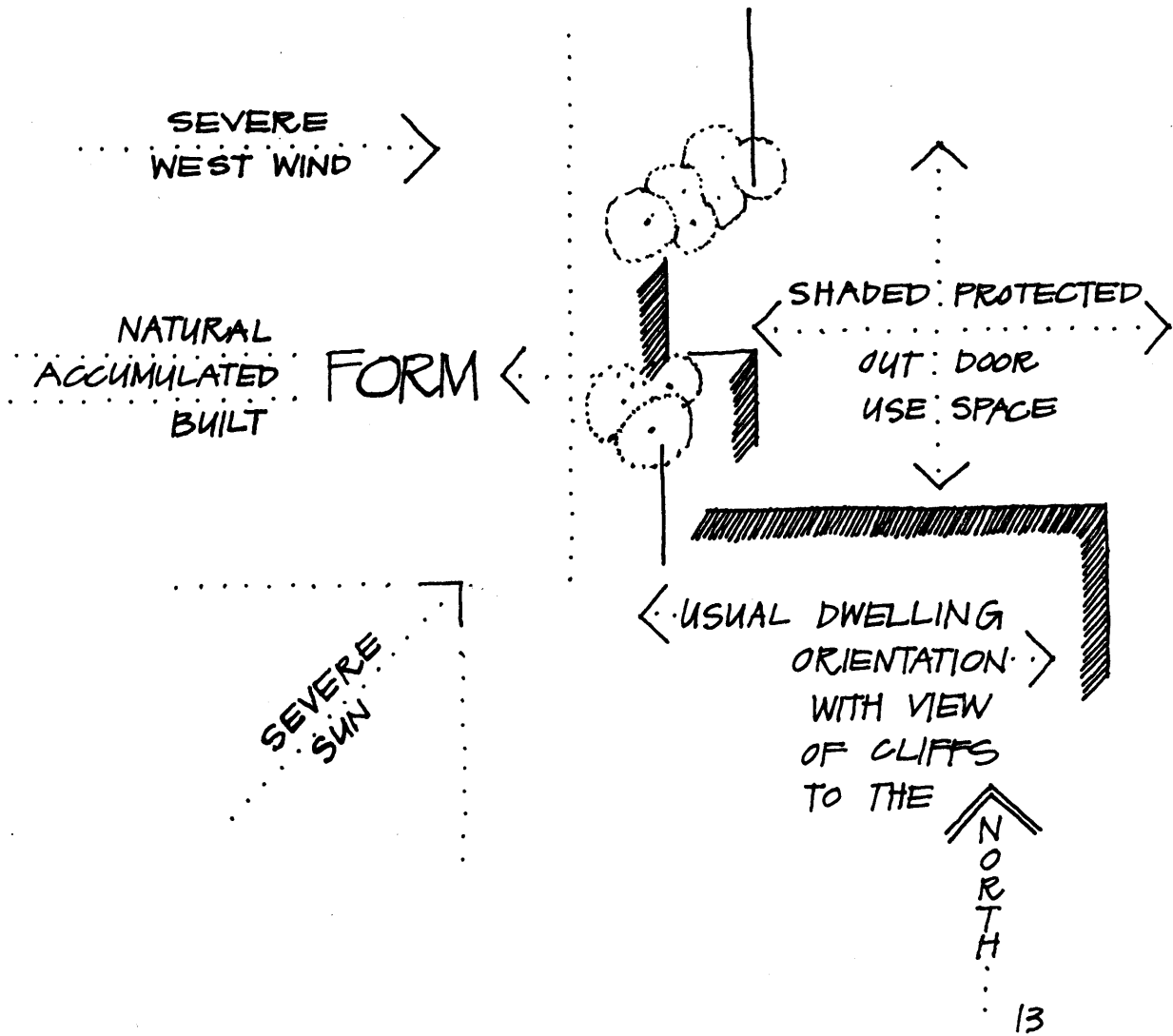
where several families are settled in close proximity. Outbuildings, piles of various materials, livestock buildings, fences and barricades, vehicles (often abandoned), and dwelling houses themselves, not to mention the natural landscape, begin to add up to an organization which is clear and understandable. (Some diagrams of this follow.) The clearest organizing principle behind these varied arrangements seems to be an almost defensive reaction to severe wind and sun conditions, as outdoor work especially is made difficult or, at times, impossible, by both. This settlement characteristic and the requirements of solar collectors were the two primary siting determinants.

## SITE CHARACTERISTICS

An important feature of the site is a slope -- of approximately 6% -- to the southwest, roughly following an irrigation ditch which runs throughout. Fairly dense vegetation is found along the course of the ditch, including a few cottonwood trees of, perhaps, 30 feet in height, cedar trees, and large shrubs. The ditch, then, in combination with the associated vegetation, creates the only significant physical edge within the site. The secondary road, which also has a fair number of trees, shrubs, and some boulders of up to four to six feet in diameter along its route, adds up to a second edge on the north boundary.

As with the region, the local site is dominated primarily by the system of cliffs to the north and the more gradual hills rolling up to mesas to the south. The severe sun, temperature, and west wind conditions discussed under "context" apply locally as well.

SETTLEMENT DIAGRAM



## STEREOGRAPHIC SUN PATH AND SHADOW ANGLE CHART

The following chart is of use in determining the effect of shadows on solar collectors (and any other form).

It gives vertical and horizontal shadow angles derived from stereographic sunpath charts.

The numbers along the top refer to hours of the day, and numbers down the columns refer to the angles at which the sun casts shadows vertically and horizontally (or elevation and plan angles) at different times of the year. Angles are measured east and west of south (for plan angles) and off the horizon (for elevations).

The "worst" time of the year, from the point of view of heating demand, is 21 January. The plan and elevation angles associated with it are of special importance, and are used for design purposes.

Two-thirds of the day's solar energy is of value for heating purposes. During other hours, the sun strikes the collector surface at too oblique an angle to be effective.

< ..... >  
 USEFUL 2/3 OF DAY  
 .....

		8	9	10	11	12	1	2	3	4
21 JAN	PLAN	54°	42	30	15	0	15	30	42	54
21 NOV	ELEV.	10°	18	24	26	28	26	24	18	10
21 MAR	PLAN	68	55	40	20	0	20	40	55	68
21 SEP	ELEV.	45	45	45	45	45	45	45	45	45
21 JUN	PLAN	90	78	60	40	0	40	60	78	90
	ELEV.	88	78	74	72	70	72	74	78	88

14

AN EXAMPLE FOR 21 JAN WOULD BE AN 8' HIGH, 8' LONG WALL, AT 9 A.M. SHADOW CONDITIONS =



## SOLAR COLLECTOR FORM ANALYSIS

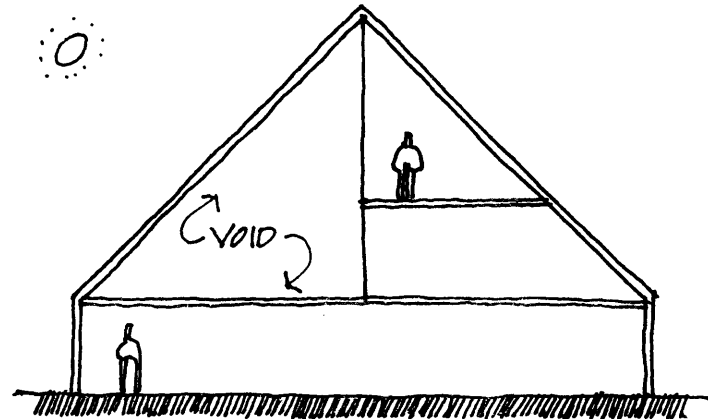
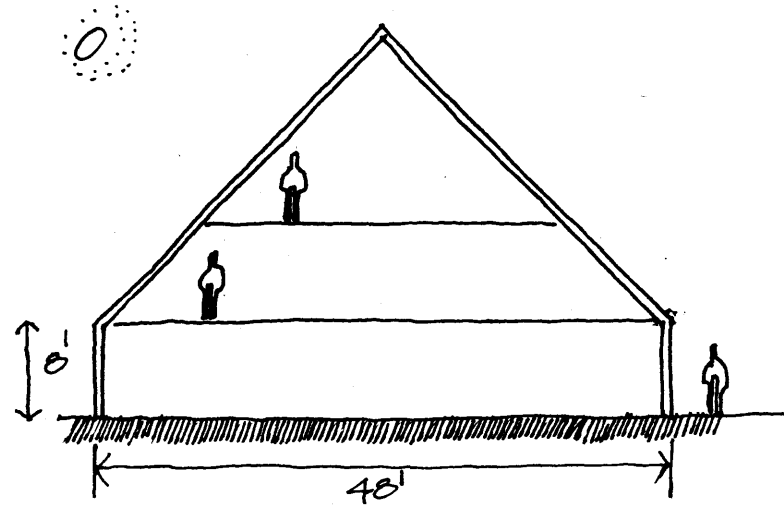
48' relates to dimension which is ultimately sought, and is used for demonstration only at this point.

Assuming a  $45^\circ$  pitch (from sun altitude as a good average), the section shows how fast the space grows vertically.

Ratio of floor s.f. to collector s.f. ought to be 2:1. Here it is 3.5+:1.

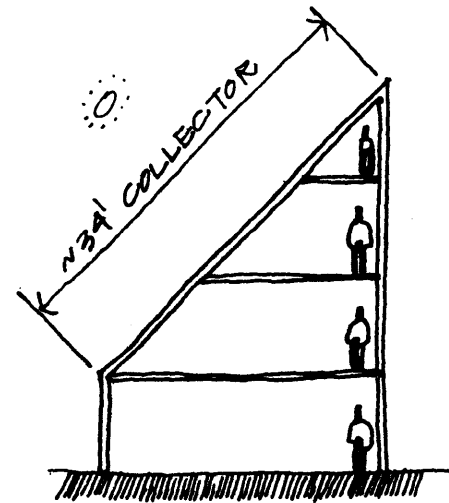
For this reason, most built form employing solar energy never makes use of the volume generated by a steep collector angle. Obviously, the case using a  $60^\circ$  angle is considerably worse.

Cutting half the upper levels still produces 96 square feet, the ideal being 68 square feet per 34 square feet of collector.



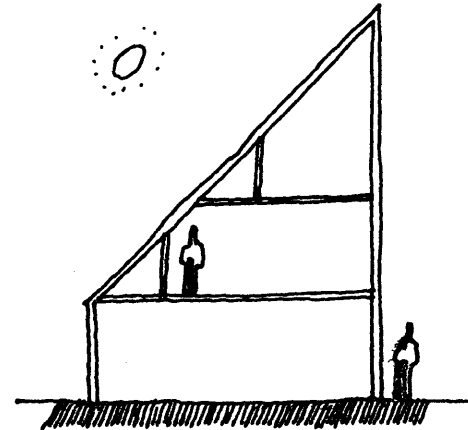
Technically, this is the section which works with about 34 square feet of collector area and 68 square feet of floor area.

Clearly, not all of what is counted as floor area is usable space. What is intended here is a diagram of a workable collector angle and ratio of collector square footage to gross floor area.

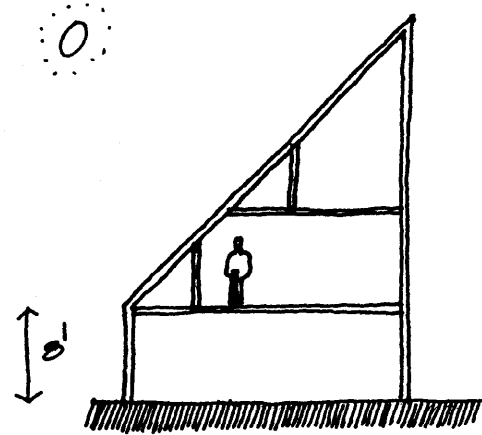


R = 2:1

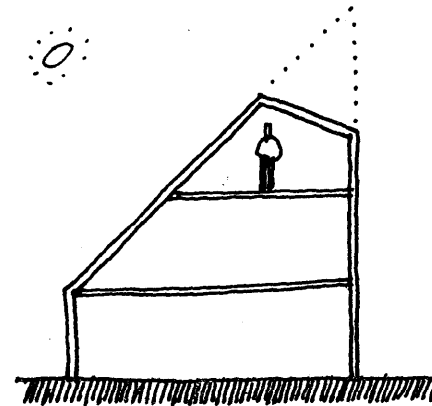
Cutting marginally useful floor area does nothing to change one's association with the south-facing edge, all of which is made up of collector surface.



Implicit in this diagrammatic section is a maximum south-facing window area of eight square feet, and a huge north-facing wall profile (with all of this occurring on the lowest level).



A couple of things can be done to change this basic section: one is to eliminate the space of minimal usefulness at the top, and using a second roof pitch on the north side. This, of course, eliminates collector area as well, which must be replaced somewhere -- the only possibility being a vertical collector, which is nearly as efficient.



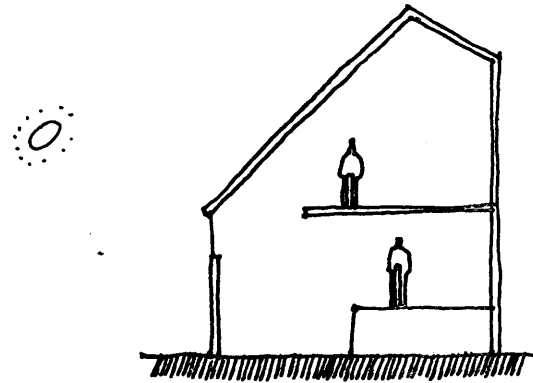
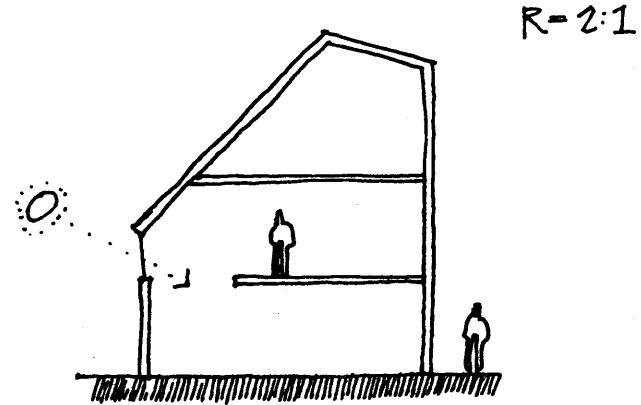
R=2:1

To regain some southern exposure, the roof can, in effect, be slipped upward to open the south wall above the vertical collector. In fact, if the roof itself is slipped next to an adjacent collector, shadowing will occur and cut the efficiency of that area.

To prevent this, the ground floor level may be dropped, producing the same opening above the vertical collector.

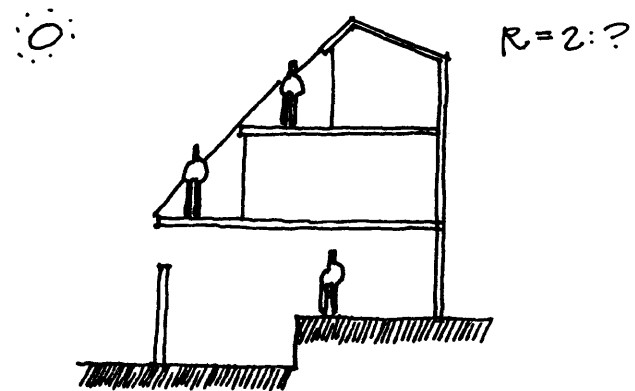
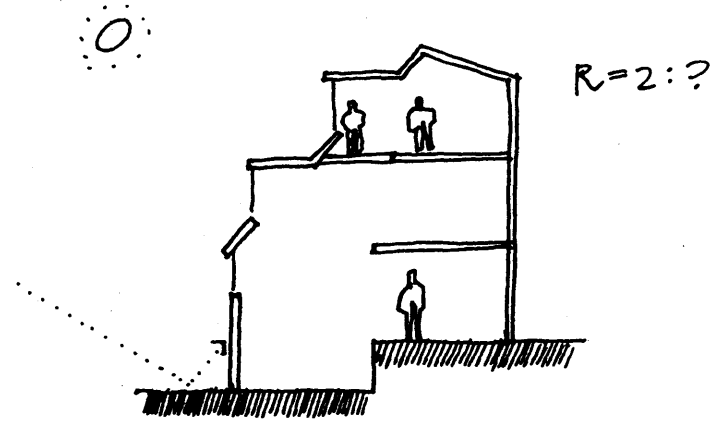
The most obvious way to avoid this shadowing problem is to refrain from building adjacent collectors.

The association with the opening shown above can be changed to a small extent by changing levels somewhat.



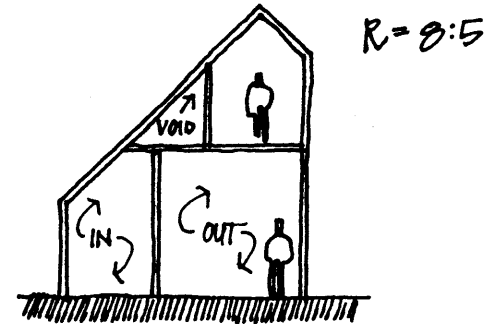
Pushing levels and/or roofs up and down works only to a point, and with minimal definitions in any case.

A couple of other possibilities especially associated with the space just under collector roofs is to build dormers out. This gets back into the problem of shadowing adjacent collector areas, not to mention cutting out some amount of collector to begin with.



Another strategy is to build inwardly, which obviously eliminates the shadowing problem. If not a use surface, the horizontal area might serve as a collector, but again with the shadowing problem. The effect on the "R" is, of course, a function of how much collector is cut out and/or shadowed.

At a point it becomes fairly clear that pushing levels up and down, and cutting holes in collectors will never add up to building with the various elements, and that one must look for a way of gaining some leverage which is both technically efficient, and will help to generate more reasonable built form.



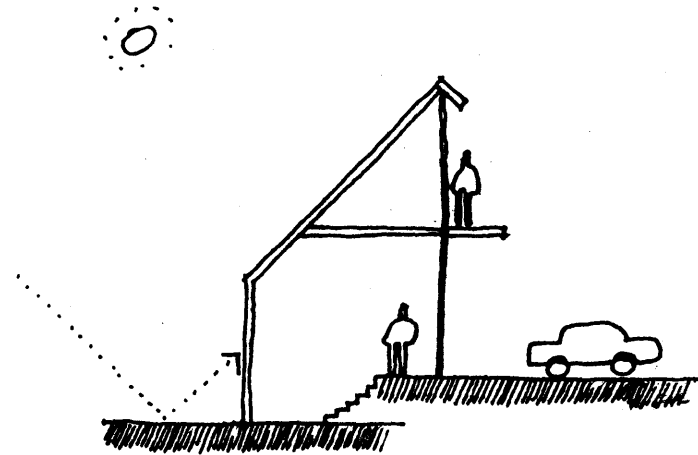
32.

One strategy is to change the problem of the basic stumbling block, i.e., collector size. TEA does this by cutting heat loss, hence energy demand, hence collector area, by thirty to fifty per cent.<sup>15</sup>

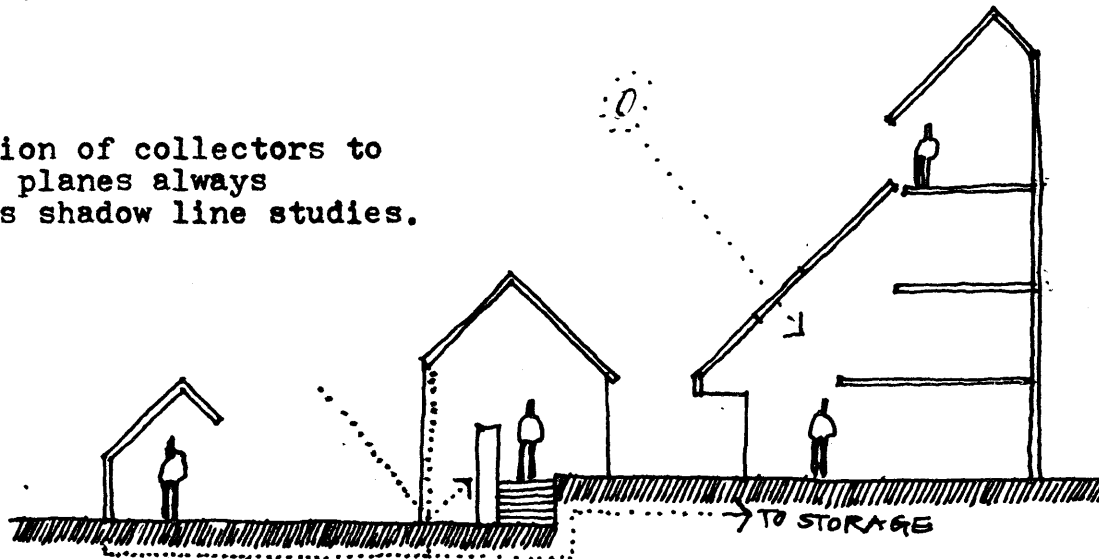
Shown above is another strategy in which a given square footage of collector is associated with significantly less square footage of space than it would be under  $R=2:1$ .

In this case the collector serves locally only as shelter, with its energy being given over to some other zone which has insufficient collector capacity.

This and/or the preceding section might be used as an entry part, or for passage or storage, and begin to combine to form outbuildings and define exterior space somewhat protected from the elements.



Separation of collectors to various planes always involves shadow line studies.

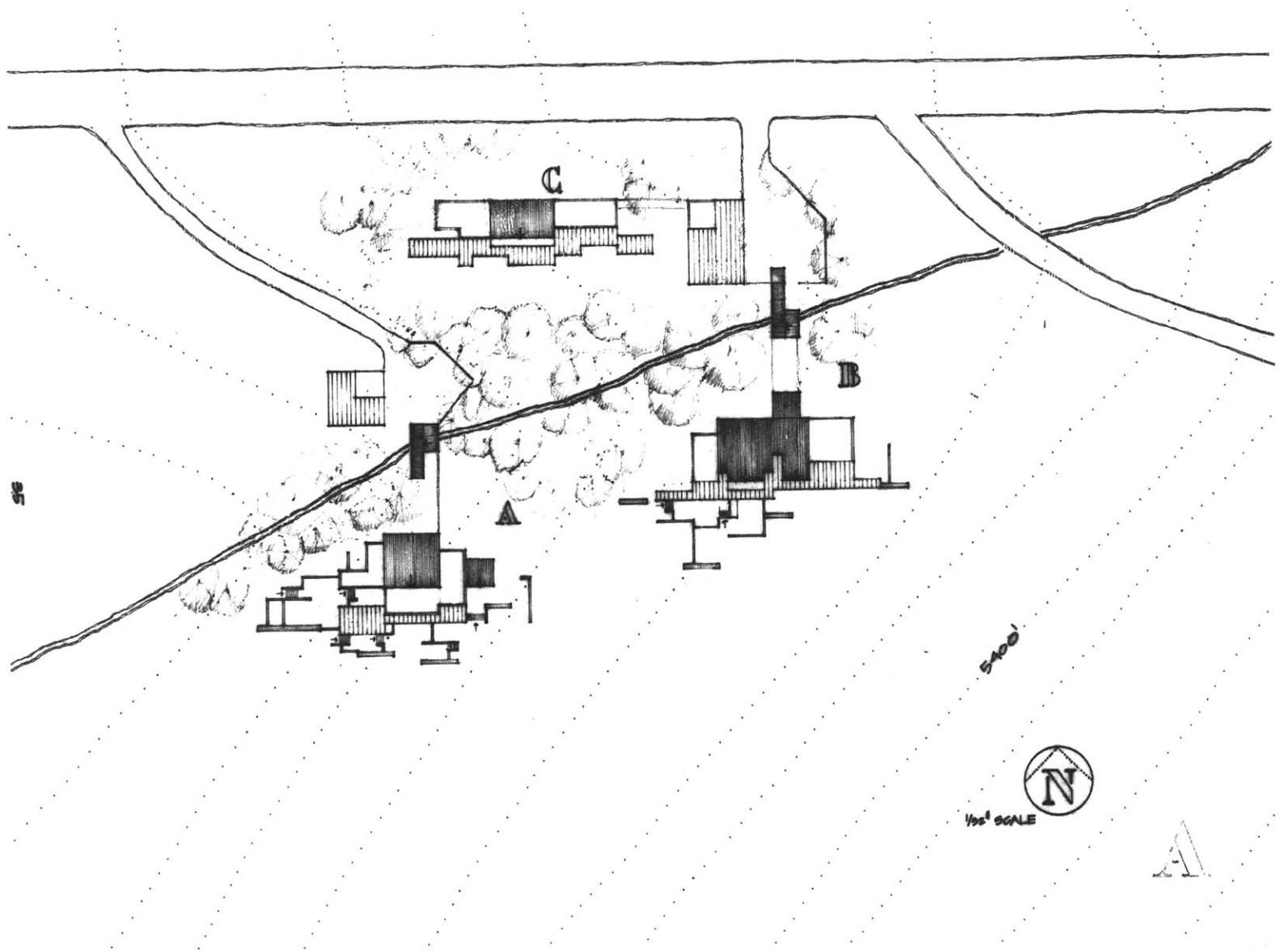


## REMARKS ON DRAWINGS

The drawings which follow represent an exploration of built form possibilities using the various solar components previously discussed -- flat plate collectors and storage elements -- but using "bead wall" collectors.

The exploration has clearly led to the design of shelters which don't suggest any particular direction toward a larger organization of solar-supported built form. While I set out to investigate something much different than single family residences, I found it necessary to start to deal with the energy exigencies at a size with which I am familiar, more comfortable, and, admittedly, more interested.

The next step, in my thinking just now, would be to project much more of the same sizes, looking for additional form/use possibilities. Beyond this I would start next time with a site which slopes steeply to the south -- any "ideal site" will help, and also consider Ralph Knowles's conceptual work on large scale applications and the forms which this work has generated.



SE

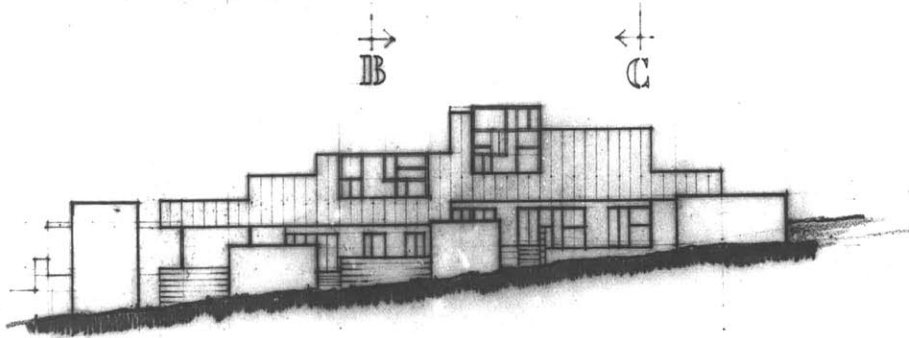
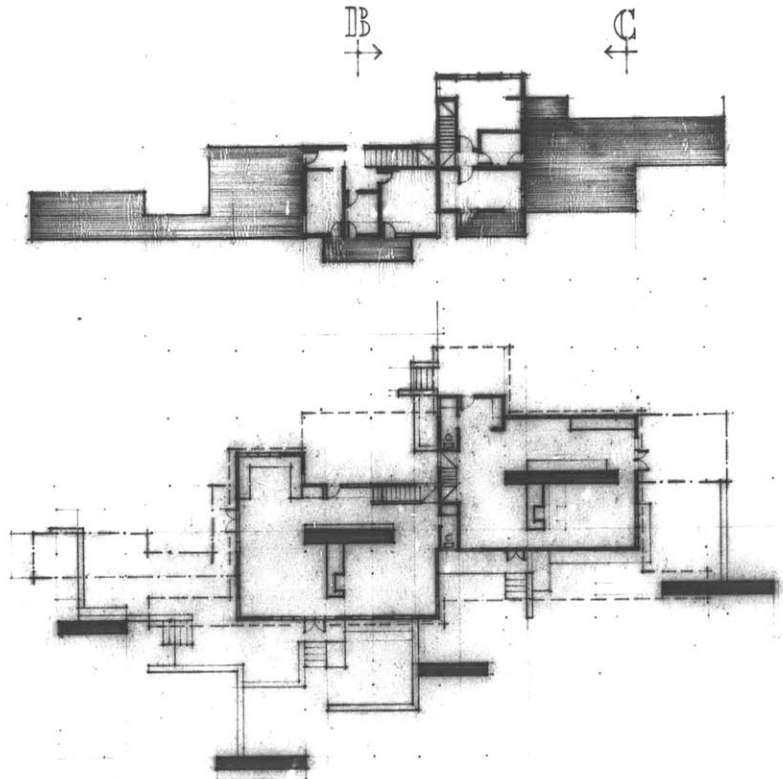
500'



1/2" = 100'

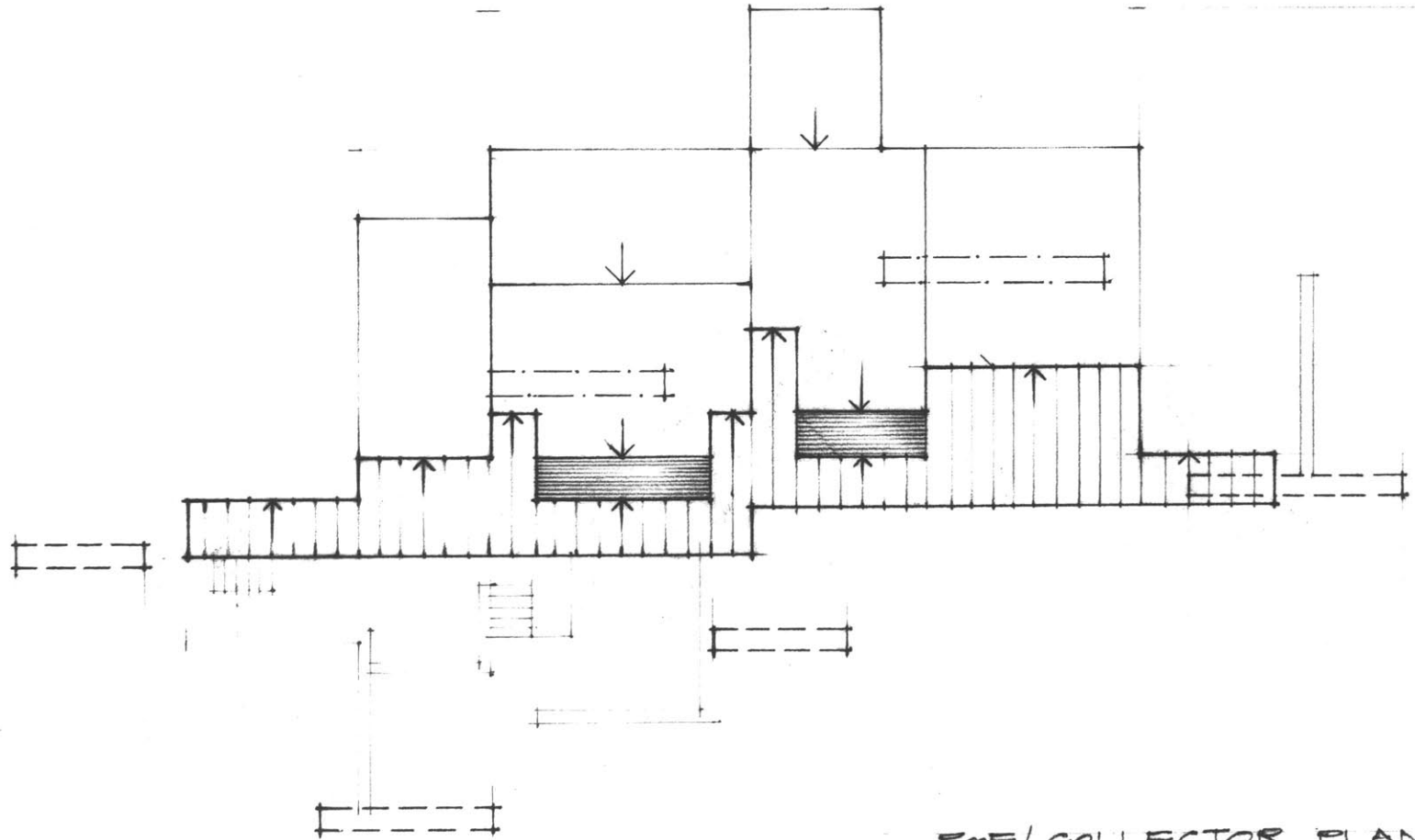


2E

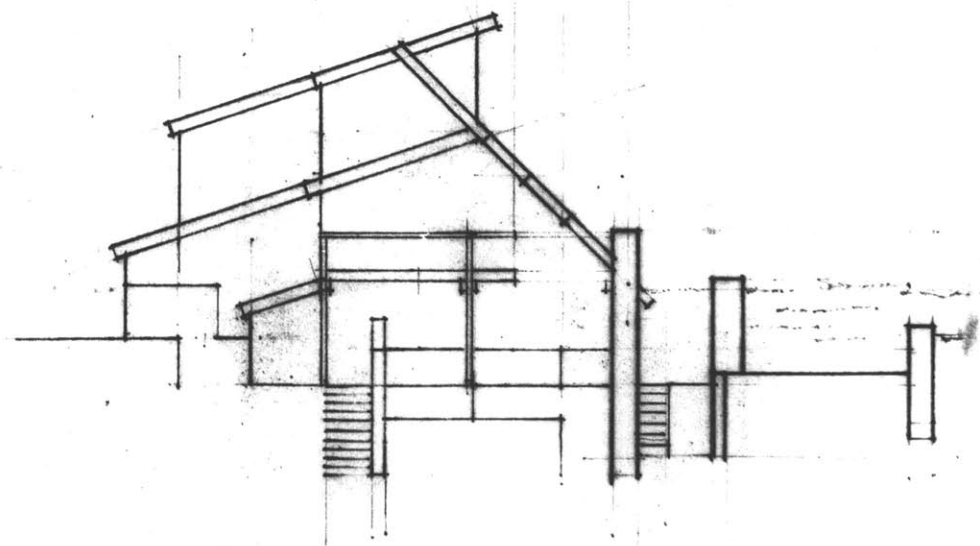


SCALE = 1/16"

37

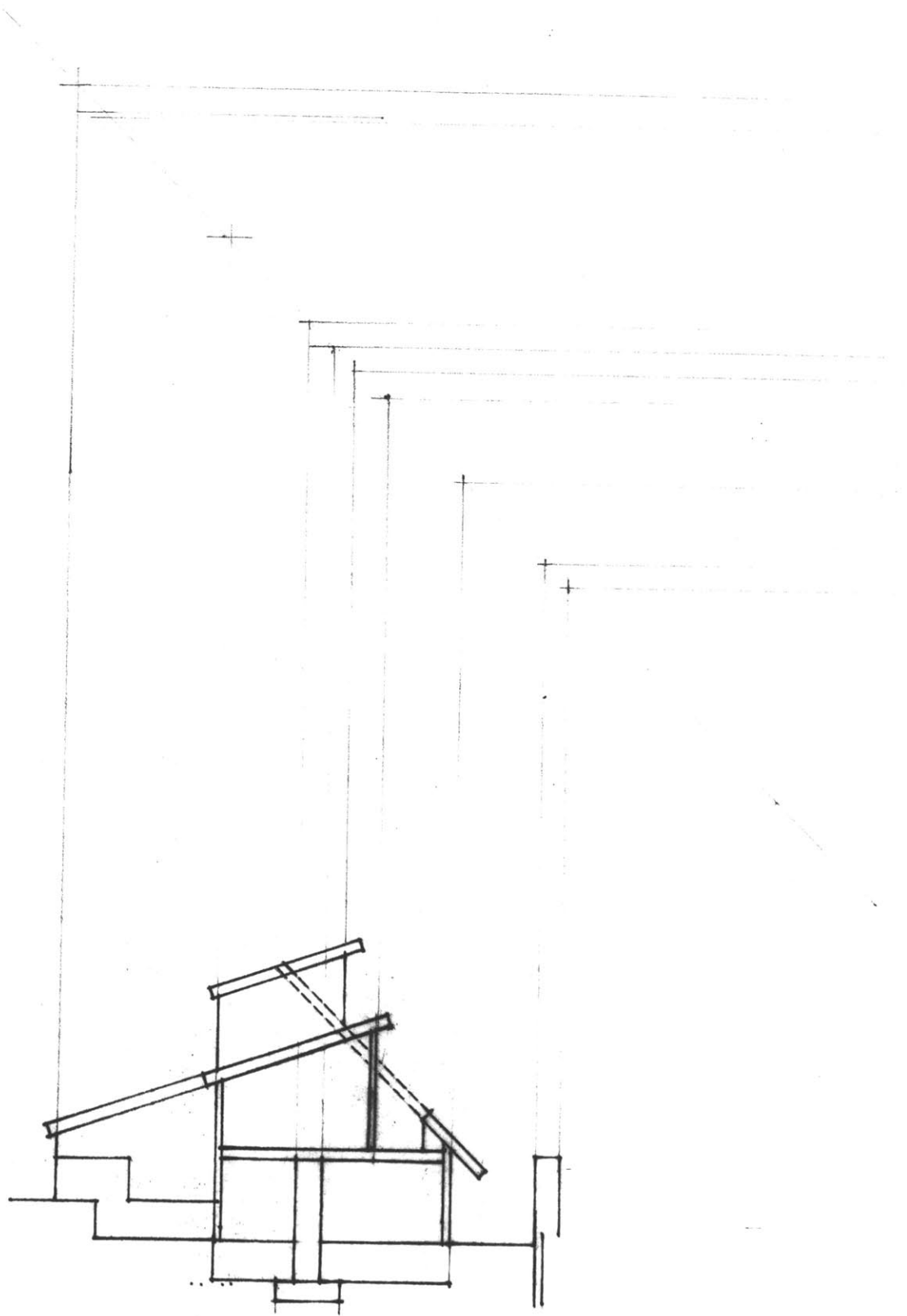


ROOF COLLECTOR PLAN



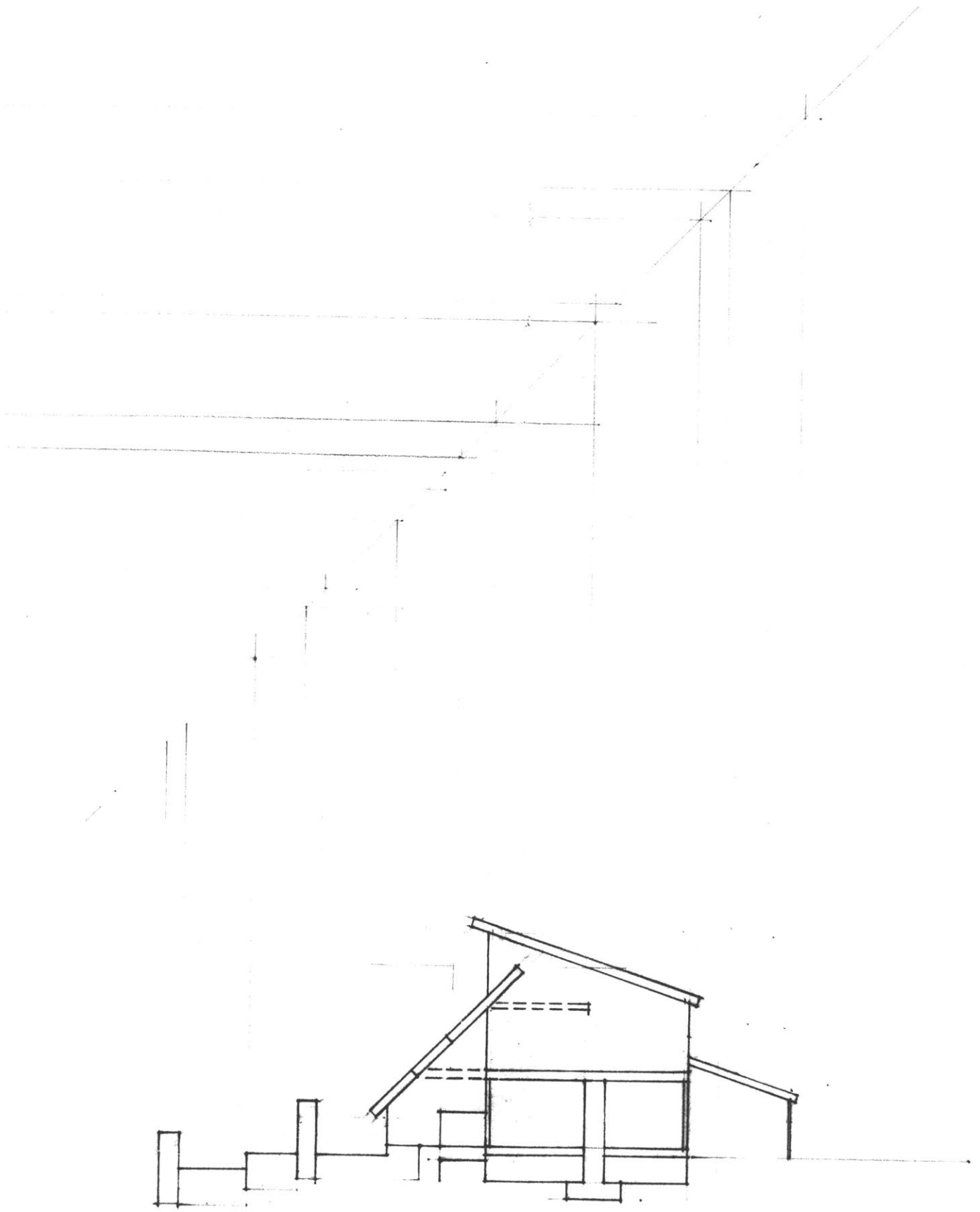
30





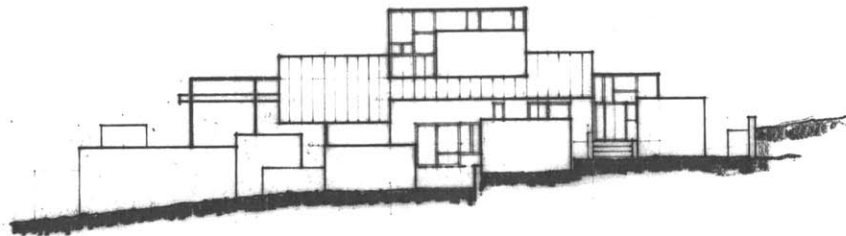
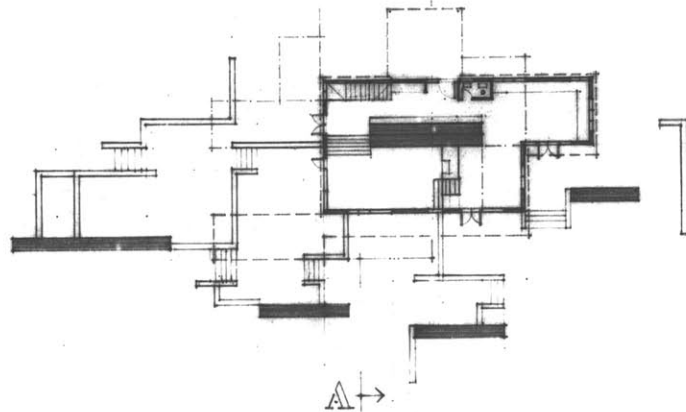
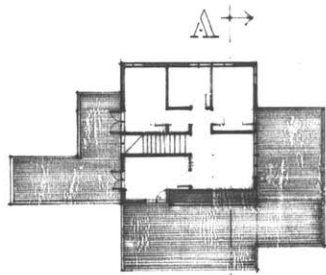
37

BBB



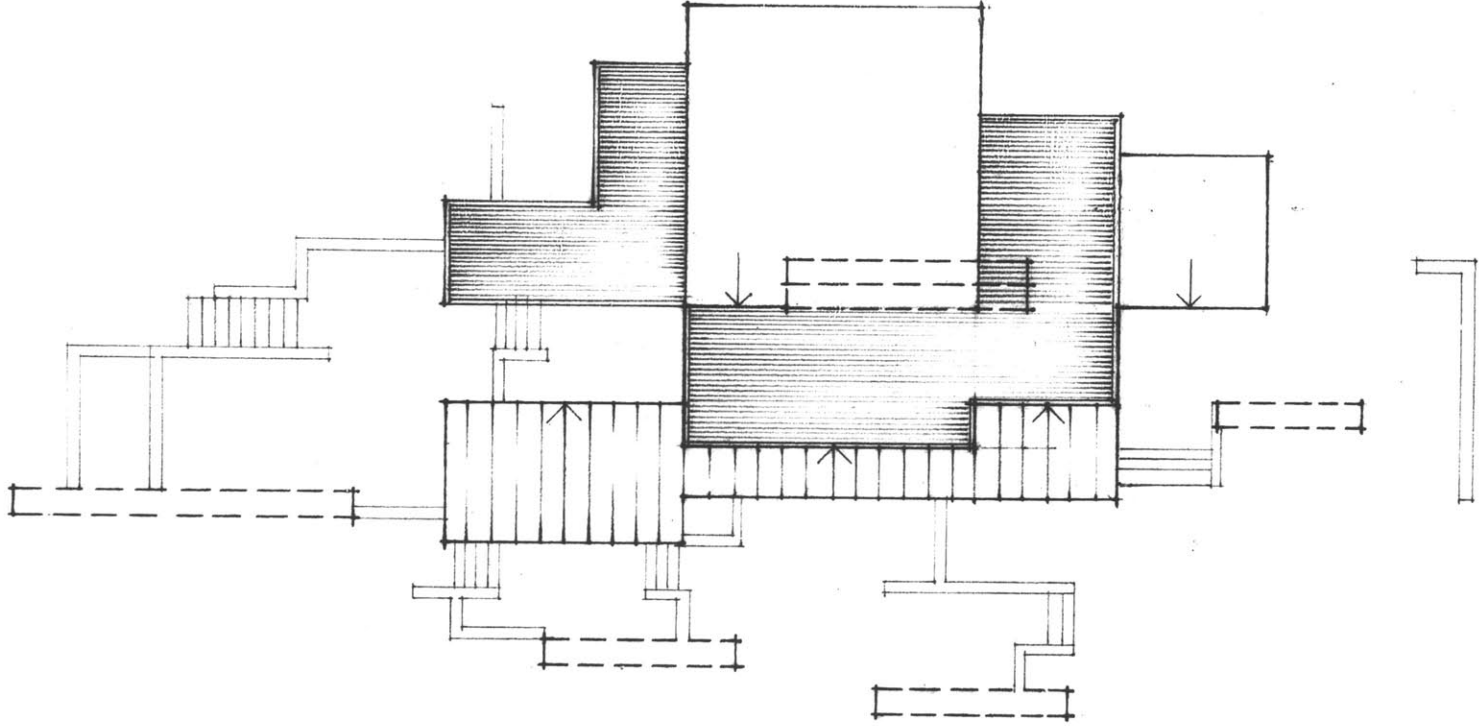
40

CC

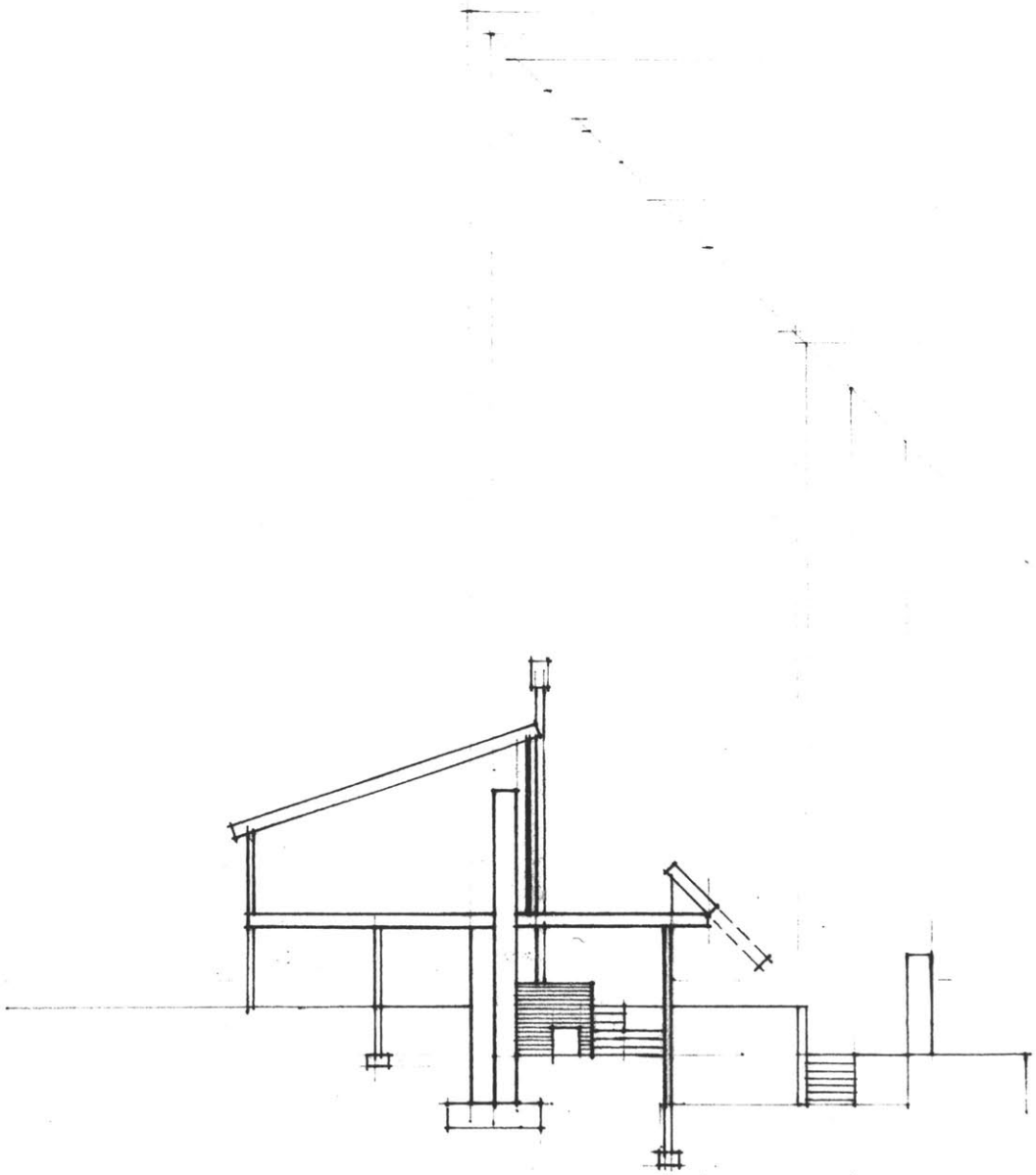


IB  
SCALE = 1/8"

42

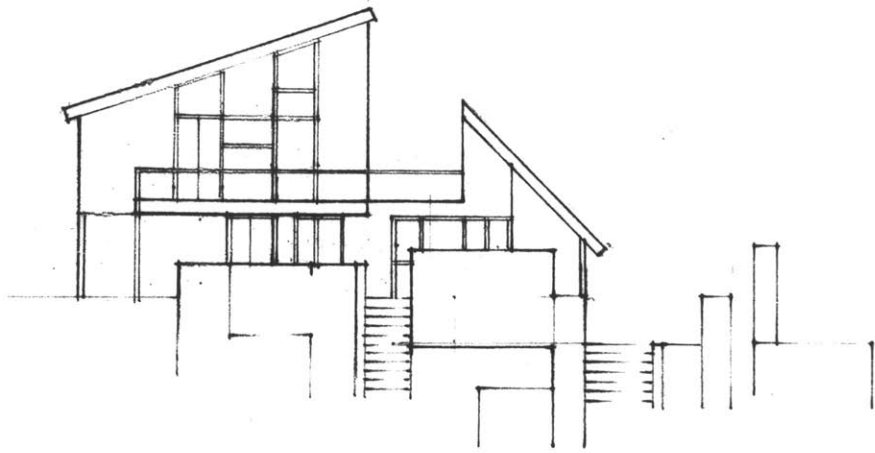


ROOF COLLECTOR PLAN

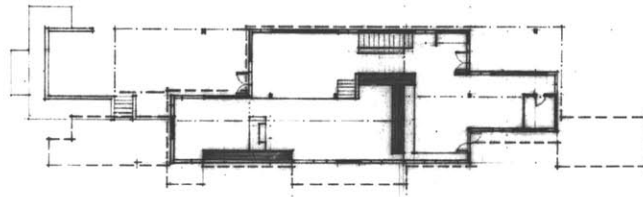
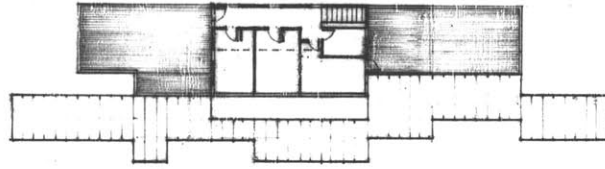


43





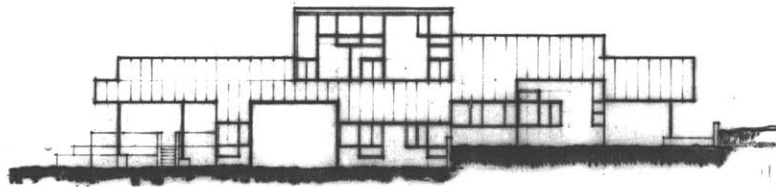
A B C  
+> +> <+



+> +> <+  
A B C



AA

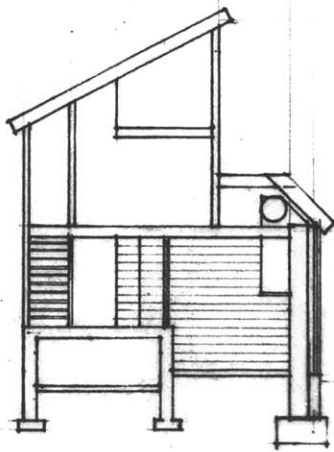


CC

C

SCALE = 1/2"

45



BB

## CONCLUSIONS

All three prototypes are successful in achieving the desired ratio of one square foot of collector to two square feet of floor area. A detailed analysis would clearly be helpful in determining the net inefficiency of the long heat transmission runs from vertical collectors to storage facilities in prototypes A and B.

Prototype A was designed first, and this problem was not resolved, but could be, as in prototype B, where approximately 20% additional collector area is provided.

Prototype C, with a comparatively "tight" organization, seems the most reliable of the three as a measure of producing a workable "solution." I say this mainly because the indeterminant factor of transmission losses from far-removed vertical collectors is not present.

In all three types, a factor of 5% was added to collector area requirements to mitigate somewhat the heat loss associated with the separation of inclined collectors from habitable space. This may be an unreasonable factor, but depends largely on insulation values which are easily changed. This, finally, suggests a strategy of energy form design not unlike that of TEA.

## REFERENCES AND NOTES

1. In particular, Knowles is interested in "envelopes" which insure no shadowing of adjacent collectors, something of a "zoning" notion concerning who gets to use the sun's energy. Also, perhaps, a way of avoiding extruded sections.
2. Farrington Daniels's book is a good source on components. So, too, is Energy Primer, one of the latest sources available.
3. My information here is largely from Bruce Anderson's thesis, and from a highly recommended Saturday session on solar energy given by Total Environmental Action of Harrisville, New Hampshire.
4. Concluded by various people, documented in TEA's AIA report.
5. See just about any source on collector/floor area ratios. A good alternative position of insulation and, hence, the larger related problems is layed out in TEA's report.
6. See Daniels, Anderson thesis, TEA report, Portola's Energy Primer.
7. Daniels's book includes the basic chemistry on eutectics.
- 8/9. Bruce Anderson's thesis and TEA's work provide these basic rules of thumb.
10. Again, Daniels. Also work done in the 40's by Telkes, as in Heating and Ventilating, 44:68, 1947.
11. This containerized water idea from bits and pieces of information along the way.
12. These ratios are developed and explained in Olgay's Design with Climate.
13. An attempt to diagram some observed generalities.

14. This information was developed from charts supplied by Tim Johnson which were used in M.I.T. course 4.49.
15. See note #5.
16. Bead wall information based on Portola Institute's book, and a few conversations with Sean Wellesley-Miller.
17. This work deals with the problem at an up to regional size.

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