

PATTERNS FOR RESPONDING TO CLIMATE
IN SHARED-WALL HOUSING

by

SUSAN KAUFMANN PAULOS

S.B. in Mechanical Engineering
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Submitted in Partial Fulfillment
of the requirements for the
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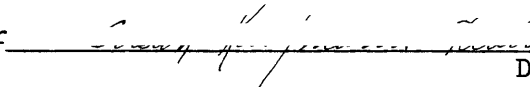
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ABSTRACT

Out of the inescapables of building come inspiration for architectural design. Decisions which respond to climate make their mark in design, just as structural requirements, lighting provisions, and the limitations of a site do.

Presented here are "patterns" which have been developed to illustrate ways in which the design of dwellings can respond to climate. Rules of thumb for passive solar design and natural ventilation are included, as well as suggestions for providing a choice of differently tempered spaces. New patterns of use are also presented for responding to seasonal and diurnal changes.

Several example designs are included. These designs all begin with the assumption of a shared-wall form and a Boston climate, but are meant for sites of different sizes, proportions, and orientations.

Thesis Supervisor: Barry Zevin

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TABLE OF CONTENTS

	<u>Page</u>
Abstract	3
Acknowledgements	4
Introduction	7
Designing With Climate	11
Patterns	17
I. Choosing Where the Sun Comes In.	18
II. Using Materials and Pieces	28
III. Providing a Choice of Temperedness	40
IV. Taking Advantage of Free Energy.	48
V. Suggesting New Patterns of Use	52
Example Designs.	57
Bibliography	97
Appendix	99

INTRODUCTION

This thesis postulates that there is a need for energy-conscious design in housing; that the dwellings being built today are smaller and closer together than has been the case in the past, and, finally, that energy-conscious or sun-tempered design is different for these dwellings than it is for the large single family home.

The need for more housing is inescapable. Although the population growth rate is declining, more households are being established as the size of the average household shrinks. And more of these households wish to live in or near urban areas. Late marriages, fewer children, more single parents, more working couples, and longer life spans have changed the identity and needs of the "average" household; many of today's households are quite different from those for whom the detached dwelling was built.

Our current concern with energy, coupled with today's changing household patterns, has created a resurgence of economical and efficient moderate density housing. These higher densities do change some priorities. They do not lend themselves to solar strategies taken verbatim from single family plans. The restrictions of smaller sites and predetermined orientations, added to basic needs such as light, air, and privacy, require compromise and invention on the part of the designer.

It is necessary to explore the influence of energy considerations on architectural decisions of

every scale - and the influence of contextual restrictions on energy-conscious design. Some of the principles which evolve out of this duality have been presented here as "patterns" for energy-conscious design.

Technology and Design

Precedents surely exist for the adaptation of residential architecture to modern needs, modern problems, and modern opportunities. Many significant changes in residential architecture originated with changes in the society or its technology. As servants disappeared, dwellings became more compact, and kitchens became a part of the family space, rather than the domain of the "help." Advances in plumbing, heating, and lighting changed the service traffic from people to hidden pipes and wires.

"All the architects were quick to include [central heating] in their new houses, but only Wright saw its ultimate implication: that it made obsolete the old honeycomb plan of boxy air-tight rooms strung like beads on a necklace."

James Marston Fitch, in Architecture and the Esthetics of Plenty.

The advent of central heating (and later air conditioning) freed the architect from the need for a fireplace or stove and a flue in every room. In turn, this contributed to the development of an open plan, since it became feasible to heat the entire house as a whole, rather than room by room.

Unfortunately, the architect's new-found freedom soon went to his head. The glass-skinned skyscraper, undifferentiated with respect to sun exposure and utterly dependent year-round on mechanical heating and cooling - often simultaneously - is an example of the architect's over-reliance on technology.

Clarity was a virtue in structural explicitness; somehow mechanical sleight of hand has been perfectly acceptable in heating, lighting, cooling, and ventilation.

Today's office building or factory will probably always require some artificial lighting and mechanical heating, ventilation, and air conditioning (HVAC). The size of these structures and the complex technologies they enclose often dictate that certain portions of the building, by use or form, will remain wholly dependent on mechanical assistance. But significant steps can be taken to return other portions of the building to less energy-demanding states. Daylighting, carefully chosen fenestration, shading, and natural ventilation - all obviously desirable in spaces for human habitation - are perfectly feasible in many applications.

Dwellings, on the other hand, are clearly ripe for the reduction of mechanical environmental manipulation to an absolute minimum. Their small volumes and shallow depths ensure adequate interchange with the outdoors.

Climate and Vernacular Architecture

"Architecture" has evolved out of man's basic need for shelter. As such, it has always been inextricably tied to climate. When the characteristics of a particular climate are examined, it can be seen that the historical approach to building in that climate has been calculated to help moderate its particular excesses.

"Sunday the 4 of February was very wet and rainie with the greatest gusts of wind that ever we had since we came forth... and it caused much daubing of our houses to fall downe."

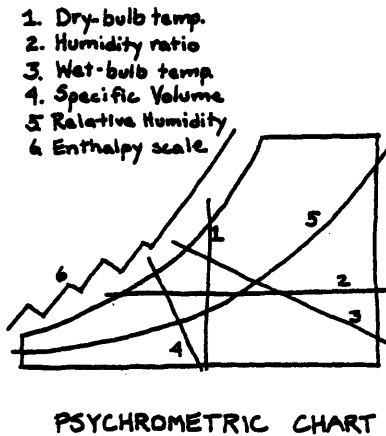
George B. Cheever, The Journal of the Pilgrims at Plymouth, (New York, 1848).

Although availability of certain building materials and special skills is unquestionably an influence on indigenous form, it can be seen that the requirements of climate often provide the incentive for innovation. The early settlers of New England built with the exposed timber framing of feudal England until the climate proved too severe. They soon saw the need for a tight sheathing to protect the structural members from the weather, and they established sawmills - outlawed in England at that time - to provide the necessary millwork.

With adjustments like this, men have adapted their buildings to climate. The various environments of the world, coupled with the societies which inhabit them, have produced wonderfully diverse and rich building forms.

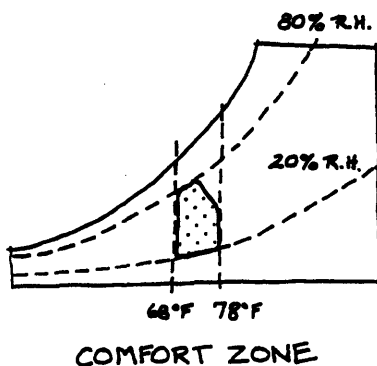
DESIGNING WITH CLIMATE

The climates of the world are generally classified as wet or dry, and cold, cool, temperate or hot. Within each of these categories, local climate will differ due to latitude, topography, and vegetation.



These qualitative descriptions are based on quantitative measures of climate. To move back one step to the data itself requires examining the psychrometric chart. The psychrometric chart is a two-dimensional chart on which can be represented numerous quantities describing the condition of air. If, for example, the air temperature and humidity are known, a point can be plotted which will singularly define the specific volume, enthalpy, and dewpoint as well.

A "comfort zone" can be identified on this chart as the group of points which correspond to combinations of temperature and humidity which are suitable for human comfort. This zone is, of course, dependent on the clothing, activity level, and expectations of each person, but physiological considerations can set some norms.



To be habitable, then, a building must be capable of bringing the ambient conditions within the comfort zone. It is possible to modify the environment by heating, cooling, humidifying, or dehumidifying the air. These actions can be plotted on the psychrometric chart as movement in different

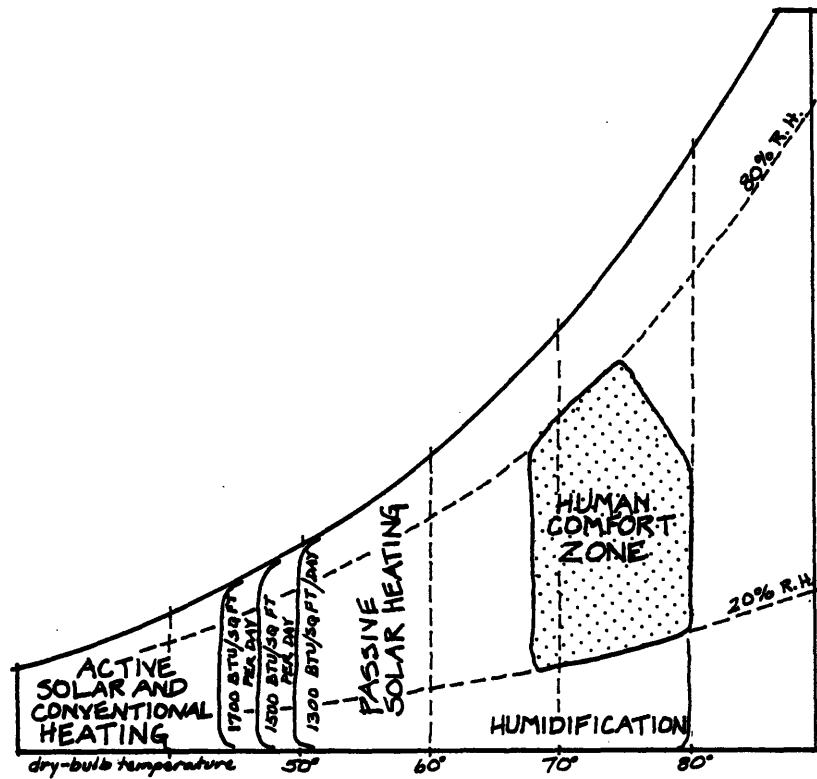
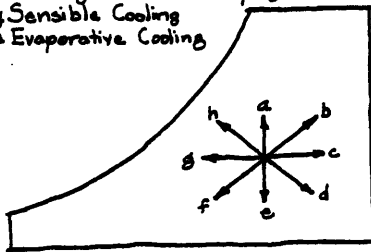


Fig. 1A. HEATING DESIGN STRATEGIES

- a. Humidifying
- b. Heating and Humidifying
- c. Sensible Heating
- d. Chemical Dehumidifying
- e. Dehumidifying
- f. Cooling and Dehumidifying
- g. Sensible Cooling
- h. Evaporative Cooling



directions. By comparing the location of the comfort zone to the location of the point representing ambient air conditions, it can be seen which processes are necessary to bring the point within the comfort zone. It is also possible to extend the comfort zone slightly into the hotter temperatures and higher humidities by increasing air flow.

Different heating and cooling methods are applicable at different ambient conditions. For example, evaporative cooling is not possible at relative humidities of over 80%, and current passive heating methods are not sufficient for dry-bulb temperatures under 45° F. Figure 1 suggests appropriate measures for different conditions.

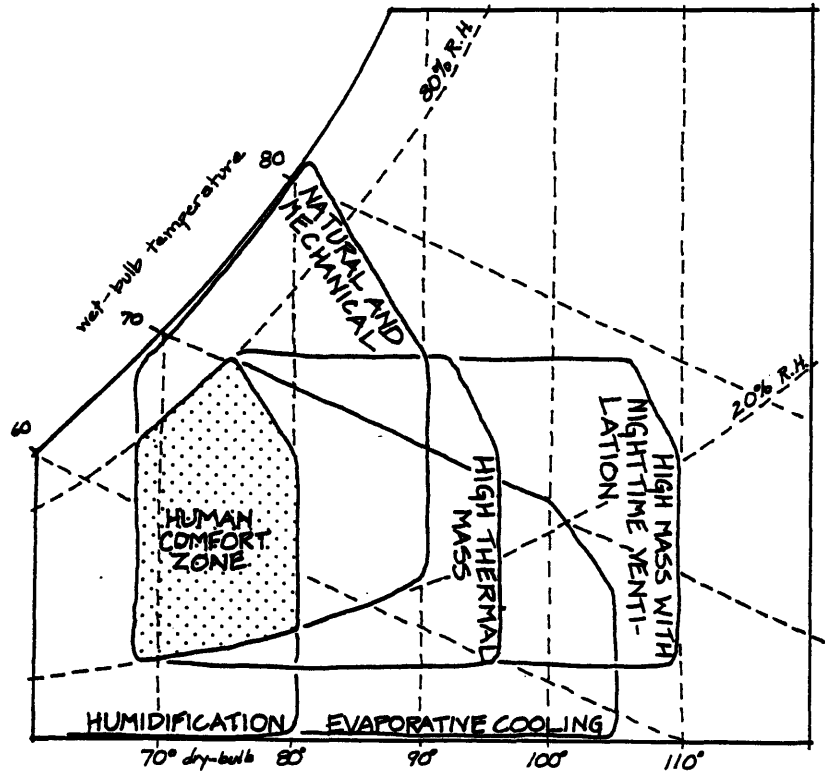


Fig. 1B. COOLING DESIGN STRATEGIES

from Murray Milne and Baruch Givoni, "Architectural Design Based on Climate," in Energy Conservation Through Building Design, ed. Donald Watson.

When typical weather data for a climate is plotted on the psychrometric chart, it can be seen during which parts of the year buildings in this climate will need to modify the ambient conditions to provide comfort, and what methods may be used to achieve the desired results.

What are the methods which enable a building to provide a thermally habitable environment? How

can temperature and humidity be controlled - in particular, using minimal mechanical assistance?

In the Proceedings of the Fourth National Passive Solar Conference, Donald Watson suggests the following "elements of climate design:"

1. Geometric modifications
2. Buffer zone modifications
3. Thermal mass
4. Insulation addition
5. Direct gain strategies
6. Indirect gain strategies

While this list was developed in the context of current and emerging design practice, it may be used to discuss historical precedent as well.

Examples of the use of geometric modifications are abundant. The compact "saltbox", low to the north and with a small surface area for its volume, is an appropriate response to its chill, windy New England locale. Similarly, the spread-out courtyard dwelling of the American Southwest and the Roman villa are appropriate to theirs.

The buffer zone, too, is not a new idea. It is, in part, a method of creating space which need not exist within the comfort zone at all times. The entrance hall has been a standard feature in northern American dwellings since Colonial times, and a lean-to kitchen soon graced the windward side of the frontier shack. In warm climates, porches surrounded and shaded dwellings, and heat-producing kitchens were removed from the main structure.

The "double envelope" house, a concept developed recently in the context of "solar" design, pro-

vides buffer zones on all exposures. (Claims for elaborate air flows within the double envelope appear to be unfounded.)

The third and fourth elements on the list, thermal mass and insulation, are directly concerned with choice of material. The Eskimo's igloo is built of snow, an insulative material, keeping in the heat from his lamp and his body. The heavy construction of warm dry climates provides plenty of thermal mass to slow the response of the building in the typically wide diurnal temperature swings, while the light construction prevalent in tropical and semi-tropical zones sheds and collects heat quickly. Furthermore, this light construction easily accepts openings for through ventilation, the only passive cooling means available for a hot humid climate.

Direct gain strategies, as well, have a long history. In far different cultures, Vitruvius and the Pueblo builders knew how to take advantage of the southern sun. While indirect gain is a more modern concept, it too can be seen prior to our generation. The efficient use of solar energy can greatly expand the possibilities for buildings which do not require combustive heating.

In addition to Watson's list, mention should be made of evaporative cooling. In the hot dry areas which can use this method, the availability of water may be subject to question, but it is an effective means of cooling. Spraying the roofs of large industrial buildings has become not uncommon in the southern United States. Ancient

builders utilized fountains in the courtyards of great palaces and gardens to evaporatively cool the air.

The patterns which will be discussed here, while using all of Watson's "elements of climate design," are classified as programmatic and design issues rather than conservation methods.

PATTERNS

Designing with "patterns" has a long history with both builders and architects. Of recent vintage is Christopher Alexander's A Pattern Language, which endeavors to provide physical solutions to specific problems which he sees. Edward Mazria's The Passive Solar Design Book is also a pattern book, but it addresses specifically the problems of building for passive solar heating.

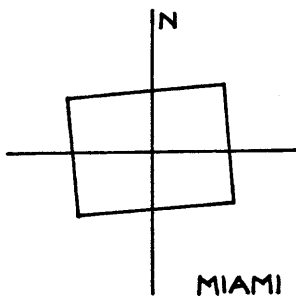
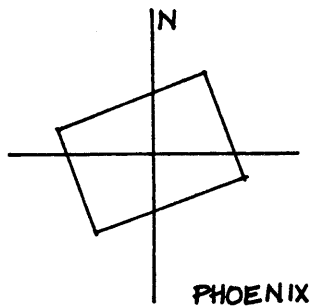
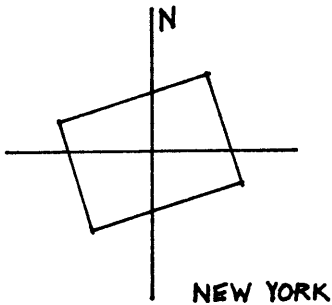
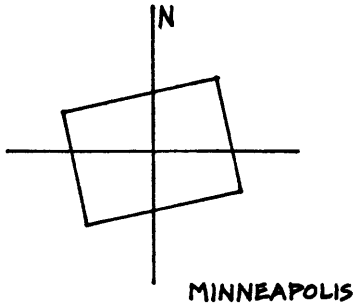
The patterns presented here occupy a middle ground. They are patterns for providing variety and depth of experience in dwelling places which are - not incidentally - at least partially passively heated.

The patterns are organized so that they can be seen as parts of schematic design: in site planning, in choosing construction materials and methods, in programming spaces and suggesting variances from the norm.

I. CHOOSING WHERE THE SUN COMES IN

This first set of "patterns" presented deals with some of the simple mechanics of passive solar design. While these patterns are not meant to substitute for the intelligent use of sunpath diagrams or climatic data, they do present guidelines suitable for schematic design.

ORIENTATION OF THE SOLAR COLLECTION AREA



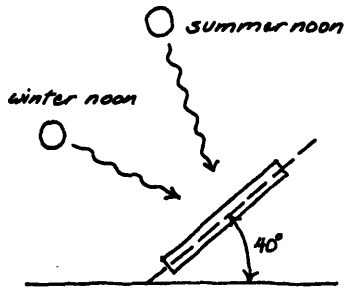
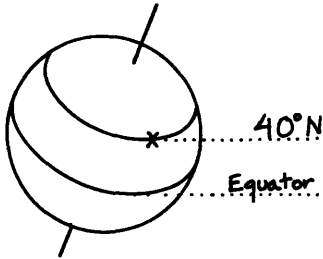
The preferred compass orientation for solar collection aperture varies according to the location of the site. For example, in cool climates such as Minneapolis, the optimum orientation for heat collection is 12 degrees east of south; for temperate zones such as New York City, it is 17.5 degrees east of south; for hot-arid places such as Phoenix, it is 20 degrees east of south; and for hot-humid climates such as that of Miami, 5 degrees east of south is preferred.

However, a variation of 15 degrees from the optimum orientation will have negligible effects on solar capability, and, for any location, an orientation between 20 degrees east of south and 32 degrees west of south will provide over 90 per cent of the maximum possible gain.

It should be noted that many designers prefer east-of-south orientation over a west-of-south orientation, in order to take advantage of morning sun to take the chill out of the building. A westerly exposure would produce high solar gains in the afternoon, when the temperature is generally higher.

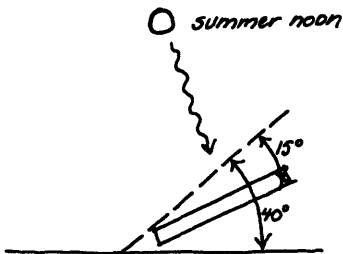
Choosing Where the Sun Comes In

COLLECTION ANGLES

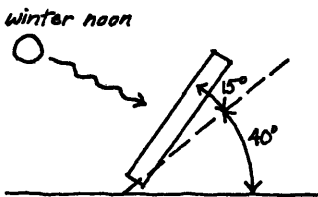


For active solar collection panels in particular, the angle of the solar collection plane is crucial. Since the path of the sun varies with the time of year, the angle at which a plane will receive the most intense radiation also varies throughout the year, as well as for location.

A compromise suited to year-round applications requires the collection plane to be at an angle above the horizontal equal to the degrees of latitude at the site.



If performance is most critical during the summer months, the collection plane should be at an angle 15 degrees less than the degrees of latitude.



In order to maximize the insolation during the winter months, the collection plane should be at an angle equal to the degrees of latitude plus 15 degrees. When snow cover can be expected, a vertical collection surface - either panels or windows - may be preferable to take advantage of ground reflections. Similarly, light colored paving can increase collection through vertical glazing.



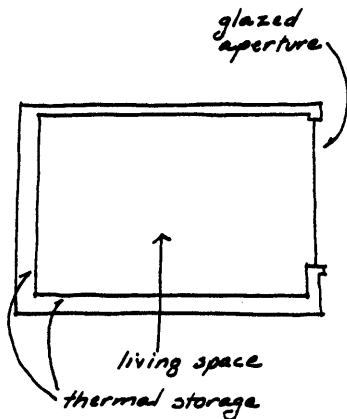
COLLECTION PATTERNS

Passive solar collection may be accomplished using a very few components:

- . an opening for the sunlight to enter,
- . thermal storage - mass which will warm up,
- . and a glazing to reduce losses.

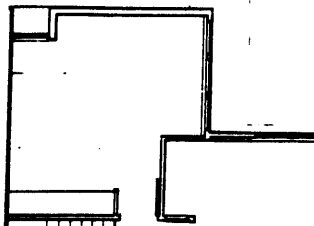
These components can be assembled in a variety of ways, placed in a variety of spaces, and formed of a variety of materials. The following patterns suggest some alternatives for sun-tempering a dwelling; other patterns will provide information on sizing the aperture and thermal mass.

1. Direct Gain



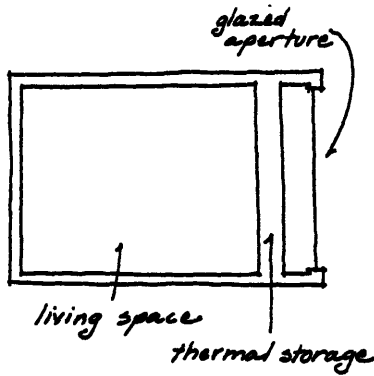
Probably the simplest and most space-efficient form of passive solar design, this pattern uses an entire room as a solar collector. Solar aperture and glazing is provided by south-facing windows, and storage is incorporated into the structure and furnishings of the room.

Direct gain is the most efficient collection technique. Typically, thermal storage should cover as much of the available surface area as possible.

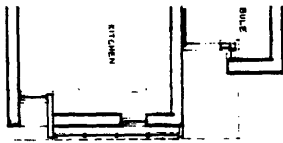


Problems associated with direct gain include the reluctance of people to occupy continually sunny spaces, the difficulty of providing sufficient thermal storage, sun damage to fabrics, glare, and the possible desire to cover thermal storage with rugs and furniture.

2. Indirect Gain/Trombe Walls

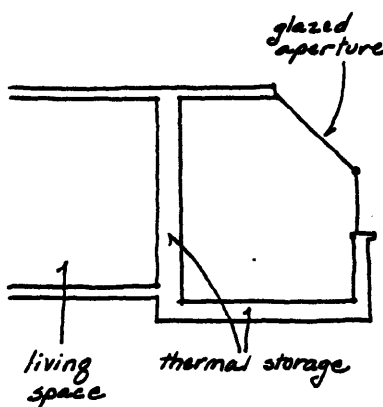


An "indirect gain" strategy isolates the occupiable spaces from the solar aperture with thermal storage. Sunlight is absorbed into the thermal mass first, and then transferred into the occupied spaces. An unmodified Trombe wall - wall-to-wall and floor-to-ceiling masonry, separated from an exterior glazing by an air space of at least four inches - is the archetype for this pattern. A Trombe wall can be modified to suit many requirements. It may be pierced with vents and windows; it may be shorter than the ceiling height or narrower than the room. The masonry may be set back from the glazing far enough to allow passage between it and the glazing.



These concepts can also be applied to a "water wall" composed of discrete containers of water.

3. Sunspace/Greenhouse



A "sunspace" can be thought of as a direct-gain space which acts as a collector for an indirect gain design. The disadvantages of direct gain spaces are then limited to a more special-purpose place, and the inner "living" space is buffered.

Corridors, breezeways, and other spaces which are not continually occupied work well as sunspaces. One alternative is to use a greenhouse as a sunspace, with thermal storage in the floor, in walls, or in containers. Potted plants will also provide thermal storage. It should be noted, however,

Choosing Where the Sun Comes In

that the more a sunspace is adapted toward optimal conditions for growing plants, the less efficient it becomes as a heating mechanism. Plants cannot tolerate the large temperature swings typical of a working sunspace, and foliage must be prevented from shading too much of the thermal mass.

Generally speaking, three times as much greenhouse glazing is required to produce a given amount of usable heat as direct gain glazing. As a rule of thumb, some designers in New England and upper midwest areas expect a seasonal heat gain equal to a gallon of oil for each square foot of south-facing sunspace window. The rear wall of a greenhouse/sunspace should be dark in color, and, in cold climates (5000 DD or more), should be provided with vents to the living spaces.

4. Skylights, Clerestories, and Sunscopes

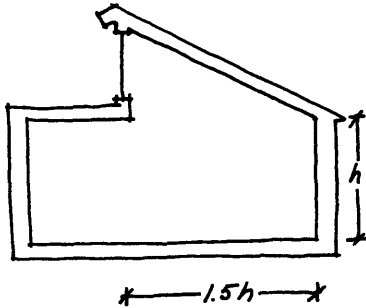
Sunlight need not be limited to the southern edge of a structure. Light can be brought into the center of the building, freeing the edges from the need to be fully glazed. The pursuit of solar heat should not outweigh the other purposes of windows. Daylight is clearly a good use of the sun's energy, and obtaining a view and an association with the outdoors is important for the occupants.

Functionally, these patterns are variations of "direct gain" designs. It is simply a matter of rearranging the glazed areas where desired. In higher density housing, in particular, it may be

Choosing Where the Sun Comes In

desirable to limit ground level windows for privacy, or it may be that sunlight is only available at roof levels. A clerestory window may provide a far view for a closely surrounded dwelling.

It is important to remember that the difficulties of horizontal and slanted skylights are numerous: leaks, shading problems, glare, high illumination levels. If a skylight is desired, it is preferable to use a small, controllable opening rather than a large expanse.



A simple rule of thumb for proportioning clerestories is that the distance from the clerestory glazing to the parallel wall should be one to one and one-half times the height from the floor to the sill of the clerestory window. This will insure that winter sun reaches most of the wall.

SIZING THE SOLAR APERTURE

The amount of solar aperture required is a function of the type of system, the storage material, and the climate.

The following table specifies the amount of solar aperture required for a direct gain system in a residence with an overall U value of 8 to 10 Btu/day-sq ft °F. (A calculation of the overall U value is included in the Example Design section.)

Direct Gain Aperture

Winter Temperature	Ratio of window area to floor area
15°	0.27 - 0.42
20°	0.24 - 0.38
25°	0.21 - 0.33
30°	0.19 - 0.29
35°	0.16 - 0.25
40°	0.13 - 0.21
45°	0.11 - 0.17

from Mazria,
p. 122.

For indirect systems, the ratio of window area to floor area is generally twice that required for a direct gain system. Since in an indirect system the aperture area is identical to the storage mass surface area, the aperture requirements for indirect gain systems are discussed in more detail under "Sizing Thermal Mass."

A greenhouse/sunspace system required more aperture yet. The table below lists adjustment factors for masonry- and water-walled greenhouses in various climates. The window area to floor area ratio given for direct gain systems should be mul-

Choosing Where the Sun Comes In

multiplied by the adjustment factor to find the appropriate window area to floor area ratio for a greenhouse system.

Adjustment Factor for Greenhouse Aperture

	Winter Temperature	Masonry Wall	Water Wall
adapted from Mazria, p. 175.	15 ^o F	n. a.	n. a.
	20 - 30 ^o F	3.7 - 3.9	2.6 - 3.2
	35 - 45 ^o F	3.0 - 3.6	2.2 - 2.6

II. USING MATERIALS AND PIECES

These patterns suggest ways of integrating the structural, thermal, and finish requirements of a building.

Choice of materials and the use of shutters and other "pieces" are strongly dependent on climate. It is important to match these patterns with their intended locations.

Using Materials and Pieces

INSULATION

In cool or cold regions, insulation is probably more important than any other energy design feature for dwellings. A well-insulated dwelling can rely on its internal gains from people, lights and appliances for a much higher percentage of its heating needs than a poorly insulated dwelling.

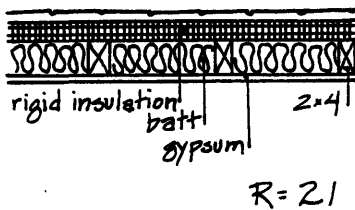
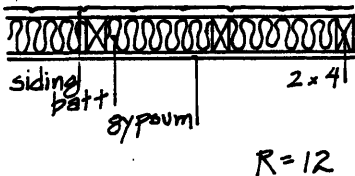
R-Values

	per inch	as given
gypsum board, 1/2"		.45
plywood, 1/2"		.62
fiberglass batt		
2-2.75"		7
3-3.5"		11
3.5-6.5"		19
6-7"		22
8.5"		30
polystyrene	4-5	
cellulose fill	3.1-3.7	
concrete	0.2-1.4	
stucco	.2	
brick, common	.2	
brick, face	.11	
concrete block, 8"		1.1-2
shingles		
asbestos		.21
wood		.9
softwoods	1.25	
hardwoods	.91	

Insulation is generally spoken of using R-values, a term for the thermal resistance of a material measured in (hours)(square feet)(degrees Fahrenheit)/(British thermal unit).

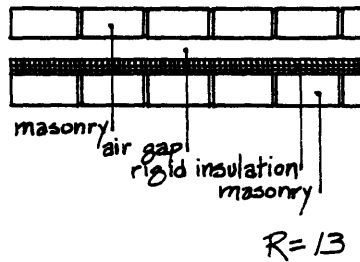
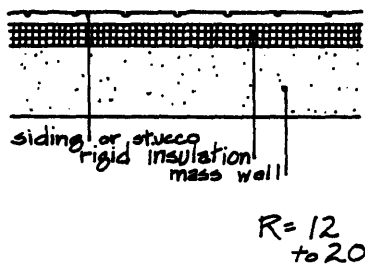
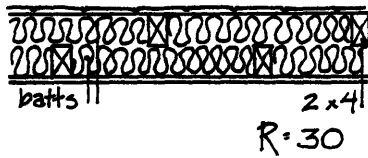
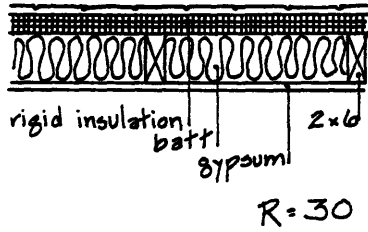
Suggested Minimum R-Values for Dwellings¹

Degree-Days Per Year	Walls	Roof/Ceiling	Unheated Slab on Grade Perimeter Insulation
8000 + (cold)	R-19	R-24	R-7
6000 (cool)	R-11	R-19	R-4.9
4000 (temperate)	R-11	R-19	R-3.5
2500 (mild)	R-11	R-19	R-2.7



If included in the design from the beginning, high levels of insulation are fairly inexpensive to build. Numerous construction details suitable for high R-value walls have been developed in recent years. The first step is to create a thicker wall cavity for insulation. Using 2 x 6 or 2 x 8 studs is one method; using a double wall of 2 x 4 studs, staggered and separated with 1 1/2 or 3 1/2 inch blocking, is another. Staggering the studs provides a more uniform thermal resis-

Using Materials and Pieces



tance. Since heat, like water, flows through the path of least resistance, it is wise to insulate over the outside of the studs on a single-framed wall. Rigid insulation can be nailed to the outside of the studs, and diagonal bracing provided, instead of plywood sheathing. In cases where no rigid insulation was added over 2 x 6 studs with R-19 insulation between studs, the nails on the studs have developed rust, indicating condensation - and heat flow.

Masonry walls should be insulated on the exterior when the walls are expected to provide thermal mass. In hot climates, a cavity masonry wall with insulation in the cavity will provide welcome thermal mass on the exterior as well, effectively "shading" the building from the summer heat.

NIGHT INSULATION

Nighttime insulation should be provided for windows, especially in colder climates. Windows lose heat by conduction, infiltration, and, at night, radiation to the dark sky. In a cold climate, even southern windows will lose more heat than they will gain each season.

Night insulation - if it is used - will reduce these losses considerably. Such insulation should have an R-value of at least 4; shades and shutters are available commercially which have R-values of 7 to 14 in place.

General opinion favors indoor insulation for ease of operation and manufacture. Outdoor insulation may double as sun reflector panels.

Many types of night insulation can be added by the resident without input from the architect. Numerous roll up shades are available, and foam insulation panels can be simply clipped to the window and set aside during the day. However, the design of integral night insulation is surely the responsibility of the architect, as much a part of his obligations as specifying the doors.

TYPES OF THERMAL MASS

Thermal mass, or thermal inertia, (previously discussed in the Collection Patterns) is necessary to prevent overheating and to store heat for the dark hours, narrowing the outdoor temperature variations to an acceptable indoor level. In essence, thermal mass acts as a flywheel, absorbing the excess heat when it is plentiful and releasing it when needed. During the summer, "charging" this flywheel can take up the daytime heat gains without raising the air temperature.

All materials are capable of providing thermal mass, but some are more efficient than others. The thermal properties of a material may be described by the parameters "specific heat" and "heat capacity". Specific heat (Btu/lb/°F) measures the number of British thermal units needed to raise one pound of material one degree Fahrenheit, while heat capacity (Btu/ft³/°F) describes the number of Btu's needed to raise the temperature of one cubic foot of material one degree F. In a material such as concrete, the material's low specific heat may be offset by a high density, creating a large heat capacity. When large amounts of heat are to be stored in modest areas of floor or wall, high heat capacities are desirable.

Material	Density lb/ft ³	Heat Capacity Btu/ft ³ /°F
Water	62.5	62.5
Steel	489	58.7
Marble	162	34.0
Concrete	144	31.7
White Oak	47	26.8
Limestone	103	22.4
Gypsum	78	20.3
Sand	94.6	18.1
White Pine	27	18.1
Clay	63	13.9
Glass Wool	3.25	0.51
Air (75°F)	0.075	0.018

from Bruce Anderson, *The Solar Home Book*.

Many building materials are suitable as thermal mass - masonry, clay tile, stonework, gypsum, even water in indoor pools. Oftentimes the structural or finish requirements and the thermal mass requirements of a building should be met simultaneously.

Using Materials and Pieces

Water, while not a structural material, is an extremely good heat storage material. Its heat capacity is high, and its ability to transfer heat through convection currents allows it to be used in greater thicknesses than masonry. Note, however, that additional structural support may be necessary for water walls.

SIZING THERMAL MASS

There are several ways, of differing complexity, to approach sizing thermal storage, or thermal mass. First, with a few very general guidelines:

- The more mass, the better.
- The more widely distributed the mass, the better.
- Mass should be in the direct sun whenever possible.
- One gallon of water has as much "thermal mass" as 42 pounds of masonry.
- A well-insulated building (R25 walls, triple glazing, R38 ceiling) can take a direct gain aperture of 6 to 8% of its floor area before overheating.

Second, with intensive computer simulations, to take into account a number of variables:

- The exact location and its typical weather data.
- Site microclimate.
- Sun orientation.
- Construction of the building.
- Type of glazing and draperies used.
- Amount of furniture.
- Window overhangs.
- Night insulation.
- Internal gains.

Third, with simple rules of thumb which take into account some but not all variables. These must be used as part of an iterative design process.

Using Materials and Pieces

Masonry in Direct Gain Spaces

- Floors should be dark in color; walls need not be.
- All other surfaces should be light in color to reflect sun onto the storage mass.
- Many small windows which spread the light over the storage surfaces are preferable to one large glazed expanse.
- Mass must be insulated on the exterior.
- If all surfaces of a space are masonry, 3 or 4 inches is a sufficient thickness of material. Otherwise 4 inches is an absolute minimum.

	Conductivity Btu/hr ft ²	Specific Heat Btu/lb-F
Dense Concrete	1.00	0.20
Common Brick	0.42	0.20
Magnesite Brick	2.20	0.20
Adobe	0.30	0.24

While all types of masonry are similar in density and specific heat, the conductivity (k), in Btu hr/ft²-F/ft varies widely. This measures the rate of transfer of heat from the surface of the material to its interior, and therefore affects the air temperature fluctuations in the space. Masonry of higher conductivity is preferred.

Estimated Daily Indoor Temperature Fluctuations

ratio of mass surface area: glazing area	suggested thickness of material	Material			
		Dense Concrete	Common Brick	Magnesite Brick	Adobe
1.5	8"+	34-46°	45-60°	30-40°	50-65°
3	8"+	24-31°	33-40°	20-26°	36-45°
9	4"+	~11°	~15°	~9°	~17°

Notice the implications of this chart's data: that the distribution of the mass is the most important factor, with the conductivity of the material not far behind.

Using Materials and Pieces

Water in Direct Gain Spaces

- Provide one cubic foot (7 1/2 gallons) of water for each square foot of solar aperture.
- Water containers should be located in direct sun.
- If the containers are not located in direct sunlight, approximately four times as much water is needed.

According to a study performed at the University of Oregon in 1977, under the direction of Edward Mazria, the expected daily air temperature fluctuations -- almost independent of climate -- are as follows:

color of container	Volume of Water per square foot of south glazing			
	1 cu ft	1.5 cu ft	2 cu ft	3 cu ft
dark	17°	15°	13°	12°
black	15°	12°	10°	9°

Using Materials and Pieces

Indirect Gain Systems

- The outside of the storage wall should be a dark color.
- In general, the storage wall should be as thick as is feasible.

The chart below, from The Passive Solar Energy Book, summarizes the rules of sizing thermal storage walls (indirect systems.) The mass is sized to provide sufficient heat to maintain a temperature of 65 to 75°F in a well insulated building, using double glazing. For a poorly insulated building, more area will be necessary; if night insulation of R8 is provided, 85 per cent of the area listed will be sufficient. The higher values should be used for northern sites.

*Recommended Thickness
of Thermal Mass Walls*

Adobe	8-12"
Common Brick	10-14"
Magnesite Brick	16-24"
Dense Concrete	12-18"
Water	6"+

Average Winter Outdoor Temp.	Ratio of square feet of storage wall to sq ft of floor area	
	Masonry	Water
15°	0.72 - 1.0	0.55 - 1.0
20°	0.60 - 1.0	0.45 - 0.85
25°	0.51 - 0.93	0.38 - 0.70
30°	0.43 - 0.78	0.31 - 0.55
35°	0.35 - 0.60	0.25 - 0.43
40°	0.28 - 0.46	0.20 - 0.34
45°	0.22 - 0.35	0.16 - 0.25

For reasons such as cost, view, or natural lighting it may not be possible to provide as much thermal wall as suggested in this pattern. A thermal wall will still perform well if undersized; it will simply provide a smaller percentage of the heating needs of the space.

III. PROVIDING A CHOICE OF TEMPEREDNESS

The aim of energy conscious architecture is not to threaten the user with subsistence levels of comfort and space, but to take full advantage of what the environment has to offer.

Mechanical climate control has tended to produce a sharp distinction between indoor and outdoor spaces, with few shades of shelter in between. It has also created the expectation of an unvarying temperature throughout a building throughout the day - and destroyed any appreciation for different thermal environments.

Providing a choice of temperedness recognizes that different activities have different thermal requirements - and that variety for variety's sake is valid in temper as well as in materials or other qualities of space. These patterns suggest some ways to provide this variety.

RANGE OF ENCLOSURE

Architecture encompasses not only indoors and outdoors, but in between as well. Porches, courtyards, and rooftops provide their own unique qualities of enclosure. The attempt should be made to include one of each in any dwelling.

The desire for variety in space and closure becomes more important in small dwellings and in minimal energy use dwellings. These spaces expand the options for inhabitation without large capital investment or energy bills.

Some spaces may actually exist as more than one type through the use of moveable enclosures. These places may adapt to different seasons and different weather, or to different uses.

MOVEABLE PARTITIONS

One strategy for limiting the amount of heating fuel necessary for comfort is to limit the size of the area heated to comfort levels. Rather than designing a dwelling as a series of boxes in the Victorian manner, the effective size of the dwelling might change through the use of moveable partitions.

These partitions may be interior or exterior, though the requirements for an exterior wall - security, water-tightness, freeze protection - may be difficult to achieve in an operable segment.

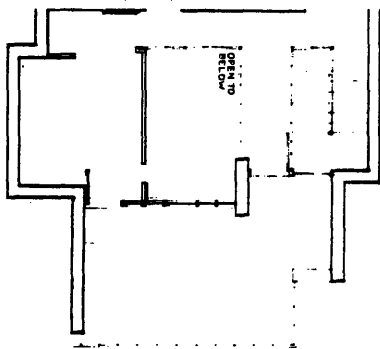
URBAN GARDENS

The requirements for a garden are simple;

light
water
soil

These needs can be met indoors as well as outdoors, and on upper stories as well as on the ground. Care must be taken to provide adequate drainage for an elevated space. On a very small scale, a bay window can be adapted for a garden.

ELEVATED OUTDOOR SPACES



A porch, rooftop, or deck should not be automatically considered second-best to outdoor ground space. In an urban setting in particular, it may very well be preferable for many uses. Height provides a measure of security for belongings and people.

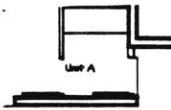
In conjunction with an outbuilding, such a space could help expand living onto the entire site (Moving Around), as well as help define outdoor spaces.

OUTBUILDINGS

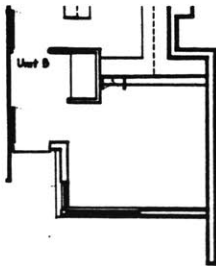
Detached structures can be useful for storage, as sun or wind breaks, or as part of a privacy wall.

An outbuilding can also provide a habitable space away from the house proper. Always placing porches and pavings on the edge of a dwelling increases its bulk and isolates the interior, and, most importantly, never encourages its occupants to stir from the center of gravity of the house and take advantage of the entire site.

VESTIBULE



A feature necessary to the design of a low heat loss dwelling is an entry air-lock or vestibule. At minimum, this vestibule must be large enough so that the first door will be closed before the second is opened. Staggering the doors across the space, or at 90°, will also help.



This air lock can be much more than just two doors, however. The inclusion of a closet and seat would provide a useful entry zone, or the entry could be part of an entire (seasonal) room.

ATTICS

An attic (defined as unfinished space below the roof) can fulfill a number of functions;

- Unheated storage

Few modern dwellings provide both the cellar and attic of the turn-of-the-century home. In some climates, a cellar may be desirable for tempered living space, while an attic is always at the temperature of the outdoors.

- A Buffer Zone against temperature changes

Attic insulation is more easily placed above a flat ceiling than attached to a sloped roof.

- Space for future expansion

If sufficient headroom is available, an attic may be converted to living space with the addition of judicious insulation. In today's housing market, more homeowners are opting to remodel rather than move.

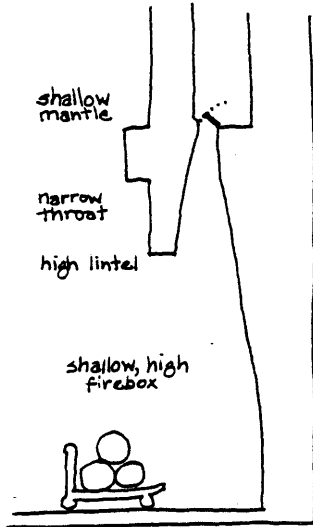
- Mechanical space for "whole-house" fans

Installation of a "whole-house" fan will allow the hot air in the dwelling to be flushed out during cool periods. A "whole house" fan is often 42 inches in diameter and requires a stable mount.

- An integral collector

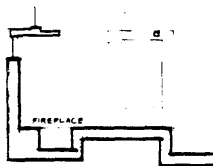
A solar attic, or attic collector, is created by providing glazing between the rafters rather than shingles. The warmed air from the attic is ducted through the house and is often supplied to a rock bed storage.

STOVE/FIREPLACE

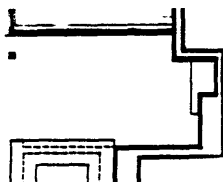


There are several measures for designing a fireplace standard in appearance but relatively high in efficiency. First, some obvious fire safeguards such as tile on the floor and glass doors covering the opening are also energy efficient. The flue should not be part of the exterior wall, in order to minimize heat loss. However, it is useful to duct in outdoor air for combustion into the fire bed. The narrow throat, shallow mantle, and high opening of the Rumford fireplace contribute to its efficiency.

The Russian fireplace is a traditional design which takes advantage of masonry's thermal mass. In a Russian fireplace, the flue has been formed into a serpentine, so that the heat of the exhaust gases warms a large volume of masonry. The masonry will radiate heat into the room long after the fire has died.



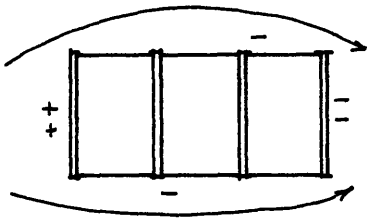
A fireplace or stove has always been the center of the home. It provides heat in a tangible fashion - not from a pipe or out of a grille. When carefully designed, this hearth can make a very special tempered zone.



IV. TAKING ADVANTAGE OF FREE ENERGY

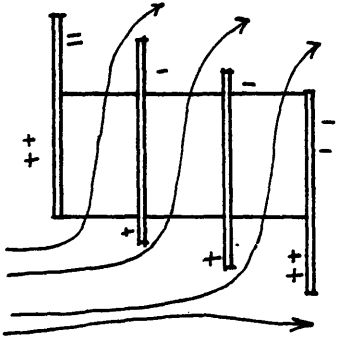
Our climate and environment provide us with not only the heat of the sun, but light as well; with rain; and with wind. These resources may be used to provide more livable places.

Taking Advantage of Free Energy

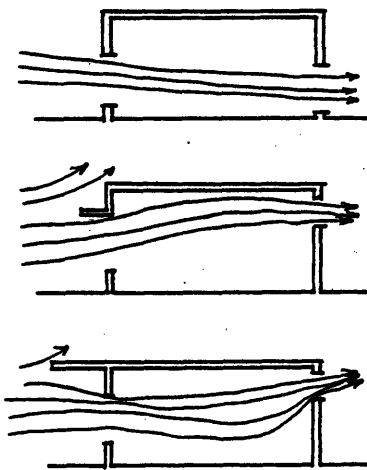


NATURAL VENTILATION

On hot humid days, the sensation of coolness is best achieved by a high speed jet of air against the skin, evaporating perspiration.

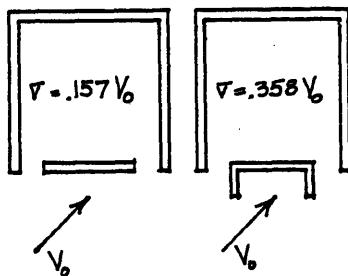


Air movement through a room or building is induced by providing a path between a location of high pressure and a location of low pressure. The existence of two windows in a room is not sufficient condition, but in some circumstances walls can be used to induce positive and negative pressures as desired.



The average velocity of the air is dependent on the size of the smaller opening. However, the distribution of the air movement is as important as the velocity for comfort. An even distribution of air flow throughout the room is achieved when the inlet is large in comparison with the outlet. The best ventilation occurs when the air has to change direction within the room. Similarly, sill height is important, as is the effect of overhangs on the windward opening.

from Martin Evans' *Housing, Climate and Comfort*



If only one exposure is possible, two windows should be placed as far apart as possible on the wall. Projections will increase the air velocity within the room.

from B. Givoni's *Man, Climate and Architecture*

EVAPORATIVE COOLING

Evaporative cooling is only suitable for hot, dry climates, since it depends on the ability of air to take up moisture. The energy required to change liquid water to a gas is removed from the air, resulting in a reduction in the temperature of the air.

Generally this process is induced by blowing air through a wet cloth or lattice or by creating a fine water spray in the air. Water may also be sprayed or dripped into the ventilation system itself.

Another form of evaporative cooling may be used to cool the surfaces of a building. Spraying roofs, particularly of industrial plants, has become a viable alternative in some areas.

SHARED WALLS

The rate of heat loss through a wall is dependent on the coefficient of heat transfer of the wall and on the difference in temperature across the wall. If there is little or no temperature difference across the wall, little or no heat will flow, no matter what the wall is made of.

Therefore, when dwelling units are connected to each other rowhouse-fashion, the heat loss through the walls can be reduced substantially. A free-standing unit requires insulation on all sides; connected units may have uninsulated party walls. If a party-wall unit is compared to another unit which is identical, but free-standing with insulated side walls, the total heat loss through the walls of the party-wall unit will be less than the heat loss through the walls of the free-standing unit in proportion to the amount of shared wall.

Historically the rowhouse was built using masonry bearing wall construction. This structural masonry can act as thermal storage as well.

Heat loss is also reduced where walls shelter one another without touching. Heated and unheated structures can be used in this way. The conduction loss through a wall between a heated space and an unheated space can be estimated to be half of what the loss would be to the outdoors.

V. SUGGESTING NEW PATTERNS OF USE

This section examines some changes which may be made in the way a dwelling is used, to provide more for less, to readapt to the environment.

None of the ideas is new, and none is beyond reach. Some involve making places which rarely exist in a modern home; some ask the user to re-think his habits.

"SEASONING" A ROOM

Just as people adapt their clothing to the weather, the finishes and coverings of a room may differ with the seasons.

The applicable phenomenon is "mean radiant temperature" which is the weighted average of the temperatures of the surfaces surrounding a space. The mean radiant temperature (m.r.t.) has a strong impact on the comfort level of a room. A one degree change in m.r.t. has a 40% greater effect on body heat loss than a one degree change in air temperature. The chart below lists air temperature and m.r.t. pairs which result in a perceived temperature of 70° F.

<i>m.r.t. (°F)</i>	65	66	67	68	69	70	71	72	73
<i>air (°F)</i>	77	75.6	74.2	72.8	71.4	70	68.6	67.2	65.8

Since any warm surface radiates heat to a cold surface, cold walls literally drain heat from the human body. In order to manipulate the mean radiant temperature of a room, the radiant characteristics - the "emmissivity" and the "absorb-tivity" - of the surfaces must be changed. Fabrics are insulators; they absorb little heat. Masonry, however, has a large heat capacitance and absorption capability; therefore, in winter heavy fabric coverings are useful for increasing the m.r.t., but in summer they should be removed to allow heat to be absorbed by the "cooler" masonry.

Suggesting New Patterns of Use

In rooms where masonry surfaces are used as thermal storage, care must be taken not to cover all surfaces. Small scatter rugs, however, will not disable a thermal mass floor.

MOVING AROUND

The modern habit is - despite the statistics on corporate transfers - quite settled. Few people migrate with the seasons, the exceptions being agricultural workers and retirees. The old upper class notion of moving out of town for the summer has succumbed to business and financial pressures.

Indeed, it is hard to imagine that such a way of life can be revived, and this is not proposed here. Instead, a migration pattern may be achieved within a dwelling. Different types of spaces may be used during different seasons or different weather - or different stages of life.

There are two strategies which may make this possible. People may adapt, picking up and moving themselves and their activities to and from porches and patios and inglenooks, or the rooms themselves may change to adapt to the season, with moveable partitions and seasonal furnishings.

EXAMPLE DESIGNS

The unit designs presented here show several different responses to the problem of energy-conserving dwellings in a New England climate. Various building lot sizes, proportions, and orientations have been assumed as starting points.

All of the designs included here are shared-wall units, and all are intended for the Boston area or a similar climate. The shared wall approach was chosen for several reasons: its thermal advantage (discussed in the pattern, "Shared Walls"), its efficient land use, and the opportunity to provide ground access to all units. An interior courtyard approach was dismissed as engendering too much surface area and being unsuited to a multistory unit.

None of the example units is large - generally two bedrooms in under 1200 square feet - in keeping with the premise that building and site costs shall continue to rise. Instead, some plans show possible additions.

1

This unit, elongated on its east-west axis, requires street access from the north. The blank east and west facades are intended as party walls.

The energy strategy combines direct-gain - in the living area and an upper bedroom - with a greenhouse attached to the dining area and curling around the fireplace corner. This corner is low-ceilinged in contrast with the rest of the living room, to allow a sun-catching balcony on the second floor.

South facing clerestory windows light the center of the unit and provide ventilation. Much of the northern exposure is buffered by storage, and an entrance vestibule/storeroom is provided.

Maximum width: 40 feet

Frontage: 40 feet

Suggested lot depth:
120 feet

Units/acre (net): 7 - 8

Energy strategy:
greenhouse,
direct gain

Overall U value: 8.1

Expected % of heating
supplied by sun: 50

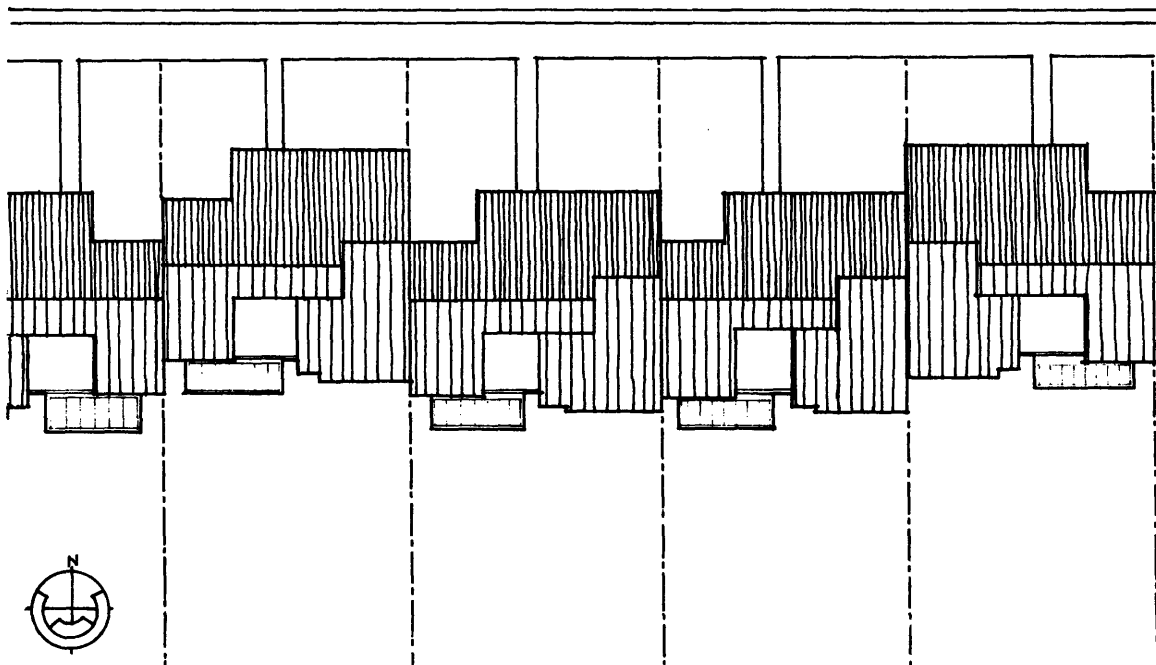
Area in square feet

Interior: 1520

Greenhouse: 85

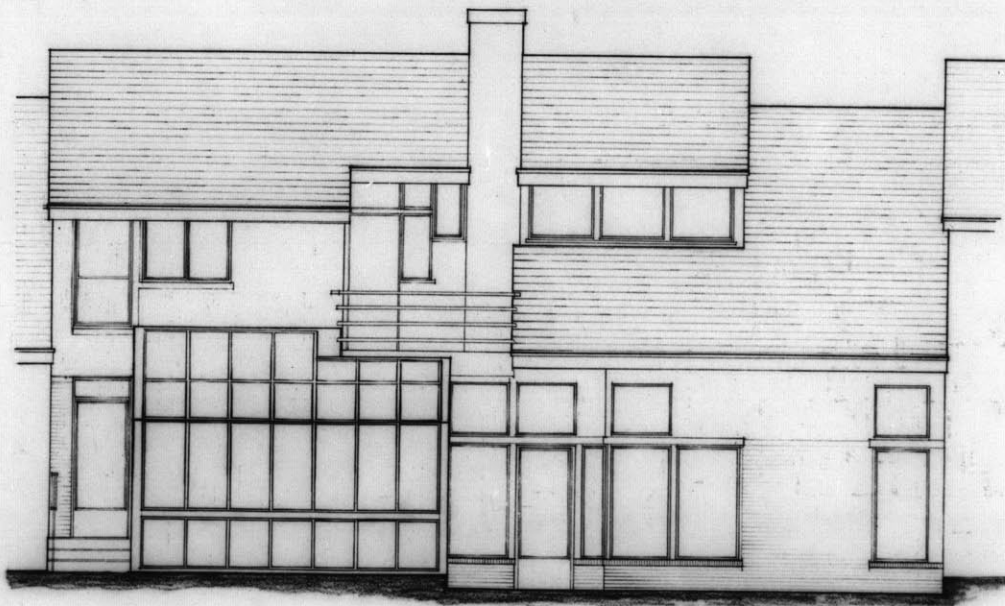
Balcony: 55

Solar aperture
greenhouse: 112
direct gain: 185

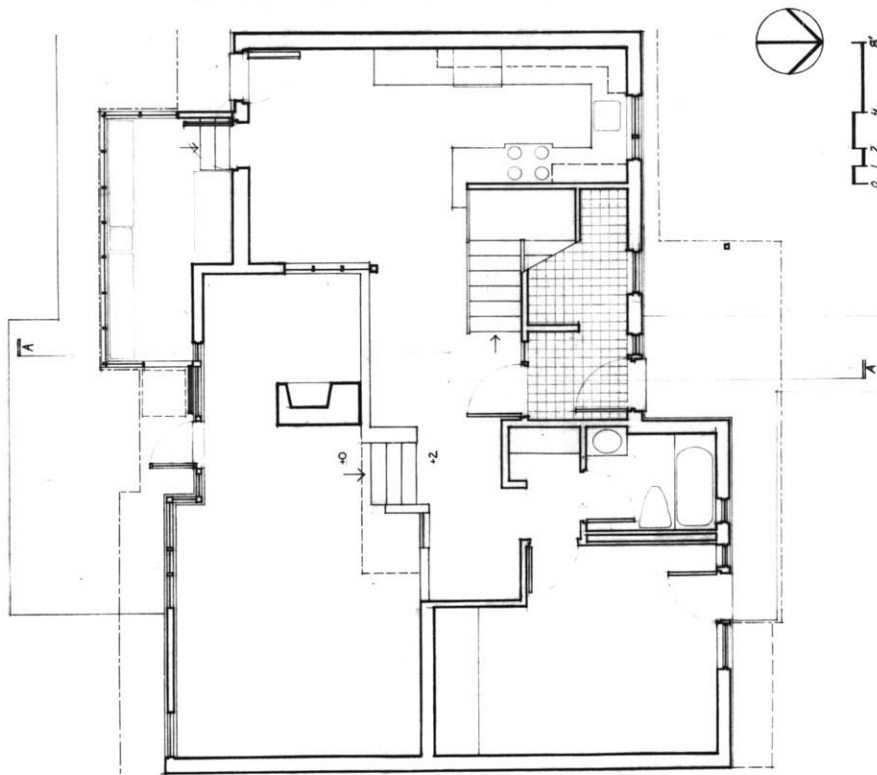
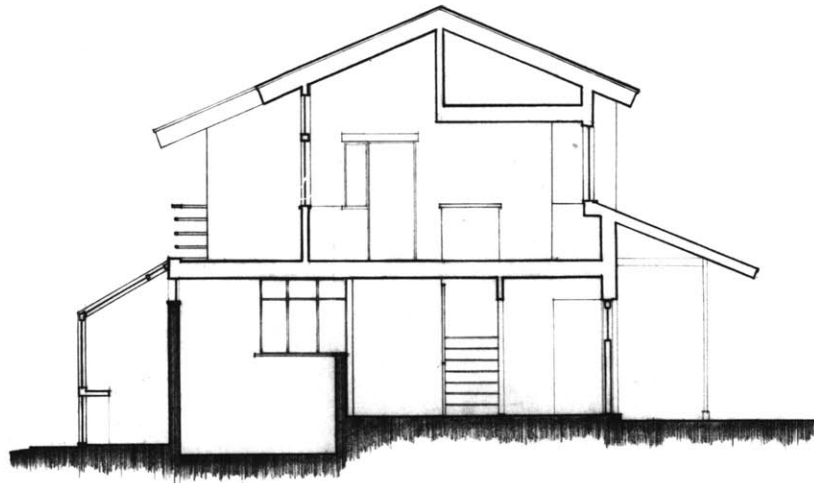


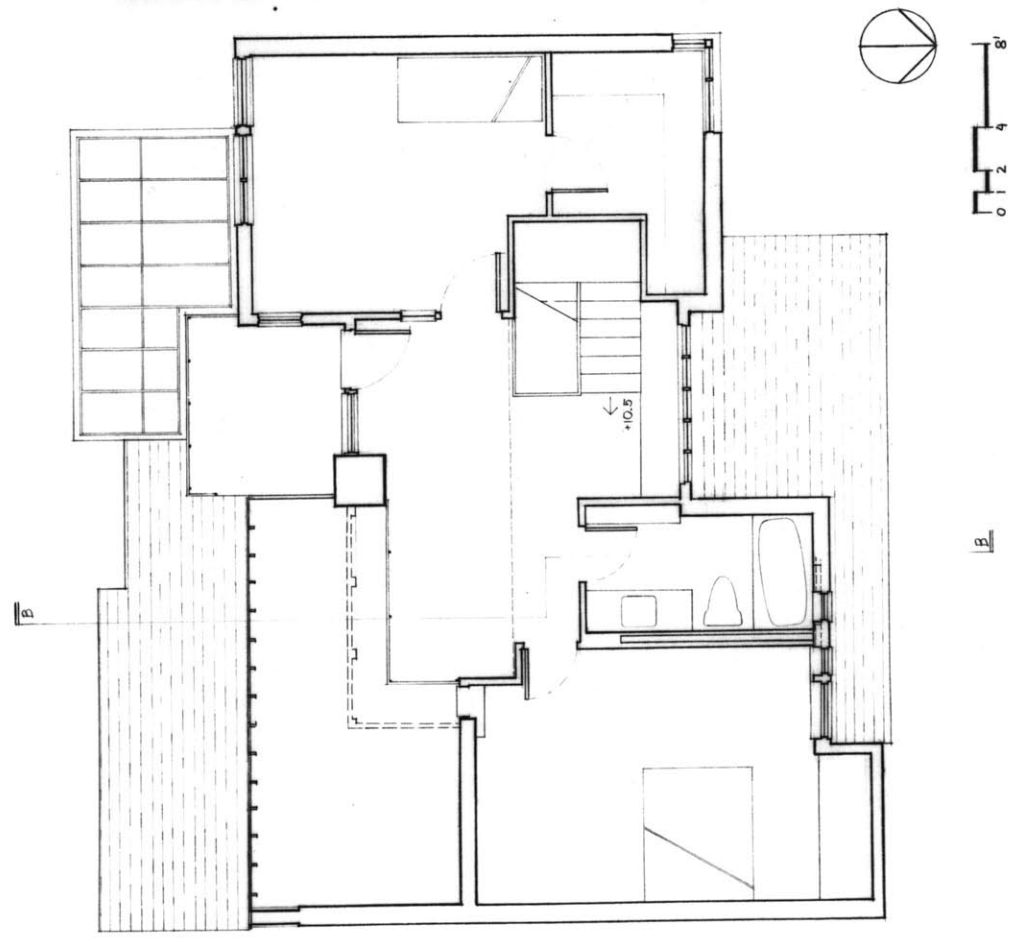
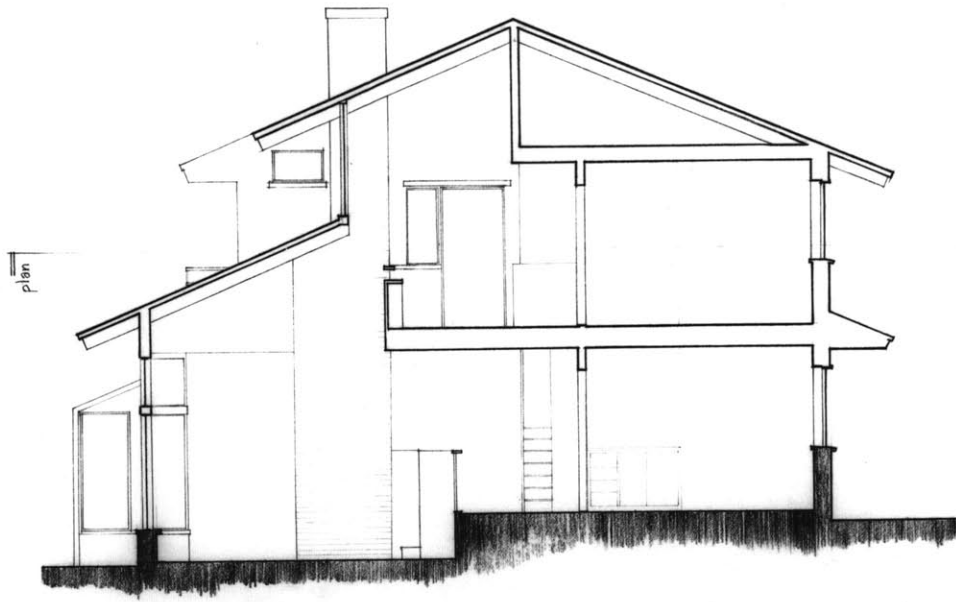


North Elevation



South Elevation





2

A pair of rowhouse unit plans is presented here suitable for street access from the west, with party walls on the north and south sides of each unit. The plans have been developed to allow significant amounts of south glazing in each unit, and to take advantage of the resulting building configuration for outdoor living.

Both of these units contain direct-gain spaces; the living area and the larger bedroom of each unit have sufficient unshaded solar aperture to maintain an average temperature of 65 °F in that space on a sunny January day. East and west windows are somewhat limited, both to reduce heat gain and glare and to provide privacy from the street.

Although a decision to site townhouses along a north-south street would probably be the result of necessity, such an alignment does create some possibilities of its own.

The north face of a building is in shade for six months of the year. For a traditional rowhouse on an east-west street, this means that half of the possible window locations will receive no sun at all for half of the year. And it is an even chance that this dark face looks onto the private yard.

Maximum width: 55 feet for 2 units

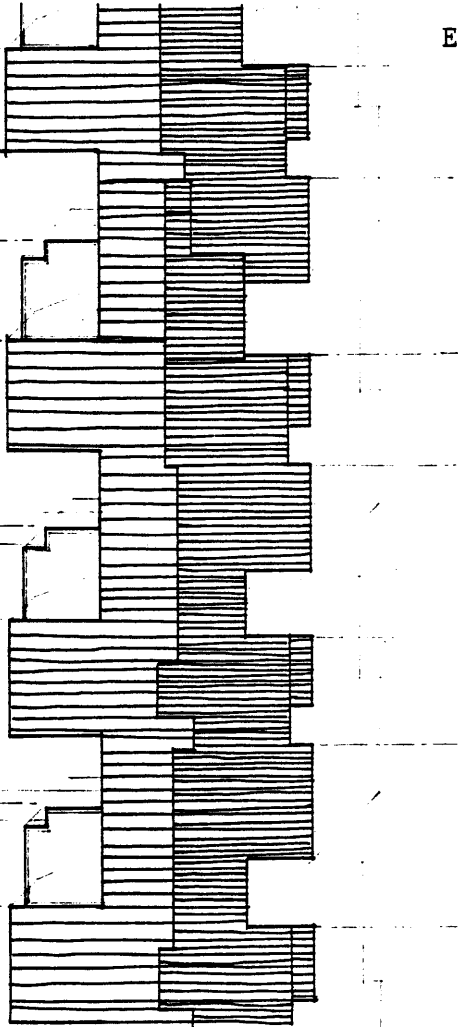
Frontage: 46 feet for 2 units

Suggested lot depth: 80 feet

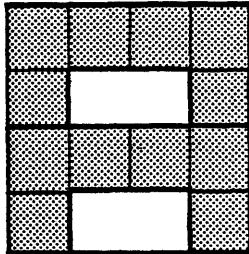
Units/acre (net): 14 - 15

Energy strategy: direct gain

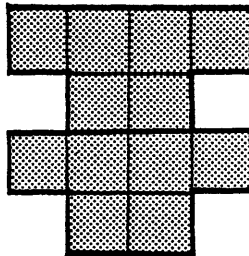
	Unit A	Unit B
Interior sq ft:	1130	1140
Balcony sq ft:	-	135
Unit frontage ft:	29	17
Solar aperture sq ft:	190	140
Overall U value:	8.6	8.6
Expected % of heating supplied by sun:	36	28



Of course, the traditional deep narrow rowhouse does not fare well on a north-south street either. East and west sun are difficult to control, and east or west windows can do no more than come out even on heat gained and lost during a northern winter.

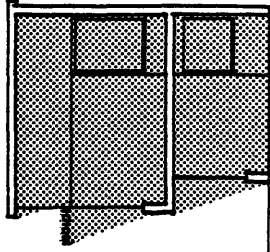


There are essentially two diagrams which will allow some south facing windows: a courtyard scheme or long fingers of living space extending east and west. The courtyard form tends to cut off its own light in the morning and afternoon, and, as part of a rowhouse block, cannot easily accept a second floor without shading a neighbor. It also requires more surface area to enclose a given amount of space than the second diagram.

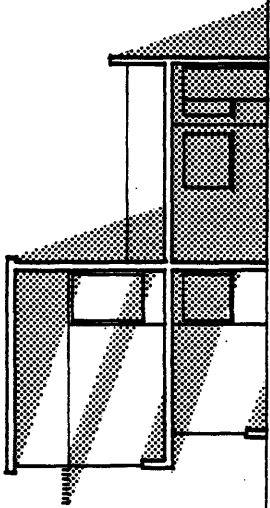


The second diagram has its limitations, of course; some spaces may become buried, and only two distinct outdoor places are possible, rather than three. However, it does not require that circulation run through the south facing spaces, and it allows a compact upper story. Some judicious give and take in the party walls can adjust sizes and sun angles. These manipulations allow sheltered outdoor spaces to be formed, and highlight the progression of the sun across the sky. It becomes possible to play the stillness of indirect light against the active sweep of the sun.

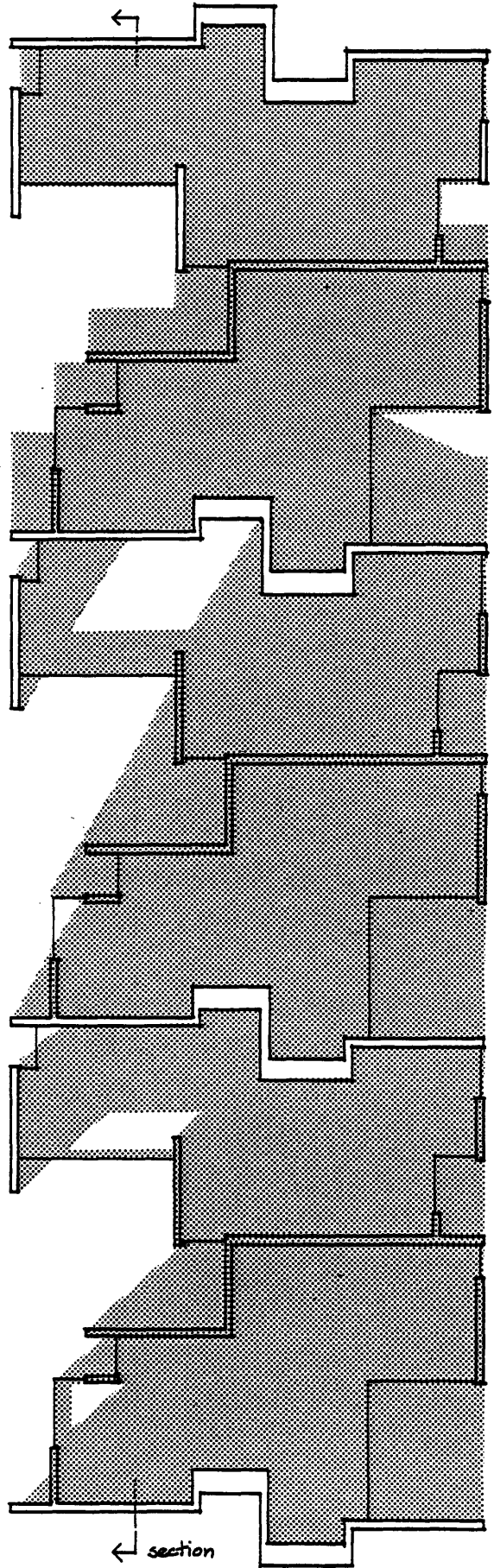
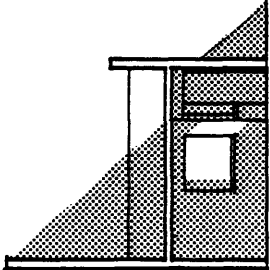
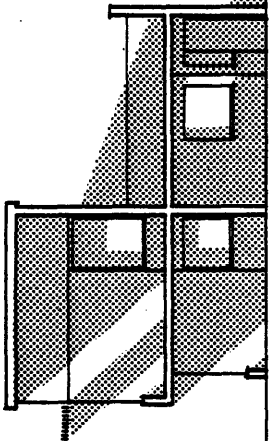
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12 noon



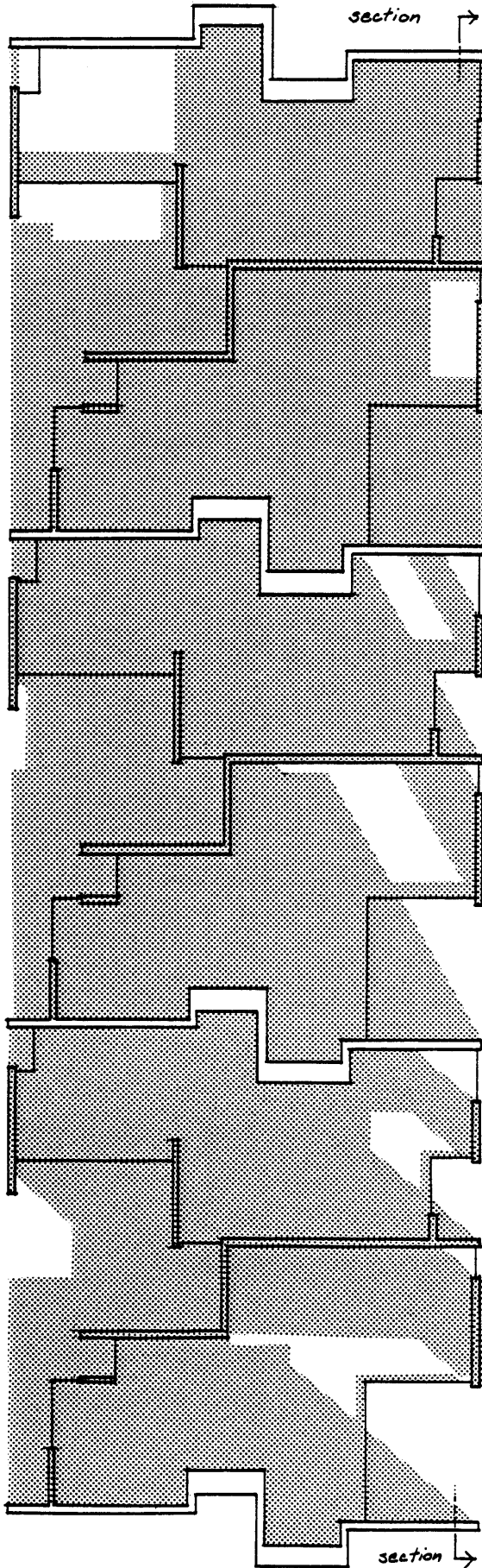
Jan. 21
2 p.m.



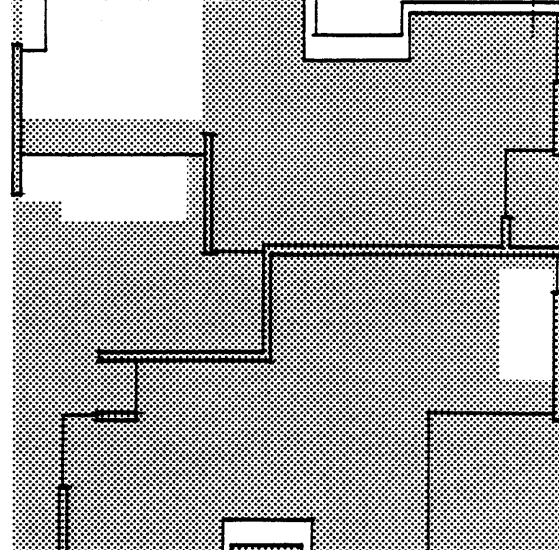
Apr 21/
Aug 21
2 p.m.



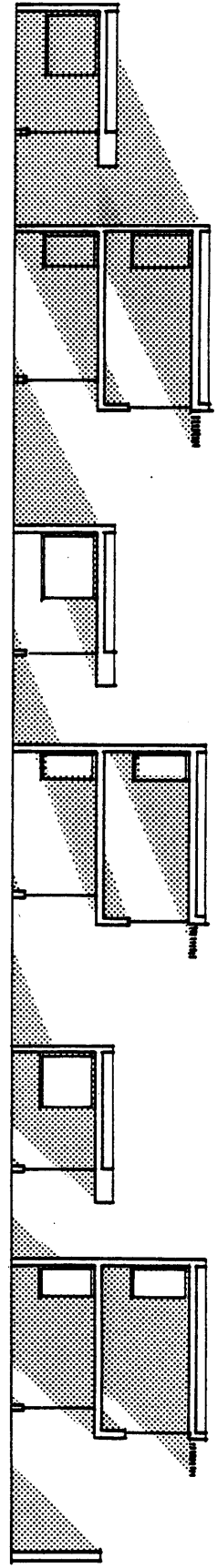
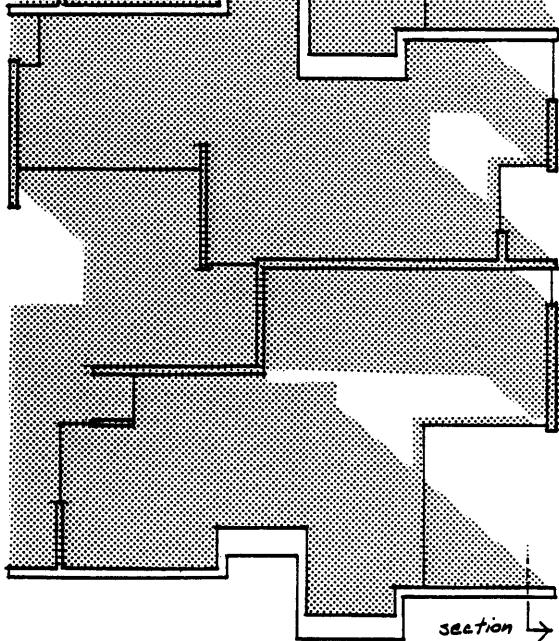
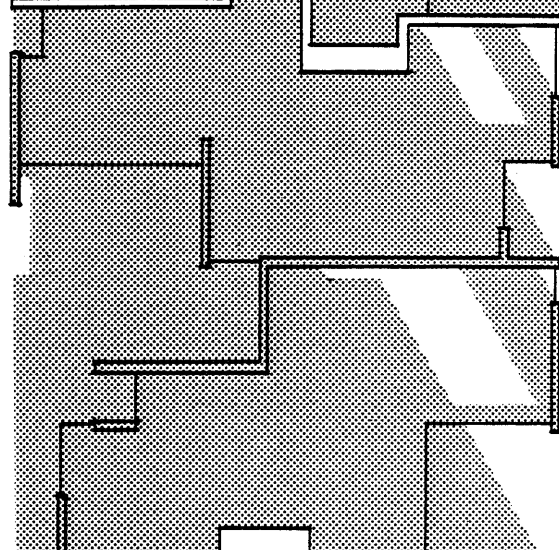
Jan 21
12 noon

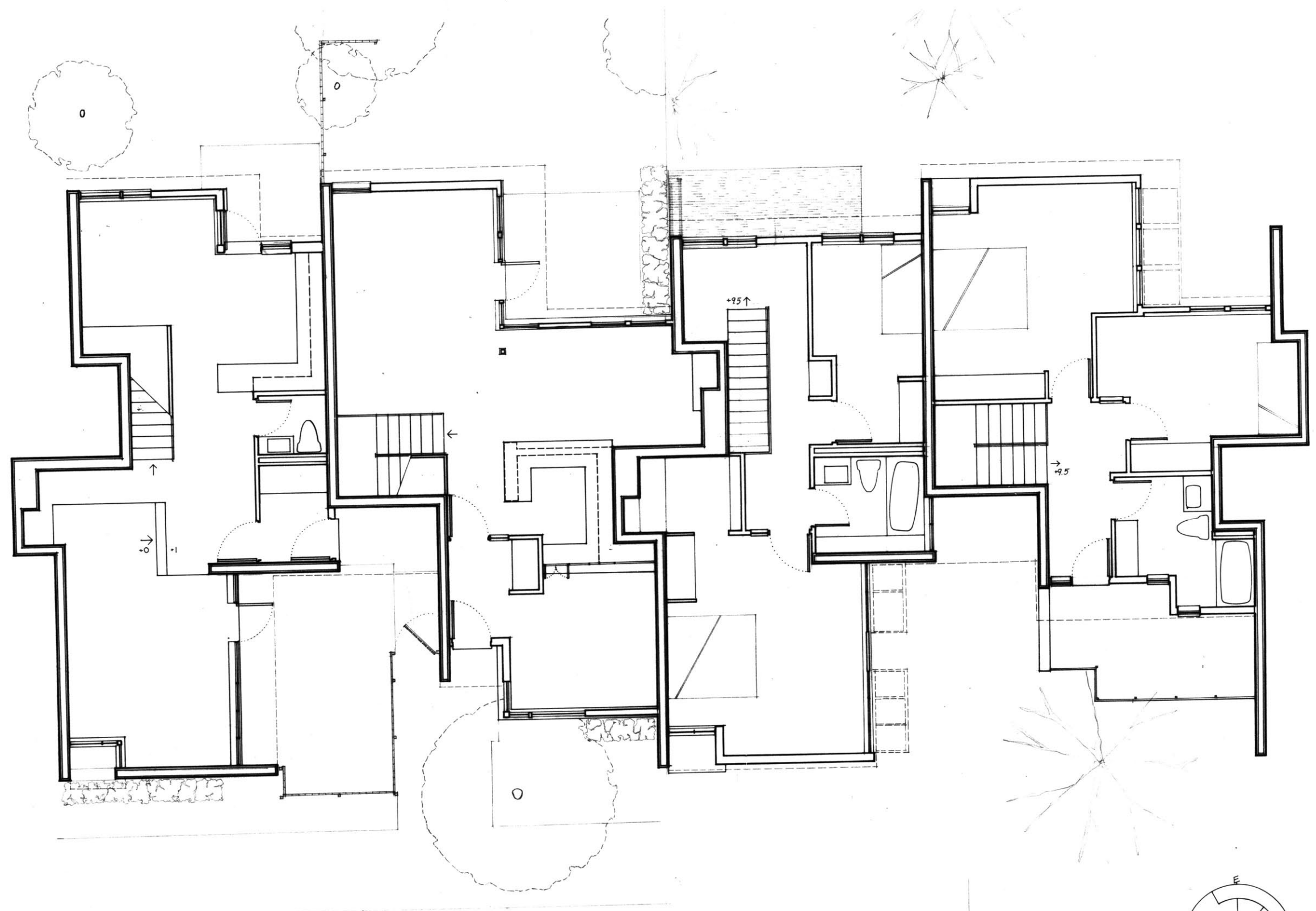


Jan 21
10 a.m.



Apr 21/
Aug 21
10 a.m.

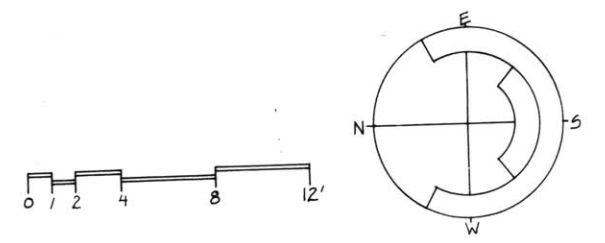




Unit A
First Level

Unit B

Second Level





SECTION THROUGH UNIT A



SECTION THROUGH UNIT B

ENERGY ANALYSIS

Rough calculations of the thermal characteristics of the buildings -- suitable for beginning fine tuning-- have been carried out using ASHRAE methods. Edward Mazria's The Passive Solar Energy Book presents a simple step by step explanation of the procedure, which has been reproduced below in some detail for Unit A.

1. Heat loss estimate for Unit A

a. Conduction losses

	U (1/R)	A sq. ft.	U x A Btu/hr-°F
roof	.026	580	15.1
exterior wall	.058	600	34.8
double glazing	.5	350	175.0
doors	.2	42	8.0
			<hr/> 232.9

b. Perimeter losses

Assume that the perimeter of the slab is insulated with R10 insulation eighteen inches deep.

$$(80' \text{ of perimeter})(0.18 \text{ Btu/hr}^\circ\text{F-ft}) \\ = 14.4 \text{ Btu/hr}^\circ\text{F}$$

c. Infiltration

Assume one air change per hour, which is a bit on the high side.

$$(1 \text{ a.c./hr})(9040 \text{ cu ft})(0.018 \text{ Btu/cu ft}^\circ\text{F}) \\ = 162.8 \text{ Btu/hr}^\circ\text{F}$$

$$\text{Total heat loss} = 410.1 \text{ Btu/hr}^\circ\text{F}$$

This corresponds to an average overall U value of 8.6 Btu/day-sq ft °F for the unit, which is within the expected range for a well-insulated residence of 6 to 12 Btu/day-sq ft °F. Given 5600 Degree

Days per year, this unit will require 55 million Btu (MMBtu) over the heating season.

$$(5600 \text{ DD})(24 \text{ hr})(410.1 \text{ Btu/hr}^{\circ}\text{F}) = 55,100,000 \text{ Btu}$$

2. Heat gain in winter

Solar gain figures are taken from the Tables in the Appendix of The Passive Solar Energy Book. This unit receives direct sun only after 12 noon, so the half day totals are used. Since the glazing is fully shaded in June, fully unshaded in December, and partially shaded during the rest of the year, the half day totals must be multiplied by an appropriate fraction. East and west glazing can be ignored.

Solar Gain per Square Foot of Aperture

January	(.95)	(779 Btu/half day)	(30.4 days/mo)	
Jan.	(.95)	(779 Btu/day)	(30.4 days/mo)	= 22,498 Btu
Feb.	(.85)	(675 Btu/day)	(30.4 days/mo)	= 15,626 Btu
Mar.	(.6)	(456 Btu/day)	(30.4 days/mo)	= 8,330 Btu
Apr.	(.5)	(246 Btu/day)	(30.4 days/mo)	= 3,739 Btu
Sept.	(.6)	(442 Btu/day)	(30.4 days/mo)	= 8,056 Btu
Oct.	(.85)	(454 Btu/day)	(30.4 days/mo)	= 11,731 Btu
Nov.	(.95)	(763 Btu/day)	(30.4 days/mo)	= 22,035 Btu
Dec.	(1.0)	(793 Btu/day)	(30.4 days/mo)	= 24,107 Btu
				<u>116,121 Btu</u>

Now multiply by 0.94 to account for absorption losses, and by 190 square feet of aperture:

Total heat gain into Unit A = 20.7 MMBtu per year

This is 38 per cent of the total heat loss calculated in part one. However, the percentage of heat which will be supplied by solar gains is less than this because some of this heat may have to be vented.

3. Average indoor temperature in living room

For a clear spell in January:

a. Heat gain

$$(779 \text{ Btu/day-sq ft})(.95)(.94)(95 \text{ sq ft of glazing}) = 66,086 \text{ Btu/day}$$

Dividing by the floor area, about 240 sq ft, we get 275 Btu/sq ft-day

b. Heat loss

windows	55.0 Btu/hr ^{°F}
walls	4.1 Btu/hr ^{°F}
perimeter	5.8 Btu/hr ^{°F}
infiltration	22.1 Btu/hr ^{°F}
	<hr/>
	87.0 Btu/hr ^{°F}

or, multiplying by 24 hours, 2088 Btu/day^{°F}

Again, dividing by floor area, we get

$$8.7 \text{ Btu/day } ^\circ\text{F sq ft}$$

c. Average temperature inside is equal to the average temperature outside, in this case 31.4^{°F}, plus the heat gain divided by the heat loss:

$$31.4 \text{ } ^\circ\text{F} + \frac{275 \text{ Btu/sq ft-day}}{8.7 \text{ Btu/sq ft-day } ^\circ\text{F}} = 63 \text{ } ^\circ\text{F}$$

To this must be added the temperature rise due to the internal heat gains produced by lights, people, and cooking or other appliances. This temperature increase is usually 2[°] to 5^{°F}. In this space, it will be on the low side since there is no cooking and the number of residents can be expected to be small.

It should be noted, however, that this does not mean that the rest of the unit will be comfort-

able without auxiliary heating. It does definitely mean that the auxiliary heating system should be zoned so that heat can be supplied only when and where needed.

4. Daily temperature swing

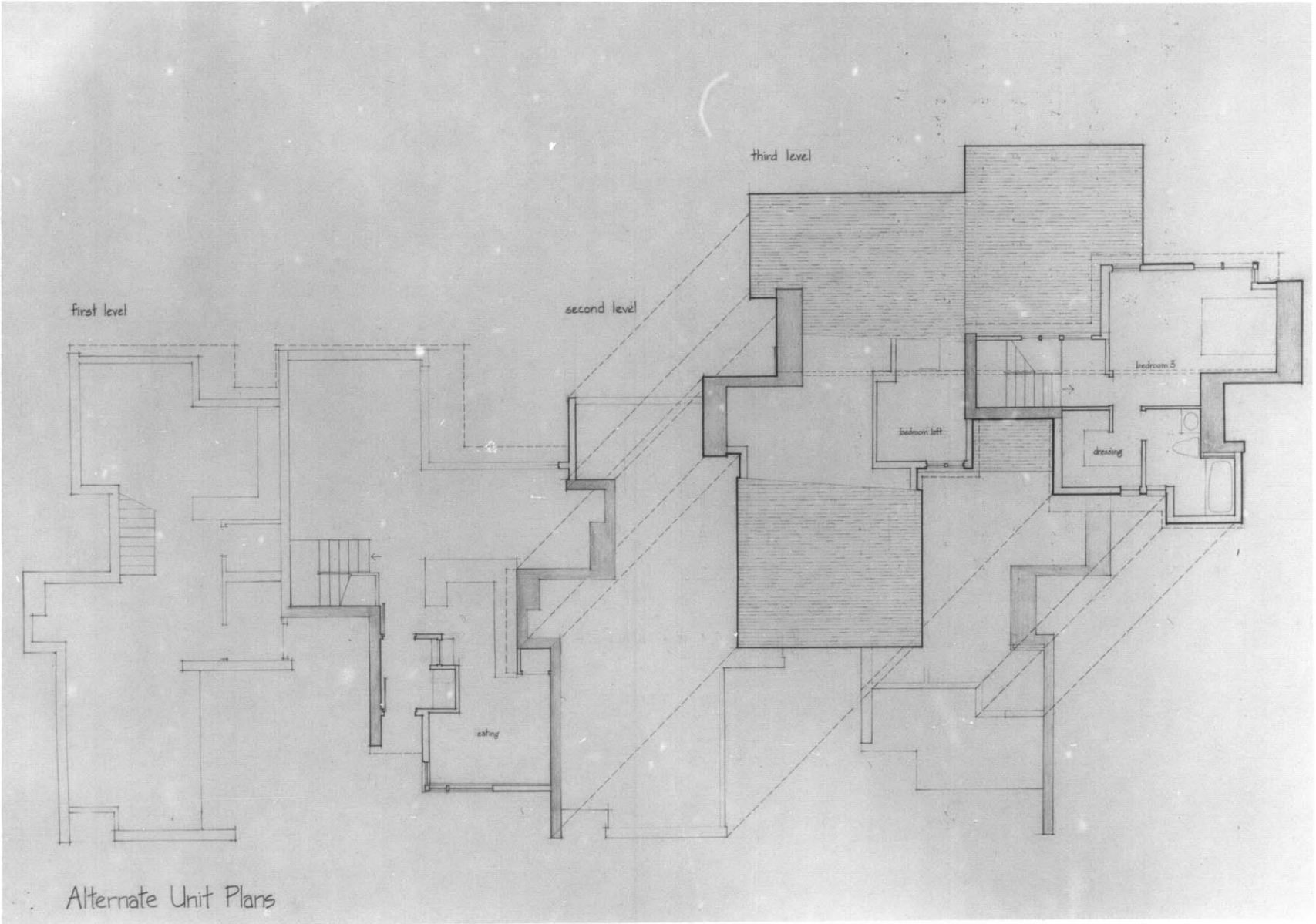
The temperature swing during the day is dependent on the distribution of the mass and its composition. With a concrete floor and magnesite brick walls, the ratio of the surface area of the thermal mass to the area of the glazing is about six. The temperature can be expected to fluctuate between 10 to 15 degrees higher and 5 to 10 degrees lower than the average temperature, peaking at around two p.m. and dropping to its lowest point at around six a.m. The day's average temperature is crossed at nine or ten a.m. and again at eight or nine p.m.

5. Determining auxiliary heat needs

The solar gain and the heat loss are calculated for each month, using monthly solar gain and degree day figures. If, in a given month, the heat loss is greater than the solar gain, the difference is the amount of auxiliary heat needed. If the solar gain is greater than the heat loss, this excess must be vented; it cannot be used against another month's deficit.

For this unit, solar gains should supply 36 per cent of the heating needs over the year.

Alternative plans are presented on the facing page. A loft is shown in the second bedroom of Unit A and a full third story plan is provided for Unit B. An alternative entrance configuration is shown for Unit B as well. Rather than combining the vestibule with a front room and limiting the kitchen to a compact work area, the vestibule is confined to a minimum and the kitchen opens onto an eating place.



3

This two-story townhouse was designed for access from the south, and requires a 30 foot wide lot.

Both direct gain and indirect gain strategies are used. The street (south) facade uses a pierced Trombe wall on ground level in front of the kitchen to provide both privacy and solar gains. On the north is a masonry "cave" with a fireplace, raised two steps above the rest of the main room. In the center of the unit is a double height space lit by south-facing clerestories.

In this way there can be three foci, for different times of the day and different seasons: the kitchen, inherently warm from cooking and provided with a thermal wall; the central volume, brightly lit by clerestories or open to the night sky; and the masonry cave, low ceilinged, separate, and the fire's place.

The large amount of thermal mass - fully 1600 sq. ft. in area - and the operable windows on the second level and high in the roof peak should combine to provide natural cooling.

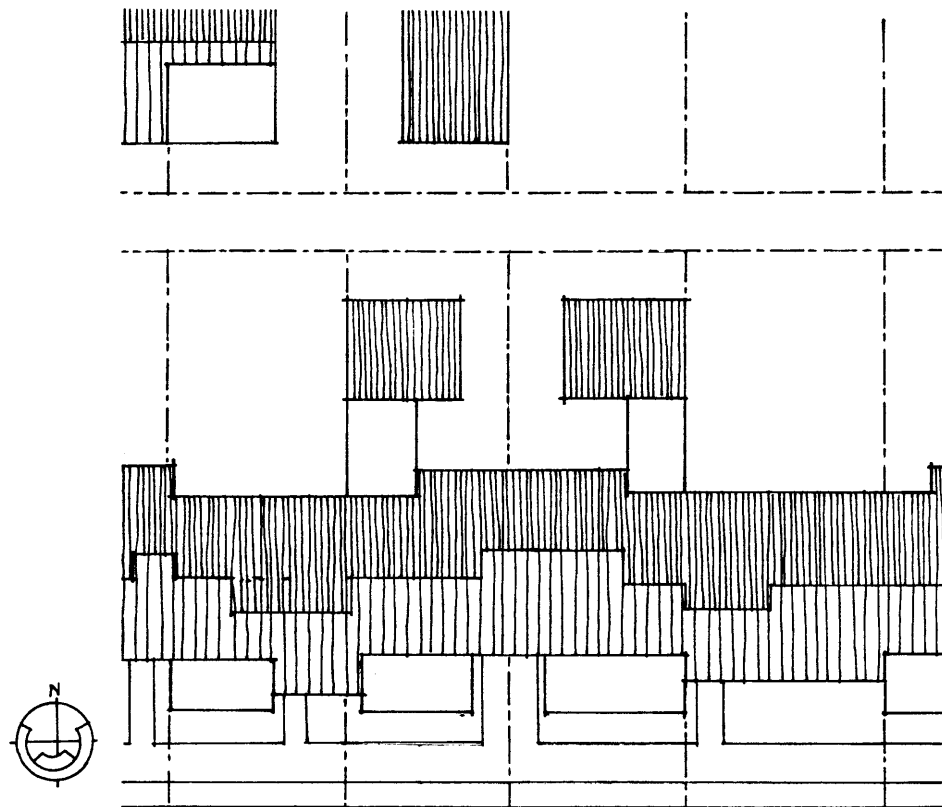
On the first floor, but fully closable from the main space, is a room which could operate as part of the outdoors, part of the main space, or as its own entity. The second floor includes a wide outdoor balcony overlooking the street, two bedrooms (one of which can rely on the sun for all of its heat) and a bath.

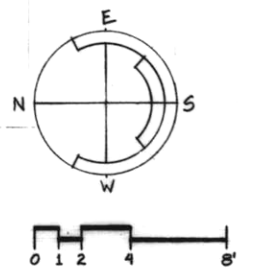
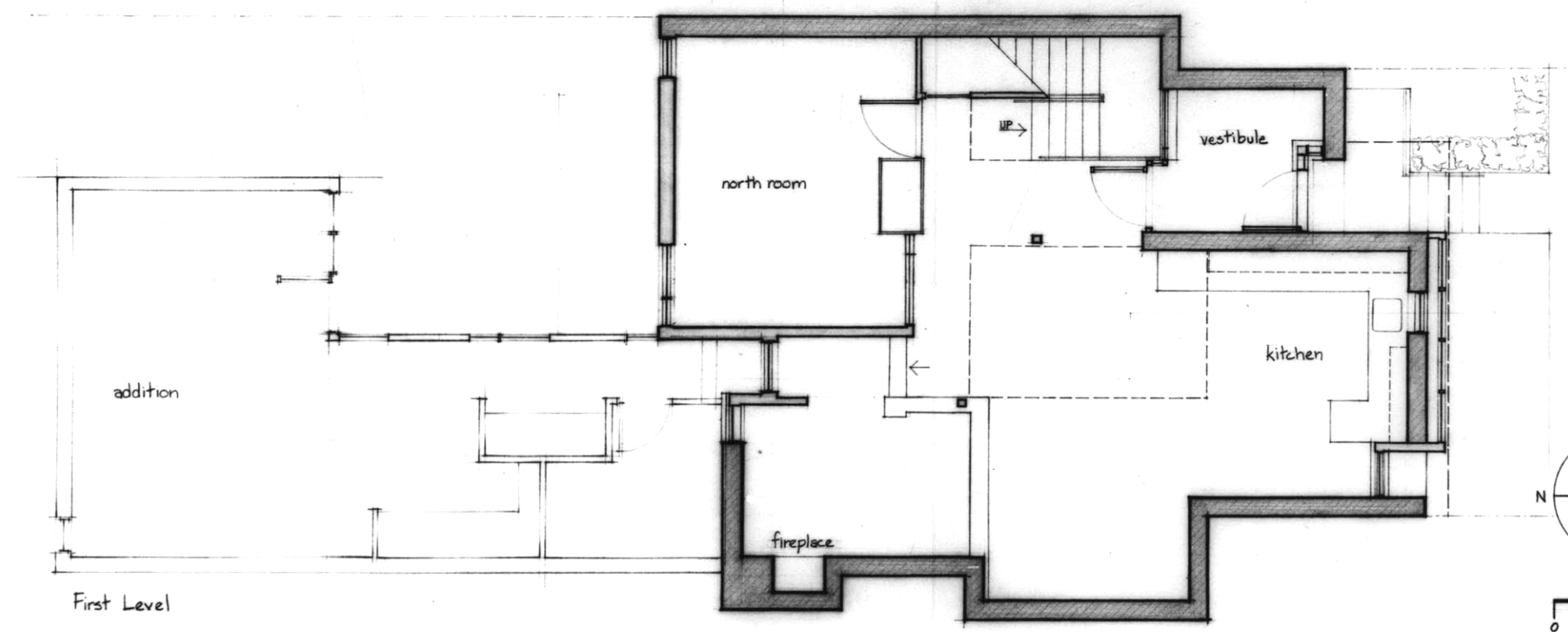
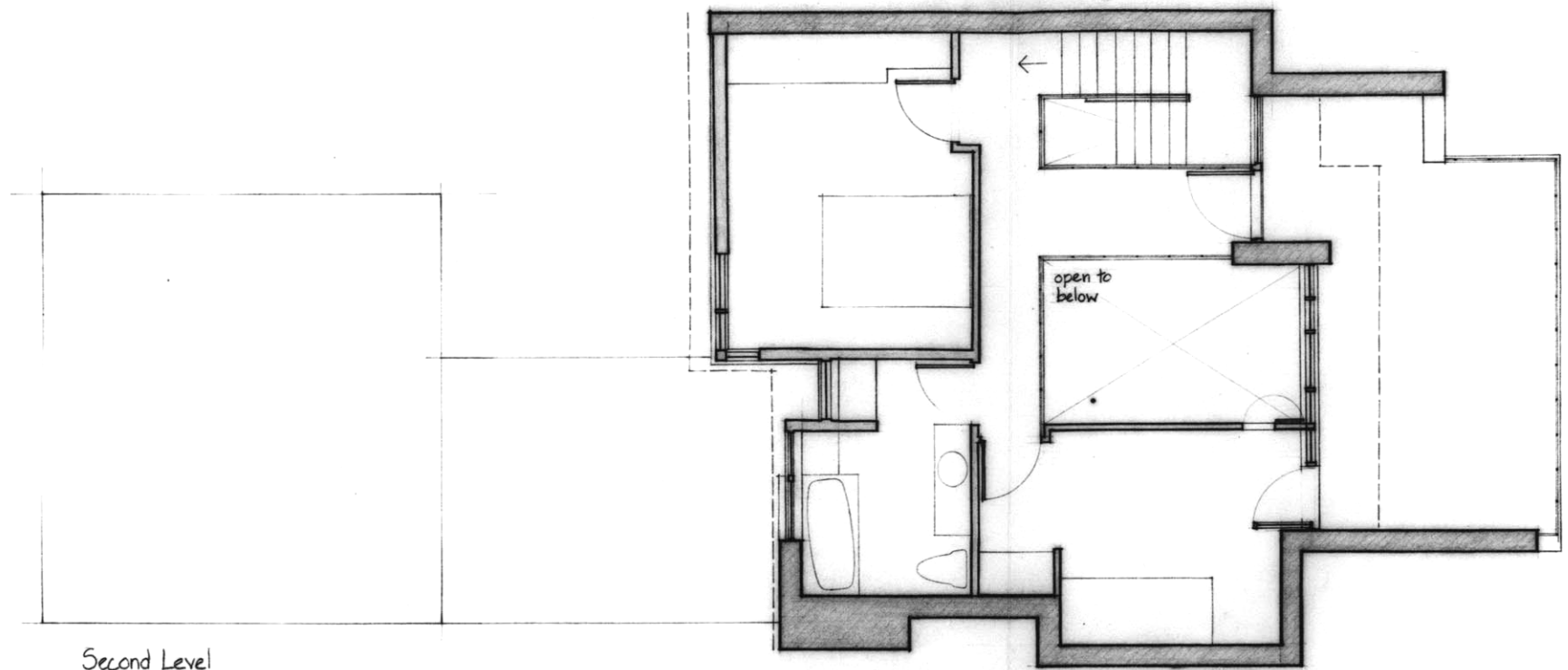
Maximum width: 30 feet
Frontage: 22 feet
Suggested lot depth:
90 to 100 feet
Units/acre (net): 12

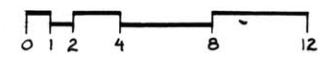
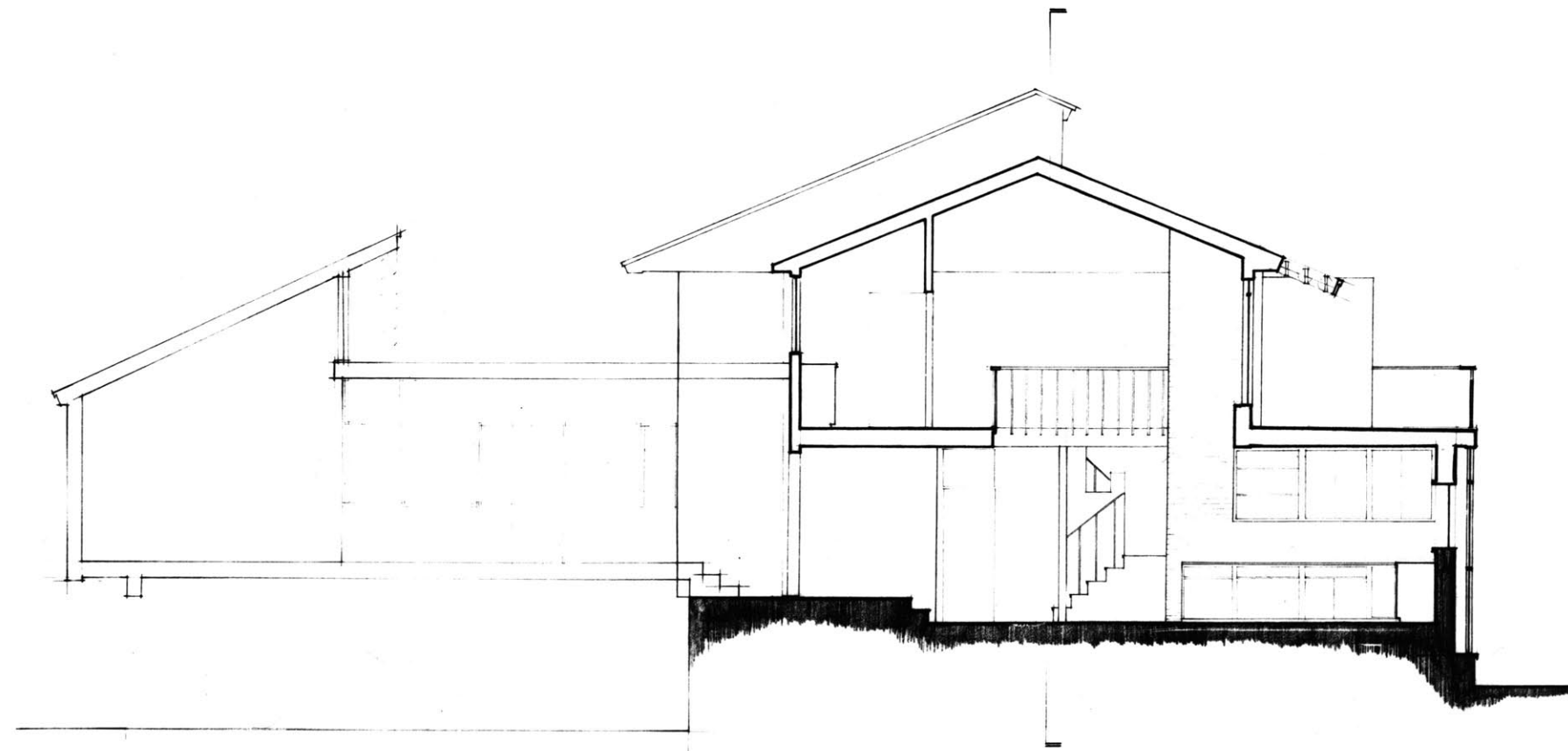
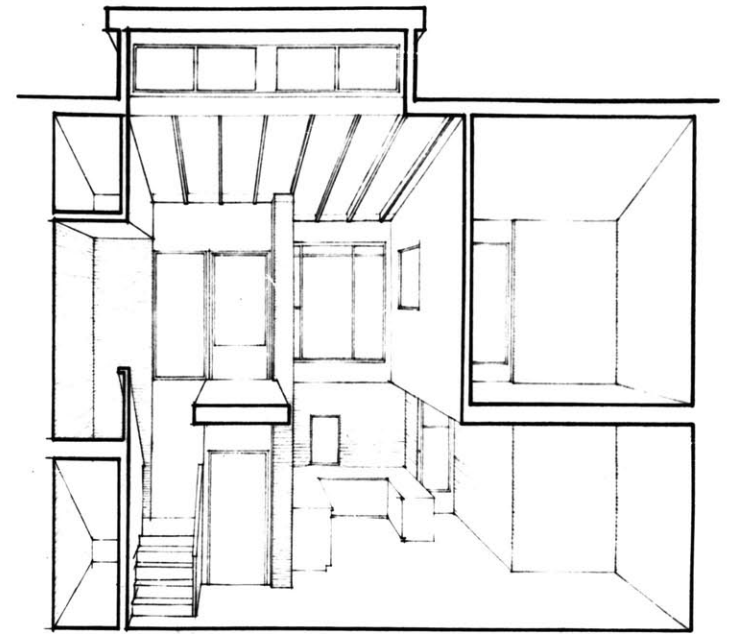
The outline of a possible addition is shown on the north, gaining southern exposure nonetheless by virtue of its distance from the main house and its sloping roof. An alley is suggested on the site plan.

Energy strategy:
direct gain,
indirect gain
Overall U value: 8.3
Expected % of heating
supplied by sun: 70

Area in square feet
Interior: 1195
Addition: 425
Balcony: 210
Solar aperture
direct gain: 135
indirect gain: 100







4

This final set of drawings belongs to a block of urban townhouses. The ground level contains private garages and a small apartment; the other units are entered from an elevated terrace. All units have direct gain and/or greenhouses.

Within each unit is a dark cave and a sunny room. While these designs are incomplete, several patterns can be recognized:

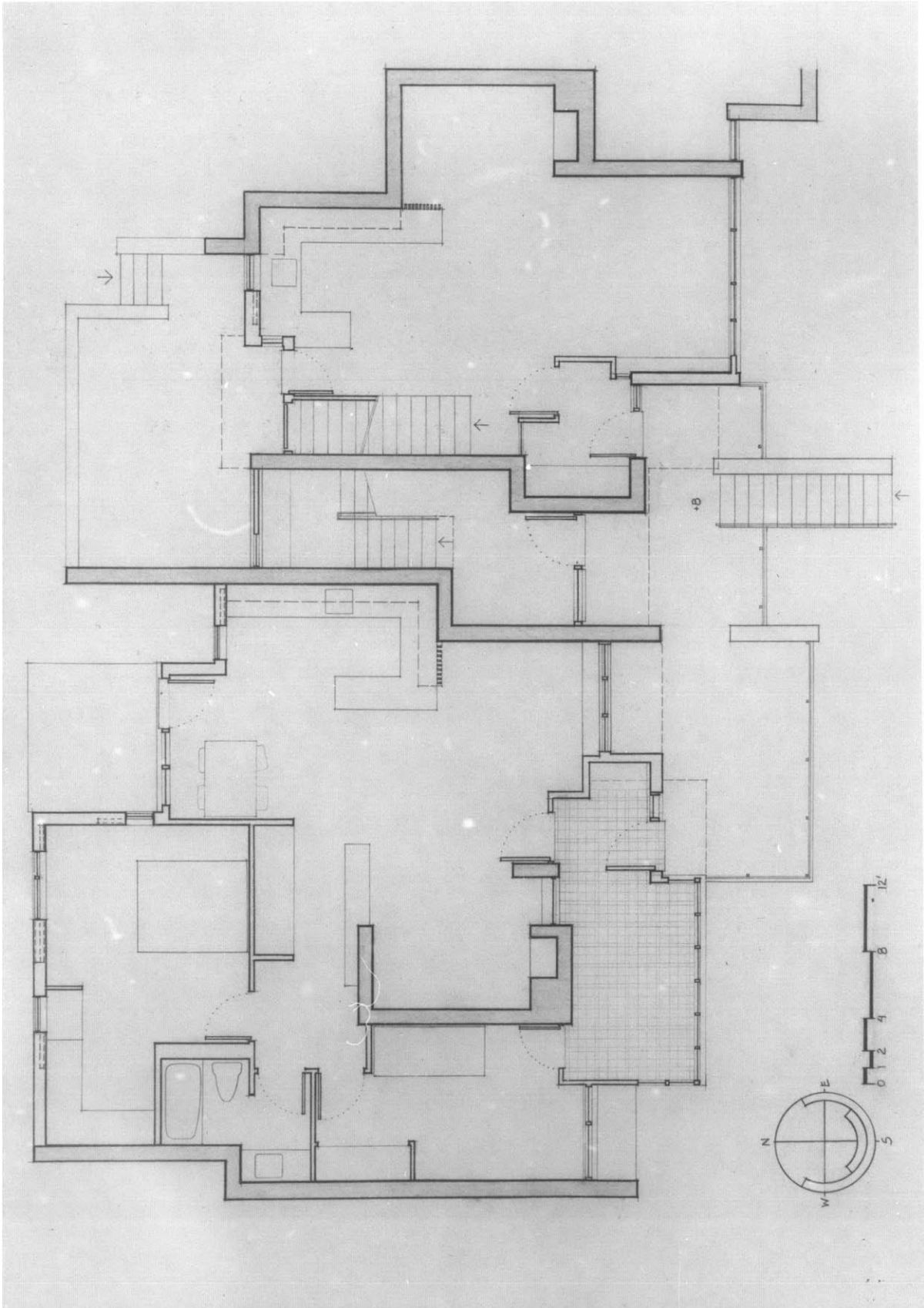
Collection Patterns: Direct gain, greenhouse
Thermal Mass
Range of Enclosure
Elevated Outdoor Spaces
Vestibule
Stove/Fireplace
Natural Ventilation
Shared Walls

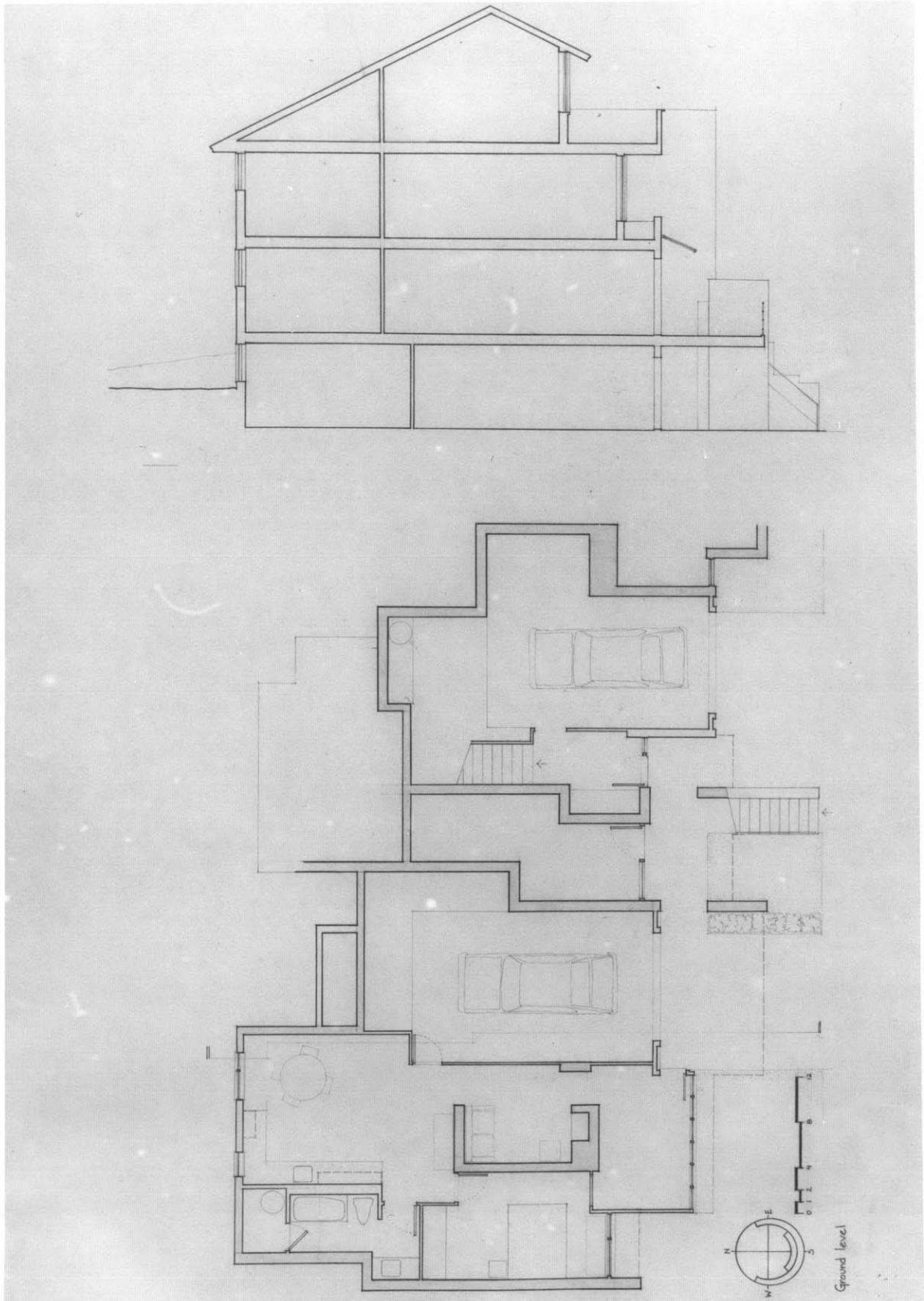
Maximum width: 68 feet for 4 units

Suggested lot depth: 80 feet

Units/acre (net): 25

	West	Unit East	Lower
Interior sq ft	890	770	630
Greenhouse sq ft	125	-	96
Balcony/patio sq ft	120	165	-
Solar Aperture sq ft			
direct	84	135	30
greenhouse	150	-	120





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APPENDIX

BOSTON WEATHER DATA

	J	F	M	A	M	J	J	A	S	O	N	D	year
HS	475	710	1016	1326	1620	1817	1749	1486	1260	890	503	403	1,105
VS	878	1052	1127	1030	944	927	940	1009	1212	1192	874	788	11,972
TA	29.2	30.4	38.1	48.6	58.6	68.0	73.3	71.3	64.5	55.4	45.2	33.0	51.3
D50	645	549	371	96	5	0	0	0	1	16	163	527	2,374
D55	800	689	524	203	29	1	0	0	4	70	297	682	3,300
D60	955	829	679	344	99	7	0	2	21	164	445	837	4,381
D65	1110	969	834	492	218	27	0	8	76	301	594	992	5,621
D70	1265	1109	989	642	355	106	32	57	180	453	744	1147	7,080
RH01	65	64	67	67	72	78	76	78	80	75	72	69	72
RH13	57	57	57	53	57	60	56	57	61	57	61	61	58
Wind	NW	WNW	NW	WNW	SW	SW	SW	SW	SW	SW	SW	WNW	W
MPH	14.2	14.1	14.0	13.4	12.2	11.3	10.8	10.8	11.2	12.1	13.0	13.8	12.6
PPS	52	56	57	57	59	63	66	67	63	61	51	52	60

HS normal daily value of total hemispheric solar radiation on a horizontal surface (Btu/ft² day)

VS normal daily value of total solar radiation on a vertical south-facing surface (Btu/ft² day)

TA $(T_{\min} + T_{\max})/2$ where T min and T max are monthly (or annual normals of daily minimum and maximum ambient temperature (°F)

Dxx monthly (or annual) normal of heating degree days below the base temperature xx (°F-days)

RH01 relative humidity at 0100 hrs (%)

RH13 relative humidity at 1300 hrs (%)

Wind prevalent direction

MPH average wind velocity (miles per hour)

PPS per cent possible sunshine

from U.S. Government data and "Climates of the States" Gale Research Company, Detroit.