

THESIS

ENERGY CONSCIOUS
MULTIPLE FAMILY HOUSING
BY
JAMES MCKEAGUE

JAMES MCKEAGUE
MONTANA STATE UNIVERSITY
SCHOOL OF ARCHITECTURE
BOZEMAN, MONTANA

MARCH 1977

P378
.M1932

LIBRARY
MONTANA STATE UNIVERSITY
BOZEMAN

**ENERGY
CONSCIOUS
MULTIPLE
FAMILY
HOUSING**

ENERGY CONSCIOUS MULTIPLE FAMILY HOUSING

UNDERGRADUATE THESIS IN ARCHITECTURAL DESIGN

by

JAMES MCKEAGUE

Submitted to the School of Architecture as
partial fulfillment of the requirements
for the degree of Bachelor of Architecture

at

MONTANA STATE UNIVERSITY

Bozeman, Montana

March, 1977

72916
1176
11113

P378
M1932

INDEX

ENERGY RESEARCH AND SITE ANALYSIS

THE PROJECT

HEAT LOSS ANALYSIS

SOLAR ENERGY USAGE

DRAWINGS

INTRODUCTION

We have reached a point in time when we must look at energy conservation as a prime element of architectural design. The technology for energy conscious design has been with us for centuries. It has only now been realized due to the economic need for a substitute for cheap fossil fuels. The time of cheap fossil fuels is over. We must now concentrate our design ability in developing structures which will function as much as possible in a self sufficient energy conscious manner.

The sun gives us enough energy every day to establish this self sufficiency. By realizing this and designing our structures to optimize this fact , we rely less on the quickly declining fossil fuels. Thus leaving these fuels for other more important uses.

I believe that, in becoming more aware of the necessary design tools, the architecture created not only becomes more efficient, but a better place to live. It is my hope that through these two quarters of research and design that I have moved at least a step in that direction.

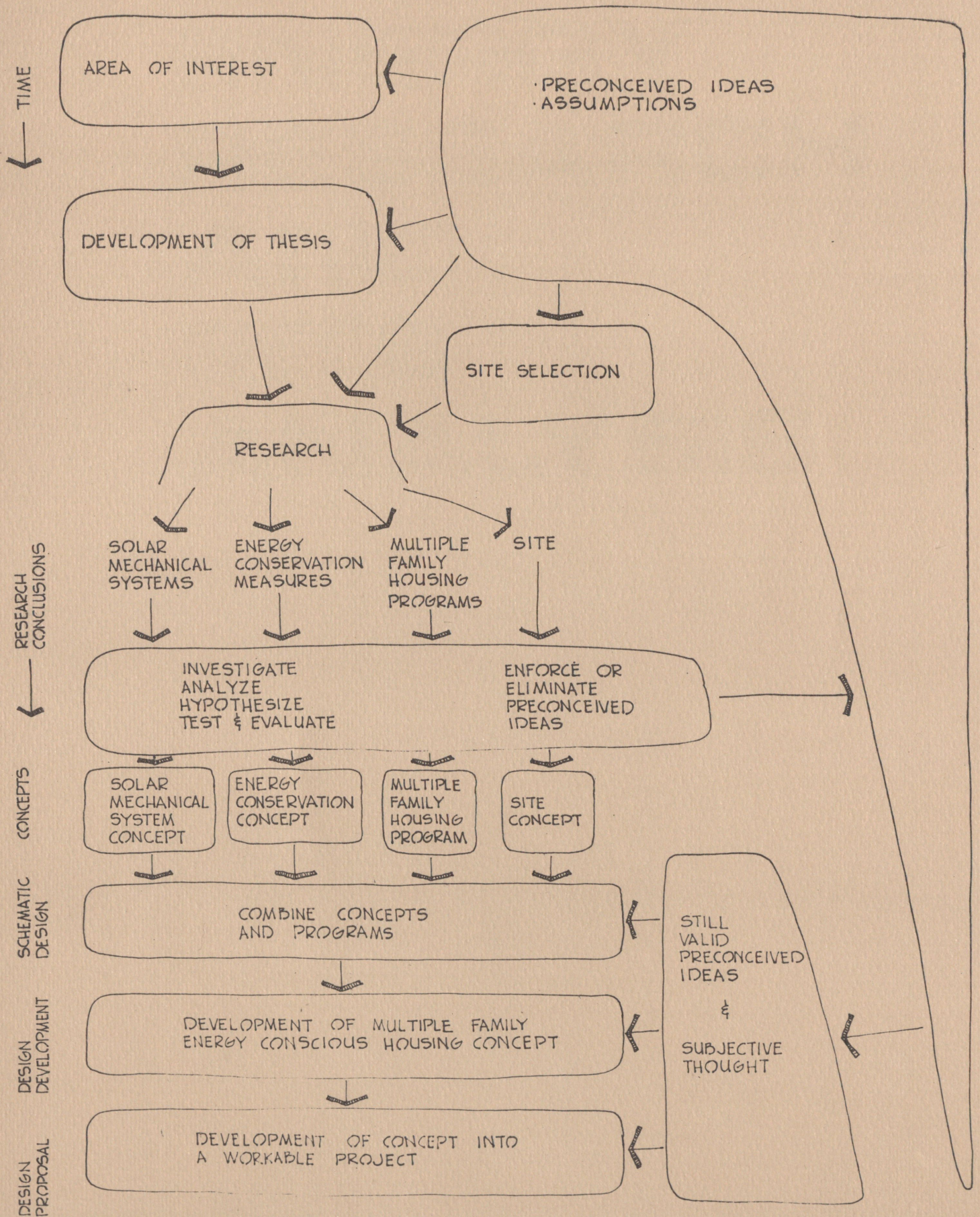
THESIS

THE INTEGRATION OF SOLAR MECHANICAL SYSTEMS AND
ENERGY CONSERVATION MEASURES, WITH MULTIPLE FAMILY
DWELLINGS, HAS A PROFOUND EFFECT ON THE RESULTING
ARCHITECTURAL FORM, AS WELL AS THE EXPERIENCE OF
SUCH ENVIRONMENTS

SUBJECT

ENERGY CONSCIOUS MULTI-FAMILY HOUSING

PROCESS



**ENERGY
RESEARCH
AND
SITE
ANALYSIS**

In analysing my thesis I found that I had four very strong concepts to develop. These being:

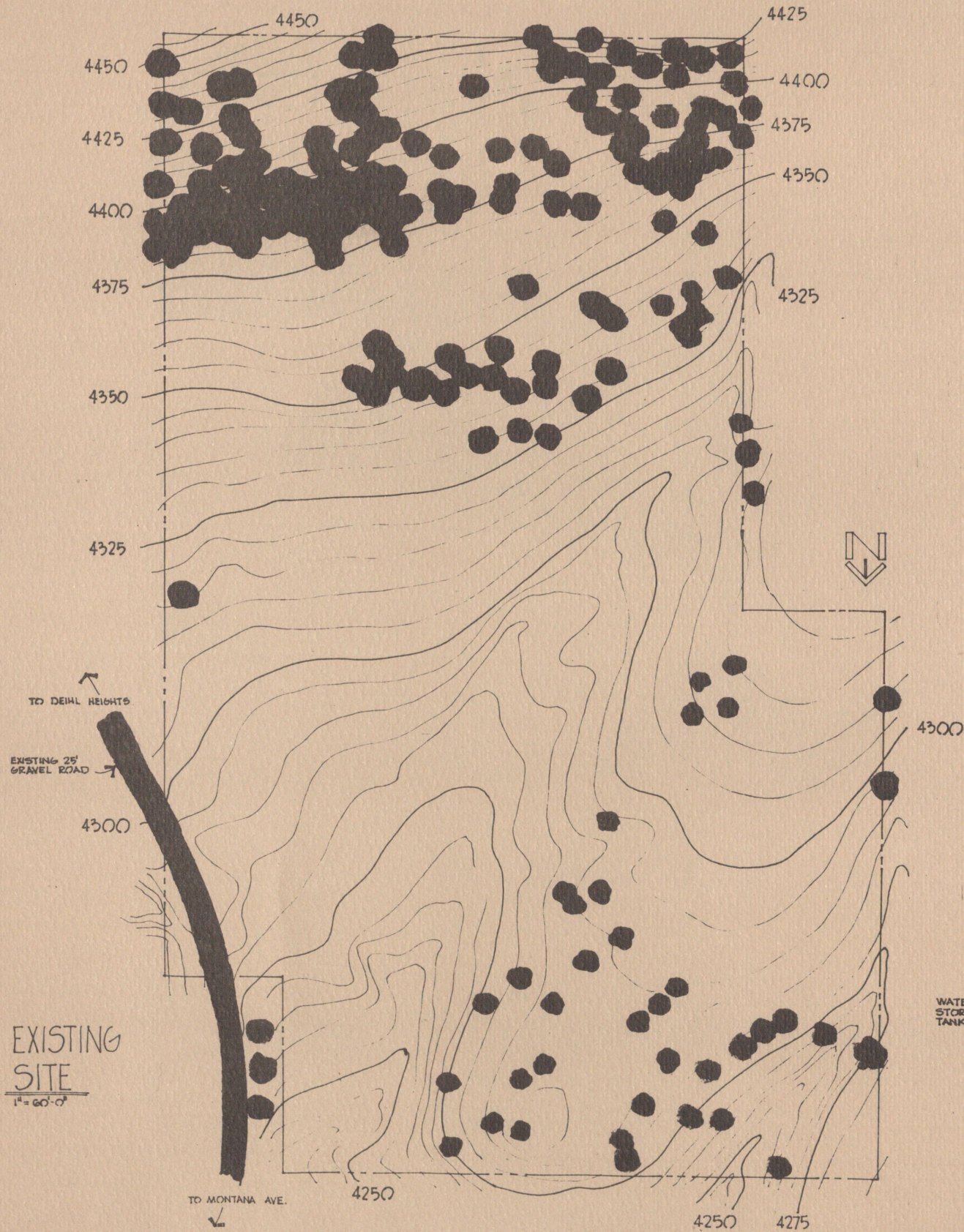
1. Site Concept
2. Multiple Family Housing Program
3. Energy Conservation Concept
4. Solar Mechanical System Concept

In order to obtain the optimal design solution for each concept they must be developed separate of the influences of each other concept. This is the method of approach that I pursued and the following pages in this section illustrate the results of my research and analysis.

SITE

The site is located in Helena, Montana which is a city with a population of about 25,000 people. Helena is located in the middle western portion of Montana and lies on the south side of a large east-west oriented valley. It is located on the 46th parallel which puts it into the cool region of the United States. The site itself is a 22 acre plot on the south side of Helena in a semi-urban-rural setting. The site slopes gradually to the north at a rate which, while not maximizing solar gain, does not hamper solar gain throughout the year.

The following pages illustrate the results of my site analysis leading up to my site concept.





VEGETATION SHADOW

1" = 60' - 0"

PONDEROSA PINE

SHADOW ANALYSIS

CRITICAL 8 HR. SHADOW
PATTERN ON DEC. 22



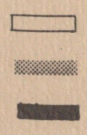
SLOPE ANALYSIS

1:60,000

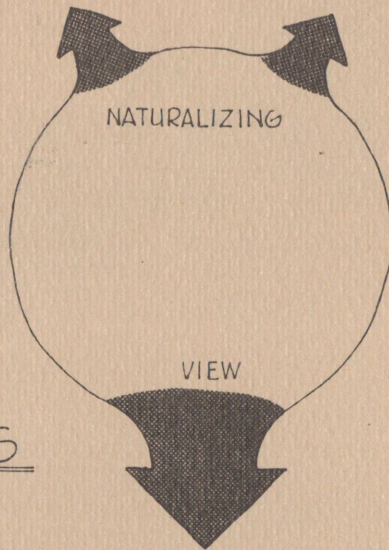
0 → 10%

10 → 20%

20% →



AMENITIES



MAXIMUM
SUN

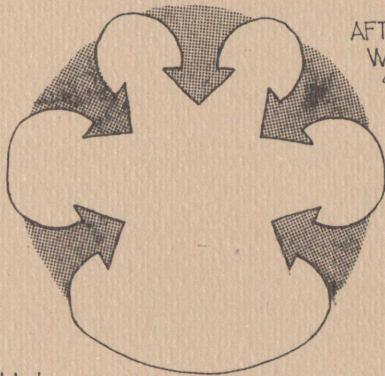
MORNING
WINTER
SUN

AFTERNOON
WINTER
SUN

MORNING
SUMMER
SUN

AFTERNOON
SUMMER
SUN

SUN



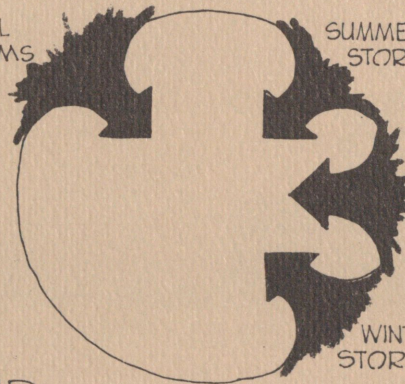
LOCAL
STORMS

SUMMER
STORMS

PREVAILING
WINDS

WINTER
STORMS

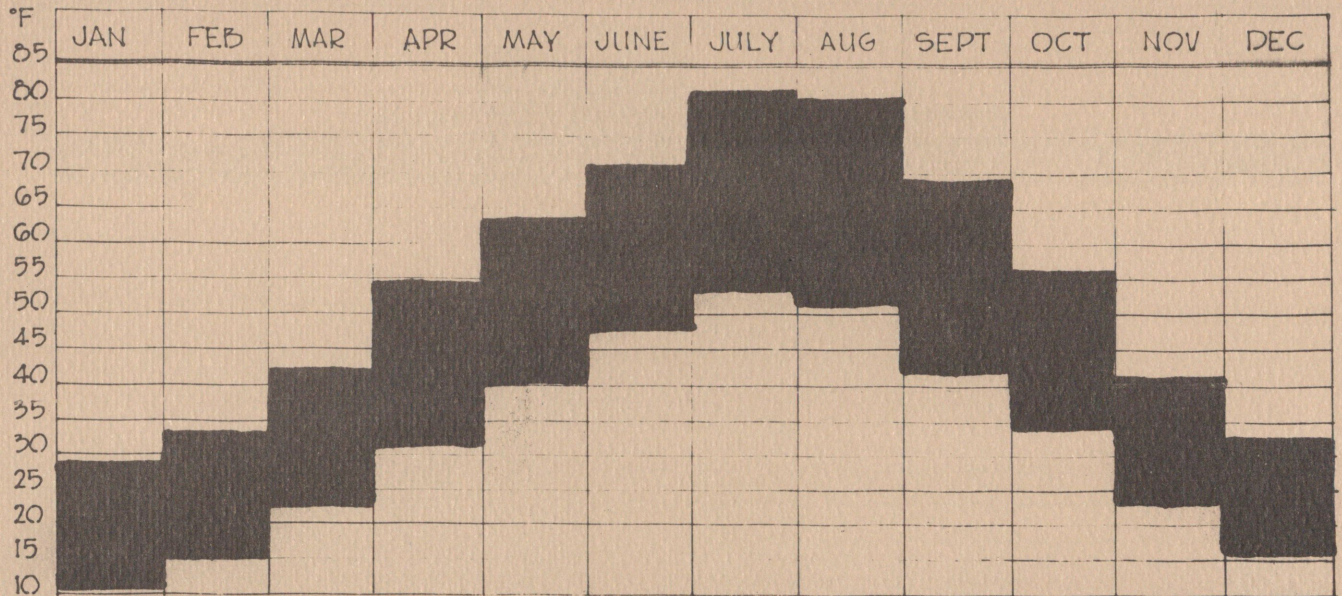
WIND



SITE
IMPACT

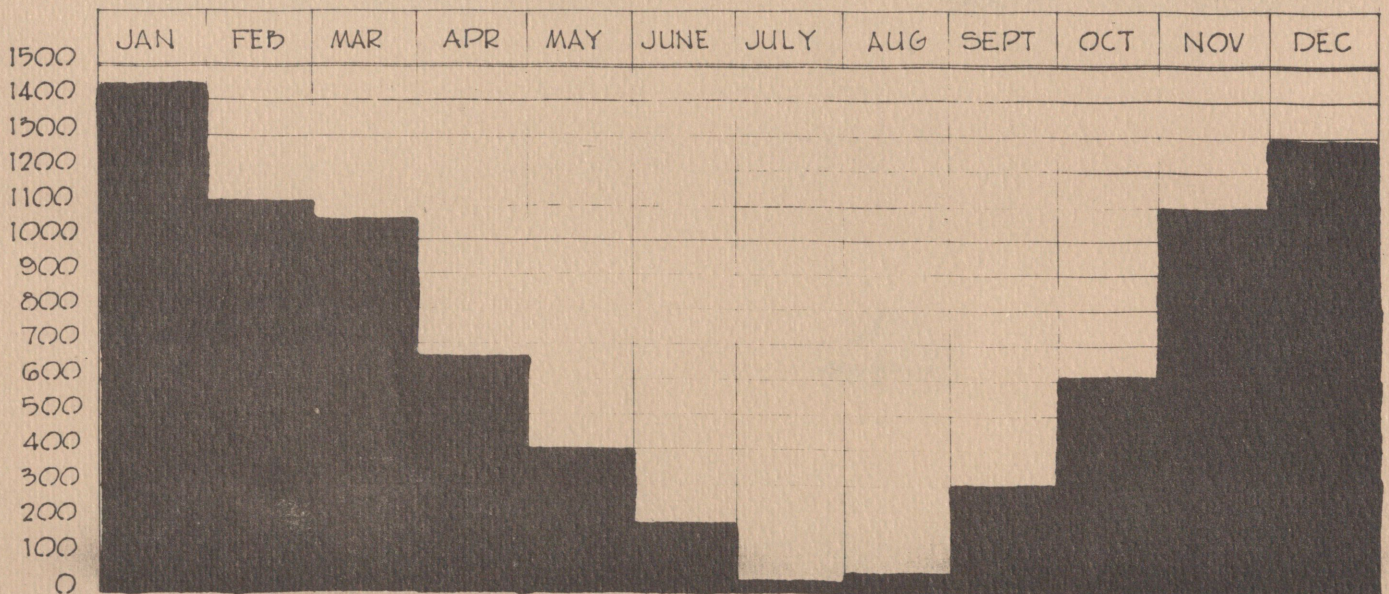


AVERAGE TEMPERATURE



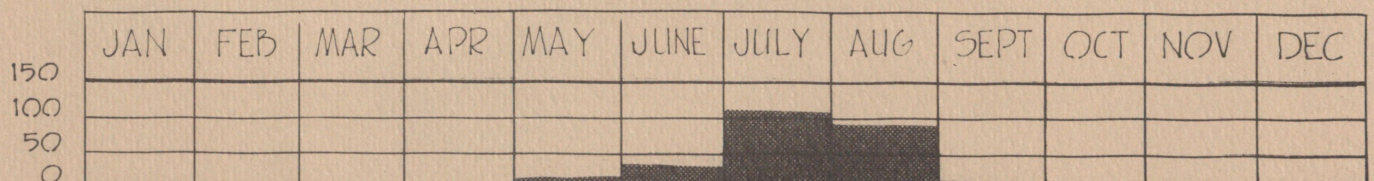
AVERAGE TEMPERATURE - YEAR 43.2°F

HEATING DEGREE DAYS



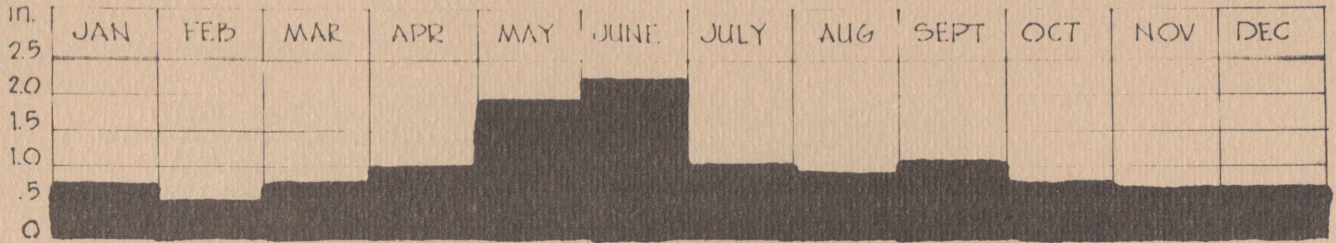
HEATING DEGREE DAYS - YEAR 8190

COOLING DEGREE DAYS



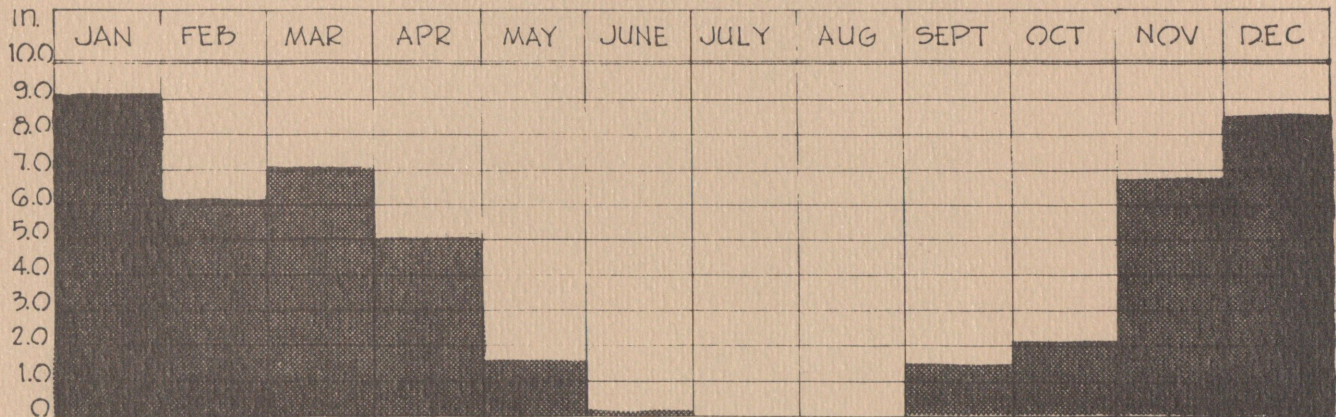
COOLING DEGREE DAYS - YEAR 263

PRECIPITATION



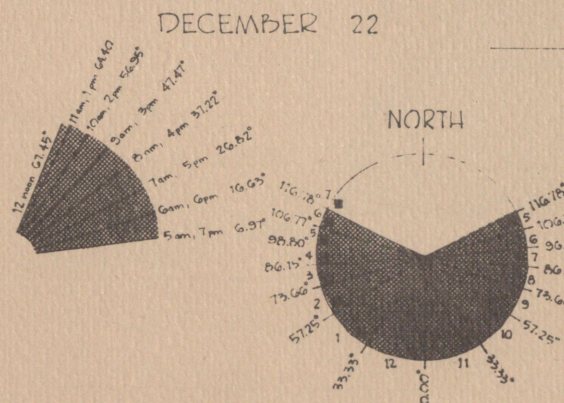
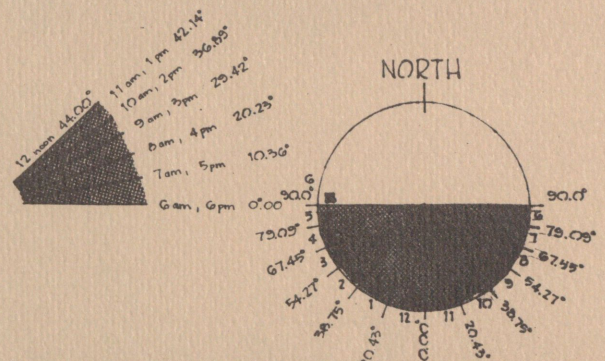
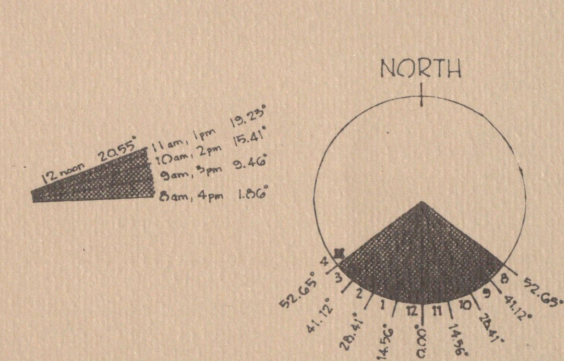
AVERAGE PRECIPITATION — YEAR 12.26

SNOWFALL



AVERAGE SNOWFALL — YEAR 48.5

SOLAR POSITION



HOURS OF SUNSHINE

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
NUMBER OF HR. SUNSHINE	138	168	215	241	292	292	342	336	258	202	137	121
% OF SUNSHINE	55.6	66.6	63.0	66.9	72.4	69.5	84.9	90.3	78.2	65.2	50.7	48.8

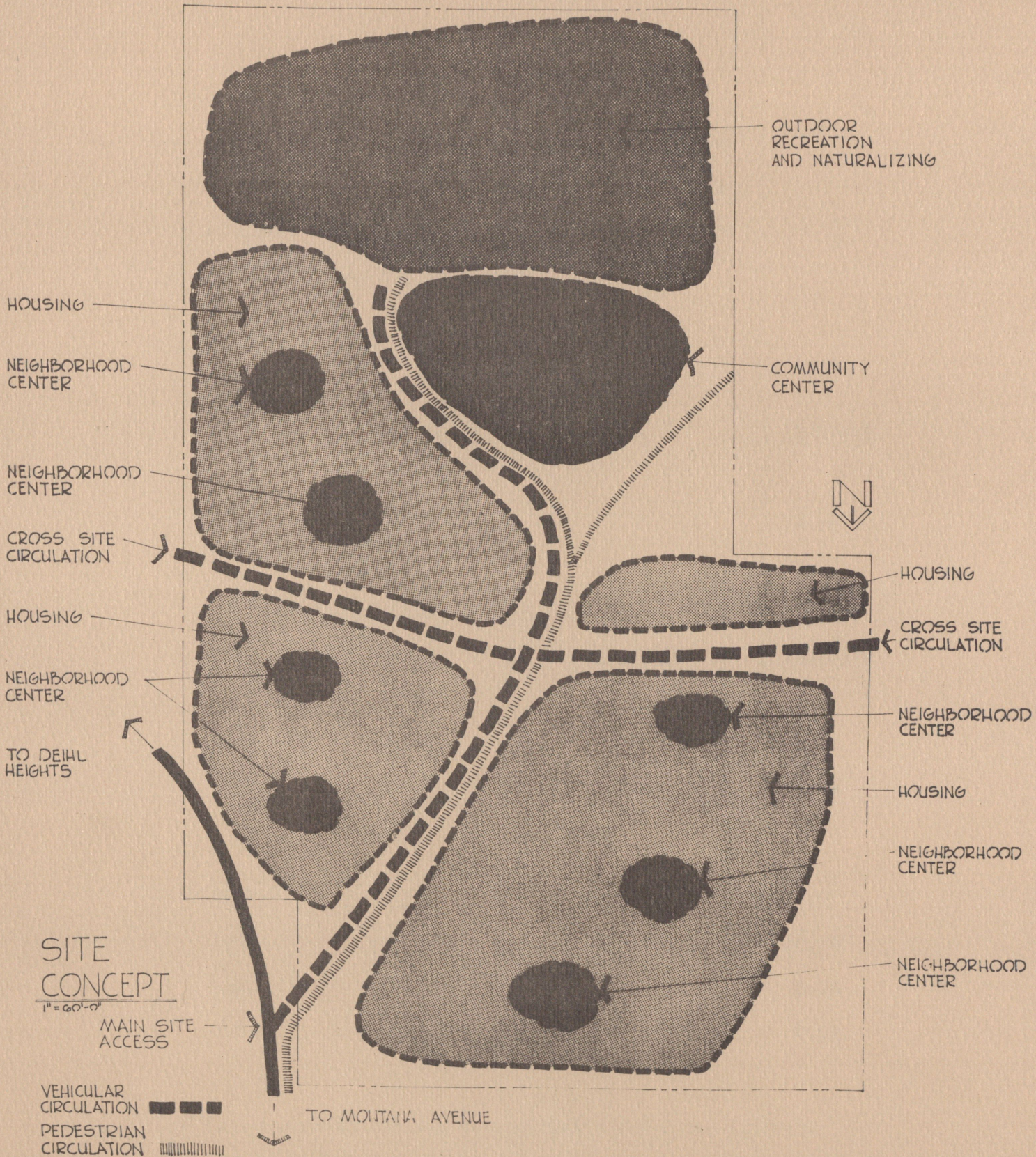
YEARLY NO. OF HOURS OF SUNSHINE 2,804
YEARLY AVERAGE % OF SUNSHINE 67.7%



SITE ANALYSIS

1" = 60'-0"

- VEGETATION SHADOW 
- 20% → SLOPE 
- DRAINAGE 
- 100% SUNSHINE 



HOUSING CONDITIONS IN HELENA, MONTANA

The city of Helena, Montana has a population of about 25,000 people. It's population is rapidly outgrowing the available housing and the population increase is growing faster than the housing growth.

AVAILABILITY OF HOUSING IN HELENA, MONTANA

POPULATION INCREASE

<u>YEAR</u>	<u>POPULATION</u>	<u>INCREASE</u>	<u>% INCREASE</u>
1960	20,227		
1970	22,730	2503	12.4%
1974	25,000	2270	10.0%

INCREASE IN NUMBER OF HOUSING UNITS

<u>YEAR</u>	<u>NUMBER</u>	<u>INCREASE</u>	<u>% INCREASE</u>
1960	7,667		
1970	8,048	451	5.8%
1974	8,650	748	9.2%

VACANCY RATIO FOR HELENA

<u>YEAR</u>	<u>OVERALL VACANCY RATIO</u>	<u>VACANT UNITS* FOR SALE</u>	<u>VACANT UNITS* FOR RENT</u>
1960	4.9%	1.1%	10.0%
1970	3.3%	1.4%	6.0%
1975	1.7%	0.5%	4.0%

* F.H.A. suggested minimum vacancy ratio for units for sale is 2.0% and minimum for units for rent is 5.0%.

FUTURE POPULATION GROWTH AND THE HOUSING SITUATION

POPULATION OF HELENA

<u>1970</u>	<u>1975</u>	<u>1980</u>	<u>1985</u>	<u>1990</u>	
22,730	26,100	30,500	35,800	42,100	TOTAL
	+3,370	+4,400	+5,300	+6,300	CHANGE

NUMBER OF NEW HOUSING UNITS NEEDED
TO ACCOMODATE POPULATION GROWTH

<u>YEAR</u>	<u>1970</u>	<u>1975</u>	<u>1980</u>	<u>1985</u>	<u>1990</u>
HOUSING UNITS NEEDED	8,037	9,135	10,675	12,530	14,735
NEW HOUSING UNITS NEEDED		+1,098	+1,540	+1,855	+2,205

The preceeding information on the housing conditions in
Helena, Montana was compiled with the help of the following
publications:

U.S. Census of population for 1960 and 1970

U.S. Census of housing for 1960 and 1970

R.L. Polk and Company, Profiles of change
for Helena, Montana

Lewis and Clark County classification and
appraisal data on housing, 1974

HOUSING PROGRAM

After studying the housing problems in Helena, Montana

I developed a housing program based on three main elements.

1. Housing
2. Neighborhood Center
3. Community Center

The housing was needed, the neighborhood because it is a rapidly dying element of our society and needs revitalization and the community center to give the project a sense of unity

HOUSING

TWO BEDROOM UNIT

- 2 Sleeping rooms
- 1½ Bath
- Food preparing area
- Eating area
- Group living area
- Air/lock (entry)
- Greenhouse
- Storage

HOUSING

THREE BEDROOM UNIT

3 Sleeping rooms
2 Baths
Food preparing area
Eating area
Group living areas
Air/lock (entry)
Greenhouse
Storage

NEIGHBORHOOD CENTER

FUNCTION

Laundry
Workspace
Mail place
Multi-purpose area
Janitor closet
Storage

COMMUNITY CENTER

GENERAL SPACE

Multi-purpose
Kitchen
Storage
Janitor

COMMUNITY CENTER

RECREATION

Gaming room
Exercise room
Sauna
Showers
Toilets
Dressing area
Equipment room
Storage

GREENHOUSE

Air/lock
Work space
Potting
Growing

ADMINISTRATION

Conference room
Office space
Storage

OUTDOOR FUNCTION

Parking
Swimming pool
Playground
Outdoor game courts
Automobile drop off and bus stop
Naturalizing areas
Bike paths

ACTIVE SOLAR ENERGY SYSTEMS

MULTI-COMPONENT SYSTEMS

COOL REGION



FLAT PLATE COLLECTOR (AIR)
FLAT PLATE COLLECTOR (FLUID)
LINE FOCUSING COLLECTOR
POINT FOCUSING COLLECTOR
PHOTOVOLTAIC COLLECTOR

RURAL
SUBURBAN



KEY

USEABLE
PARTIAL USE
LACK OF USE



MONOCOMPONENT SYSTEMS



FLUID MEDIUM
SOLID MEDIUM



PASSIVE SOLAR ENERGY DEVICES

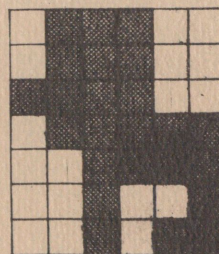
SITE AND BUILDING



LOCATION ANALYSIS
ORIENTATION ANALYSIS (SOLAR)
SHADOW ANALYSIS
VEGETATION (DECIDUOUS)
VEGETATION (CONIFEROUS)
VEGETATION (HEDGES)
VEGETATION (VINES)



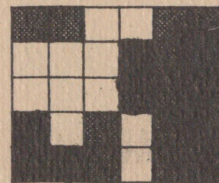
NORTH
SLOPED EAST & WEST
SLOPED EAST
SLOPED WEST
SLOPED EAST
SLOPED SOUTH
FLAT



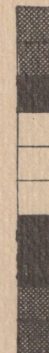
BUILDING (ROOF)



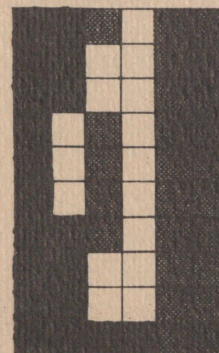
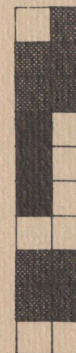
COLOR ANALYSIS
ECO ROOF
DOUBLE ROOF
TRANSLUCENT ROOF
RAINWATER COLLECTION (PONDING)



BUILDING (WALLS)



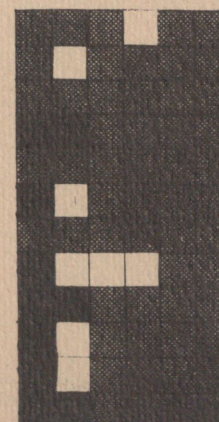
COLOR ANALYSIS
RERADIATION ANALYSIS
OVERHANG (UPPER STORY)
SUNSCREEN (LOUVERED-HORIZONTAL)
SUNSCREEN (LOUVERED-VERTICAL)
SUNSCREEN (EGG CRATE)
SUNSCREEN (GRILL)
AIRCOOLED
AIRHEATED
BEAD WALL



BUILDING (OPENINGS)



WINDOWS (ORIENTATION ANALYSIS)
WINDOWS (LOCATION ANALYSIS)
WINDOWS (SIZE ANALYSIS)
WINDOWS (CONFIGURATION ANALYSIS)
WINDOWS (TYPE ANALYSIS)
REMOVEABLE SUNSCREEN
CURTAIN / BLIND
SKYLIGHT
GREENHOUSE
SOLAR WINDOW (BAY)
SOLAR WINDOW (LOUVERED)
SOLAR WINDOW (TERRARIUM)



PASSIVE ENERGY CONSERVATION DEVICES

SITE AND BUILDING

COOL
REGION

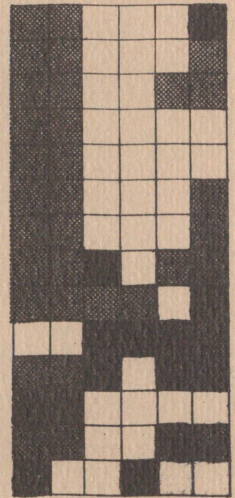


LOCATION ANALYSIS
ORIENTATION ANALYSIS
PROPORTION ANALYSIS
AERODYNAMIC ANALYSIS
VEGETATION (DECIDUOUS)
VEGETATION (CONIFEROUS)
VEGETATION (HEDGES)
EARTH BERM
CONSTRUCTION (RECESSED)
CONSTRUCTION (RAISED)
ENCLOSED COURTYARD
EXTERIOR LIVING SPACE
CLOSED FENCE
OPEN FENCE

RURAL
SUBURBAN



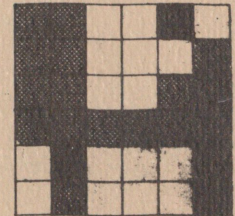
SLOPED NORTH
SLOPED EAST & WEST
SLOPED WEST
SLOPED EAST
SLOPED SOUTH
FLAT



BUILDING (ROOF)



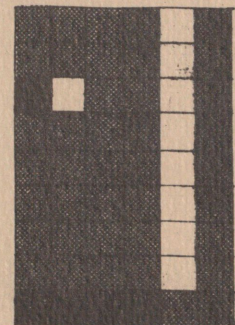
NORTH ECO-ROOF
ECO ROOF
DOUBLE ROOF
INSULATION
RAINWATER COLLECTION (STORAGE)
WIND POWERED VENTILATION



BUILDING (WALLS)



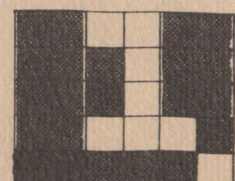
BUFFER (GARAGE)
BUFFER (STAIRWAY/ENTRY)
BUFFER (GREENHOUSE)
BUFFER (PORCH)
BUFFER (STORAGE)
BUFFER (CABINET)
INSULATION
VAPOR BARRIER
BEAD WALL



BUILDING (OPENINGS)



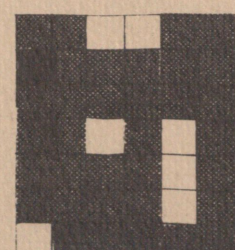
ENTRY LOCATION ANALYSIS
VESTIBULE
PORCH
SHUTTERS
CLEAR STORY



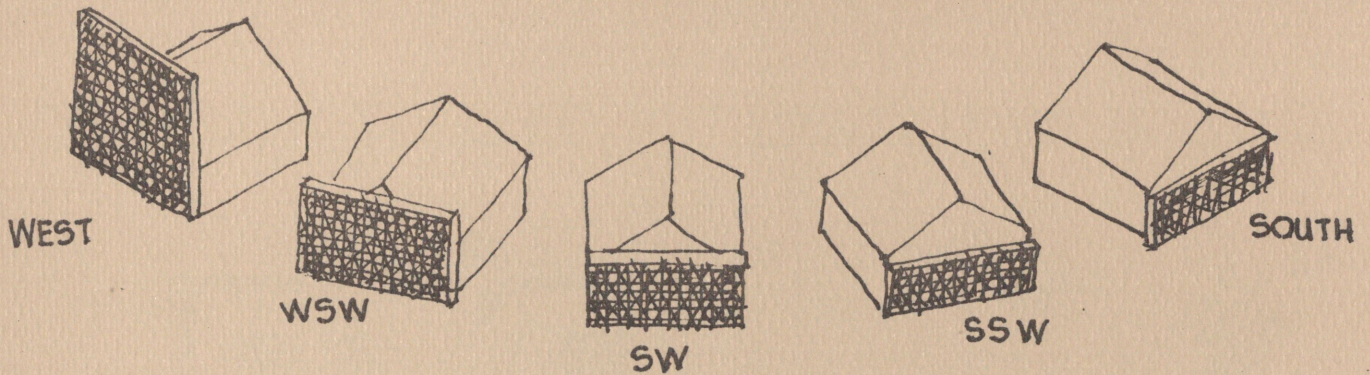
LIVING UNIT



SPATIAL ORGANIZATION ANALYSIS
CROSS VENTILATION ANALYSIS
MATERIAL ANALYSIS
CENTRAL KITCHEN
CENTRAL FIREPLACE
CENTRAL FIREPLACE (INTEGRAL DUCT)
CENTRAL STAIRWAY

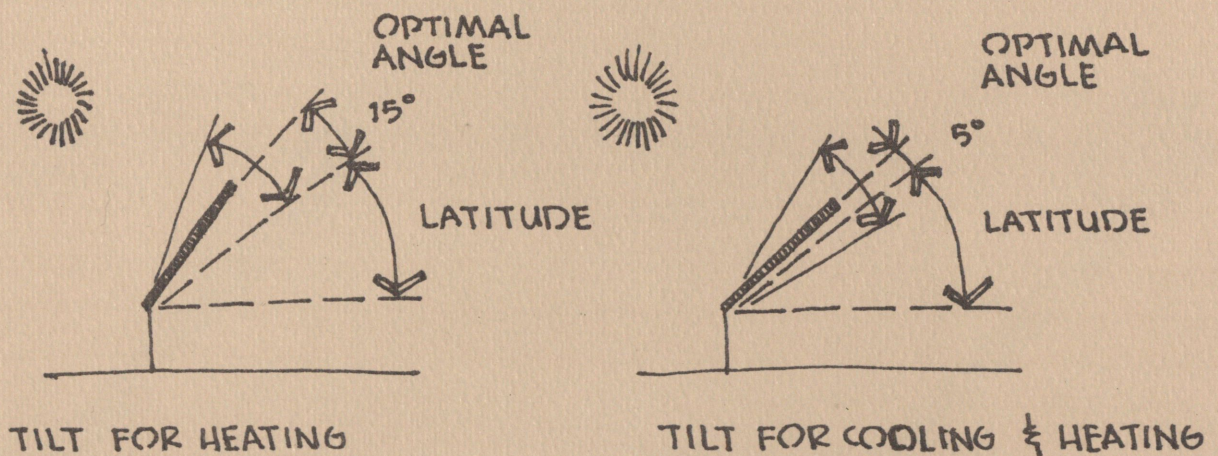


ORIENTATION OF VERTICAL COLLECTORS

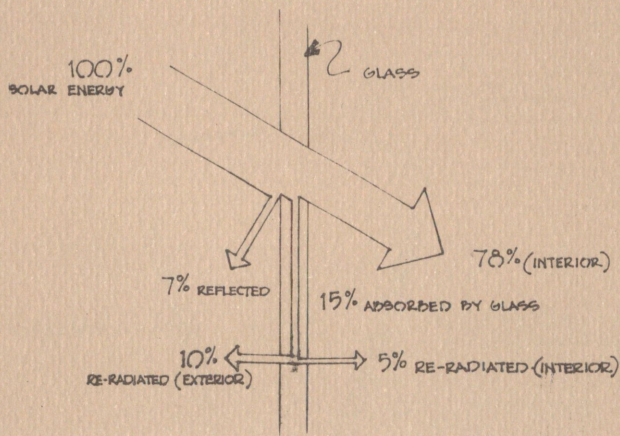


THE ABOVE DIAGRAM SHOWS HOW THE SIZE OF A VERTICAL COLLECTOR SUPPLYING 50% OF A DWELLING'S HEATING NEEDS MIGHT VARY FOR ORIENTATIONS FROM SOUTH TO WEST.

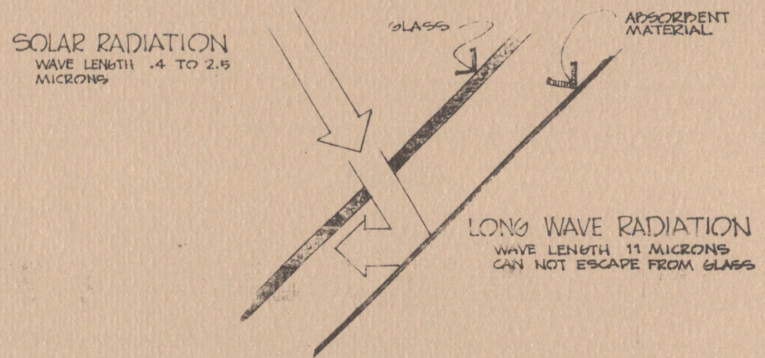
COLLECTOR TILT



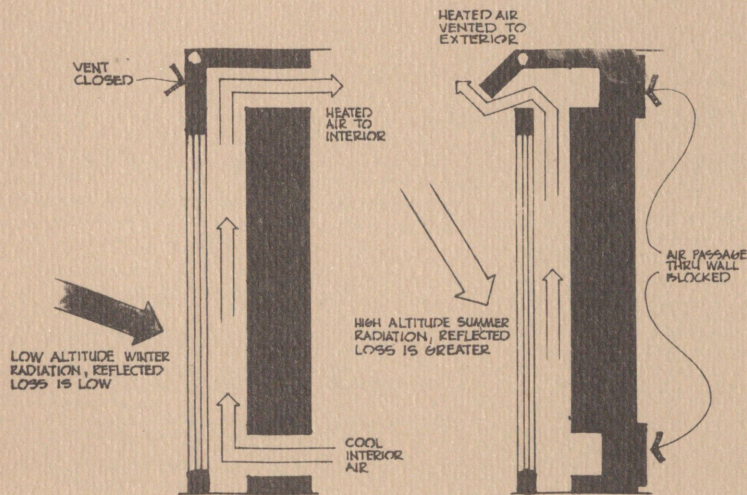
NOTE:
NO MAJOR CHANGE
WITHIN 30° ARC



SOLAR ENERGY THRU GLASS



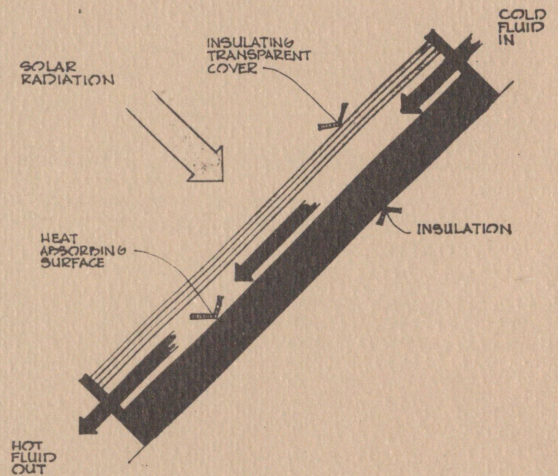
SOLAR ENERGY WAVELENGTH



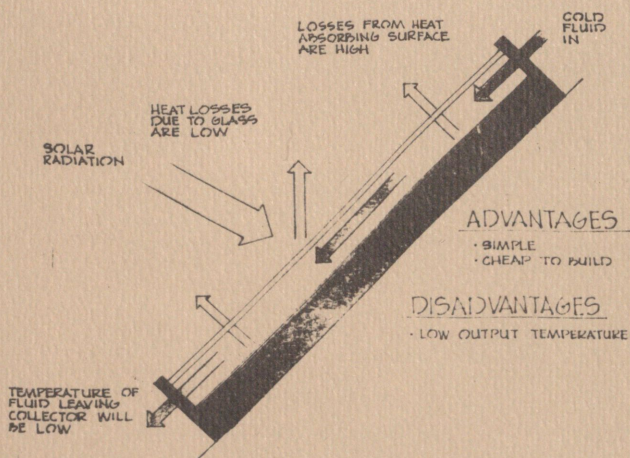
WINTER CYCLE

SUMMER CYCLE

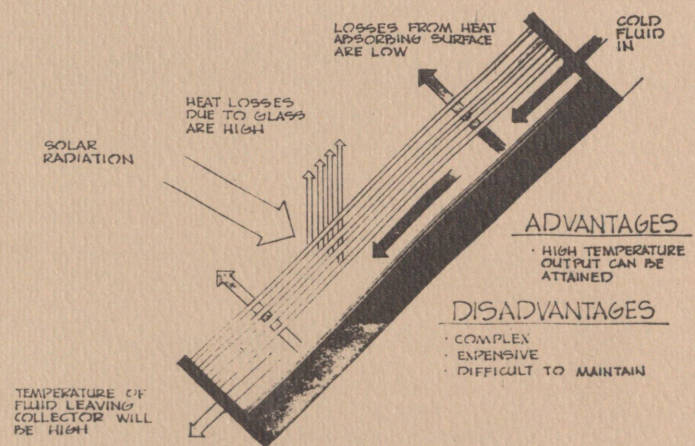
PASSIVE SOLAR COLLECTOR



ACTIVE SOLAR COLLECTOR

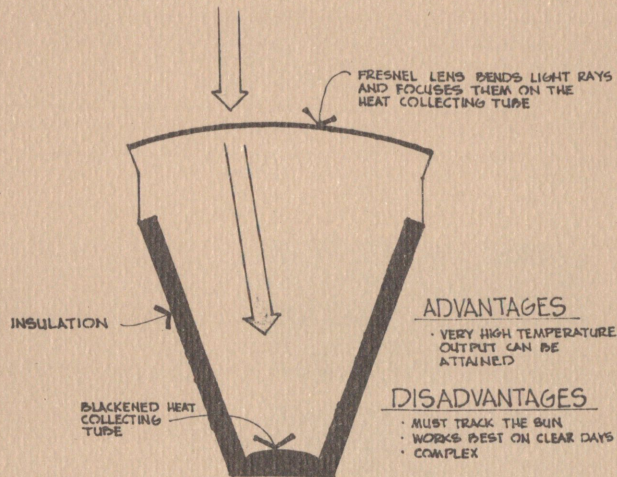


SINGLE GLASS COVER

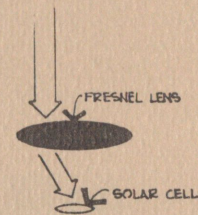


MULTIPLE GLASS COVERS

ACTIVE SOLAR COLLECTOR



CONCENTRATING COLLECTOR



SOLAR CELL

ENERGY STORAGE

TYPES OF STORAGE

1. STORE HEAT FROM SUMMER TO USE IN WINTER

ADVANTAGE

- COLLECT HEAT DURING MOST EFFICIENT PERIOD OF YEAR

DISADVANTAGE

- REQUIRES VERY LARGE AREA OF STORAGE
- EXPENSIVE

2. EXCESS HEAT STORED ON SUNNY DAYS TO USE ON OVERCAST DAYS

ADVANTAGE

- SMALLER STORAGE AREA REQUIRED
- HEAT IS USED SOONER SO LESS HEAT LOSS

DISADVANTAGE

- LIMITED STORAGE CAUSES INEFFICIENCY DURING PROLONGED CLOUDY PERIODS

3. HEAT STORED DURING THE DAY TO BE USED AT NIGHT

ADVANTAGE

- SMALL SHORT TERM STORAGE
- INEXPENSIVE

DISADVANTAGE

- INEFFICIENT DURING OVERCAST PERIODS

STORAGE CAPACITY OF MATERIALS

MATERIALS	SPECIFIC HEAT KCAL/KG/°C	DENSITY KG/M ³	UNIT HEAT CAPACITY		
			NO VOIDS	50% VOIDS	KCAL/M ³ /°C 40% VOIDS
WATER	1.0	1000	1000	(1000)	(1000)
SCRAP IRON	0.11	7840	881	909	828
MAGNETITE	0.17	5125	849	893	815
SCRAP ALUMINUM	0.22	2720	577	400	352
CONCRETE	0.27	2242	609	416	368
ROCK	0.21	2883	553	416	352
BRICK	0.20	2242	449	320	272

SALT STORAGE

ADVANTAGES

- VERY EFFICIENT ADSORPTION OF HEAT
- A SIMILAR AMOUNT OF HEAT IS REQUIRED

DISADVANTAGE

- LOSSES EFFICIENT WITH USE
- STRATIFICATION AND SEGREGATION OF THE WATER AND SALT
- CORROSION OF CONTAINERS

INSULATION REQUIREMENTS

F.H.A. "U" VALUE

CEILING	0.04
WALL	0.09
ROOF WITH EXPOSED STRUCTURE	0.09
WINDOW, DOOR	0.65
FLOOR	0.08

F.H.A. DESIGN

INFILTRATION AIR CHANGE/HR	1.0
HEAT GAIN BTU/HEATING SEASON	NONE

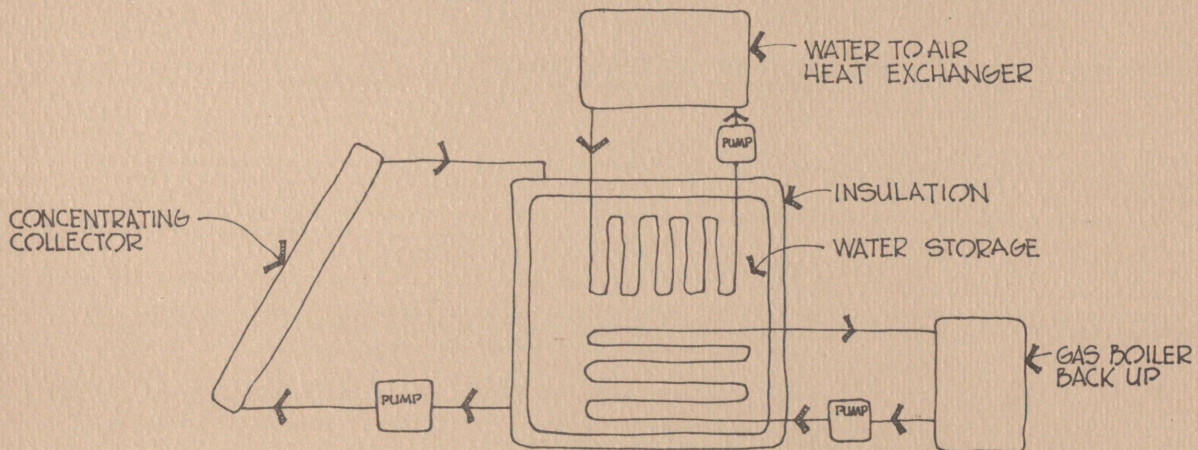
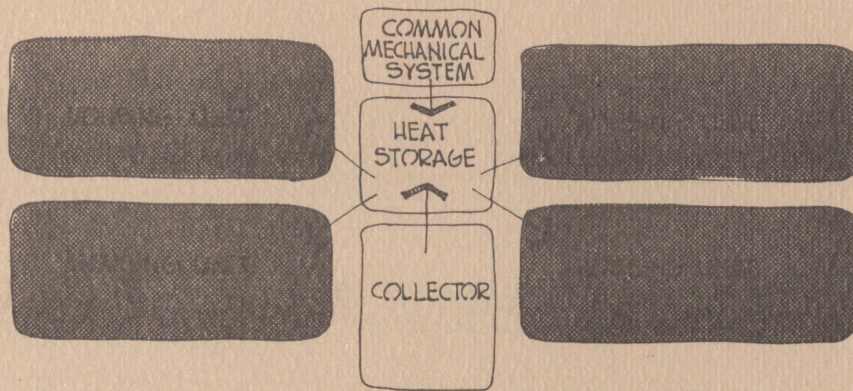
ENERGY CONSCIOUS "U" VALUE

0.035
0.05
0.035
0.35
0.055

ENERGY CONSCIOUS DESIGN

0.5
25% HEATING LOAD

SOLAR MECHANICAL SYSTEM CONCEPT



SIZING

COLLECTOR AND STORAGE WILL BE SIZED TO PROVIDE 3 DAYS HEATING REQUIREMENTS DURING THE COLDEST MONTH WHICH IS JANUARY. THIS WILL PROVIDE $\frac{1}{3}$ TO $\frac{1}{2}$ OF THE TOTAL ENERGY NEEDS DURING THE HEATING SEASON.

COLLECTOR

A CONCENTRATING COLLECTOR IS USED BECAUSE OF THE HIGH TEMPERATURE OUTPUT AND THE NEED FOR A FAST RECHARGE OF THE STORAGE SYSTEM DURING THE LESS SUNNY WINTER MONTHS.

STORAGE

A WATER/GLYCOL STORAGE SYSTEM IS USED AND IS INSULATED WITH POLYURETHANE TO REDUCE HEAT LOSS TO 10°F PER DAY.

ENERGY CONSERVATION CONCEPT

LOCATION ANALYSIS

POSITION THE BUILDING TO BEST CAPTURE THE AVAILABLE SOLAR ENERGY IN THE WINTER. AREAS OF 100% SUNSHINE FROM VEGETATION SHADOW ANALYSIS.

ORIENTATION ANALYSIS

ORIENT BUILDING TO MAXIMIZE SOLAR COLLECTION BY BOTH ACTIVE AND PASSIVE DEVICES. (20° EAST OR WEST OF SOUTH)

PROPORTION ANALYSIS

EASTERN EXPOSURES DIRECTLY RECEIVE THE LOW INTENSITY MORNING SUN WHICH WARMS THE BUILDING FROM THE PREVIOUS NIGHT. THE SOLAR ENERGY IS MOSTLY ABSORBED IN THE BUILDING MATERIALS. IN THE AFTERNOON, THE ROOF AND SOUTHERN EXPOSURES ARE FURTHER HEATED BY THE SUN. SOLAR INTENSITY IS AT ITS MAXIMUM OVER THE AFTERNOON, AND THE BUILDING MATERIALS ACHIEVE THEIR MAXIMUM TEMPERATURE LATE IN THE AFTERNOON. THE HEAT TRANSFERRED TO THE BUILDING MATERIALS BEGINS TO TRAVEL THROUGH THE BUILDING MATERIALS REACHING THE INTERIOR SPACES. THE HEAT CONTAINED IN THESE WALLS CONTINUES TO HEAT THE INTERIOR SPACES INTO THE NIGHT. IN ORDER TO MAXIMIZE SOLAR HEAT GAINS, THE EXPOSED AREAS SHOULD BE CONSIDERABLY LARGER THAN THE SUNLESS EXPOSURES, AND THE BUILDING SHOULD BE COMPACT IN NATURE TO REDUCE THE HEAT LOSS.

SHADOW ANALYSIS

VERTICAL LOUVERS FOR EAST AND WEST EXPOSURES ARE AN EFFECTIVE MEANS OF PROVIDING SUN PROTECTION IN THE MORNING AND EVENING WHEN THE ALTITUDE OF THE SUN IS LOW. OVERHANGS OR HORIZONTAL LOUVERS ARE DESIRABLE FOR SOUTHERN EXPOSURES. IT IS IMPORTANT THAT THE SHADING DEVICES DO NOT INTERFERE WITH THE WINTER SUN PENETRATION INTO THE INTERIOR SPACES.

VEGETATION (DECIDUOUS)

DECIDUOUS VEGETATION IN THE FORM OF TREES IS ADVANTAGEOUS IN PROVIDING SUMMER SHADING. IN THE SUMMER, THEY REDUCE THE OUTSIDE AIR TEMPERATURE IN THE SHADED AREA BY EVAPORATION OF THE MOISTURE FROM THE LEAVES. IN THE WINTER, DECIDUOUS VEGETATION LOSE THEIR LEAVES, ALLOWING WINTER SUN TO PENETRATE TO THE BUILDING

VEGETATION (CONIFEROUS)

CONIFEROUS VEGETATION REMAINS GREEN THROUGHOUT THE YEAR AND THE BENEFITS OF WINTER SUN PENETRATION THROUGH TO THE BUILDING ARE LOST. BUT IT CAN BE USED AS A WINTER WIND SCREENING DEVICE.

COLOR ANALYSIS

DARK COLORS ABSORB MOST OF THE SOLAR ENERGY AND EMIT VERY LITTLE WHILE LIGHT COLORS REFLECT MOST OF THE SOLAR ENERGY AND EMIT MOST OF THAT WHICH IS ABSORBED. DARK COLORED SHADED WALL SURFACES WITH LIGHT COLORED SHADING DEVICES WORK WELL. IN THE SUMMER, MOST OF THE SOLAR ENERGY IS REFLECTED BY LIGHT COLORED SHADING DEVICES. IN THE WINTER, DARK COLORED WALL SURFACES ABSORB MOST OF THE SOLAR ENERGY, WHEN LIGHT IS ALLOWED TO PASS BEYOND THE SHADING DEVICE.

ECO ROOF

A LANDSCAPED SOIL ROOF, LAYERED OVER THE EXISTING ROOF, PROVIDES EXTRA INSULATION FROM THE SUN IN THE FORM OF A THICKER ROOF THAT IS SHAPED BY THE VEGETATION. THE SOIL ACTS AS A DENSE MASS OF HEAT ABSORBING MATERIAL TO INHIBIT AND DELAY HEAT TRANSFER TO THE INTERIOR SPACES.

SUNSCREEN (OVERHANG & LOUVERED HORIZONTAL)

HORIZONTAL OVERHANGS ARE EFFECTIVE SUN CONTROL DEVICES FOR SOUTHERN EXPOSURES WHERE THE SOLAR ALTITUDE IS GREAT. HORIZONTAL LOUVERS ARE MORE EFFECTIVE SHADING DEVICES THAN A SINGLE LARGE OVERHANG BECAUSE THEY PROVIDE MORE LOCALIZED COVERAGE. ADJUSTABLE HORIZONTAL LOUVERS BECOME MORE EFFICIENT.

WINDOWS (TYPE ANALYSIS)

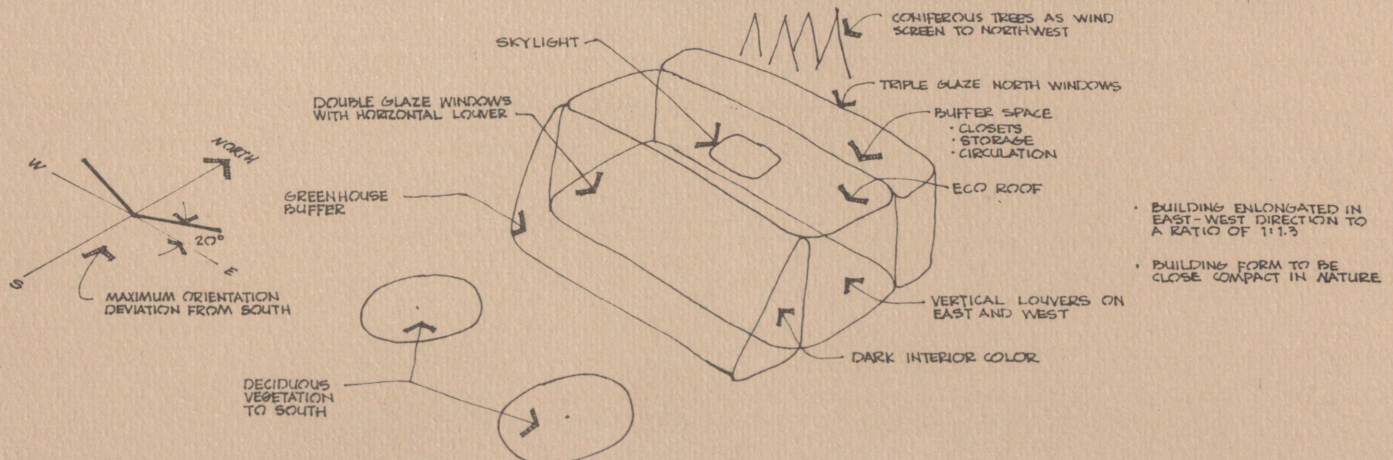
DOUBLE GLAZING SHOULD BE USED ON ALL WINDOW TYPES AND NORTHERN WINDOWS SHOULD BE TRIPLE GLAZED.

SKYLIGHT

SKYLIGHTS ARE USEFUL DEVICES TO BRING SUNLIGHT INTO THE INTERIOR SPACES. INSULATED INTERNAL LOUVERS ARE USED TO INSURE AGAINST HEAT LOSS DURING THE NIGHT. THESE LOUVERS ALSO CONTROL THE AMOUNT AND DIRECTION OF THE INCOMING SUNLIGHT. SKYLIGHTS CAN ALSO BE USED TO VENT HOT AIR FROM THE BUILDING DURING THE SUMMER.

GREENHOUSE

A GREENHOUSE ATTACHED TO THE SOUTHERN EXPOSURE PROVIDES A BUFFER SPACE. THE SOUTHERN EXPOSURE BEHIND THE GREENHOUSE IS HEATED BY THE SUN DURING THE DAY WHICH REDUCES HEAT LOSS IN THE WINTER AND DECREASES HEAT GAIN IN THE SUMMER WHEN THE GREENHOUSE IS VENTED. THE USE OF A BEAD WALL SYSTEM FOR THE GREENHOUSE WILL HELP MINIMIZE WINTER HEAT LOSS FOR BOTH THE GREENHOUSE AND THE HOUSE, AT NIGHT, WHEN THE BEADS ARE IN PLACE.



THE PROJECT

HEAT LOSS ANALYSIS

HEAT LOSS IN DWELLINGS

A dwelling is a living space climatically detached from the outdoors. Heat loss reflects the amount of separation. Energy conscious design minimizes the amount of heat loss and therefore the energy requirements for heating. Heat always travels from a greater temperature to a lesser temperature.

There are three mechanisms of heat transfer: conduction, convection, and radiation. An additional energy loss occurs during the exchange of interior air with the exterior air either through ventilation or infiltration.

CONDUCTION

Conduction is the direct transfer of energy by molecular interaction. This energy transfer results in a very large scale energy flow from the higher temperature area to the lower temperature area. To stop this heat loss due to conduction an insulator is used. An insulator is a material with a low k value.

Conduction heat loss also depends on two other factors, these are the area and the thickness of the material. Heat loss is directly proportional to the area of material and indirectly proportional to the thickness of the material.

Heat loss due to conduction can be calculated by the following formula:

$$q_c = A \frac{k}{t} (T_1 - T_0) = A \frac{k}{t} \Delta T$$

where

q_c equals the rate of heat transfer by conduction
(BTU/hr)

A equals the area (ft²)

k equals the thermal conductivity (BTU-in/hr-ft²-°F)

t equals the thickness (in)

T_1, T_0 equal the inside and outside temperature (°F)

CONVECTION

Convection heat losses occur when heat is transferred through fluids or gases in contact with solid surfaces. the rate of heat loss due to convection is directly proportional to the temperature difference of the fluid or gas and the adjacent solid surface; the heat transfer area; and a convective (film) coefficient which describes the specific properties of the fluid or gas. Thus the convection heat loss can be determined using the following formula:

$$q_{cv} = A f (T_s - T_f)$$

where

q_{cv} equals the heat loss due to convection (BTU/hr)

T_f, T_s equals the fluid and surface temperature ($^{\circ}\text{F}$)

f equals the convective or film coefficient

($\text{BTU}/\text{ft}^2\text{-hr-}^{\circ}\text{F}$)

A equals the area (ft^2)

The direction of heat transfer is determined by the relative size of T_f and T_s .

RADIATION

Radiation is the loss of heat due to electromagnetic waves. Losses due to radiation are difficult to calculate and the best method of deterring this heat loss is by placing a reflective material such as aluminum foil between the warm interior surface and the cooler exterior.

AIR EXCHANGE

Heat loss also occurs when warm interior air is exchanged with cooler exterior air. This happens by two methods: infiltration and ventilation.

Infiltration is the result of the unintentional loss of air through cracks in the building around windows and doors and due to poor construction techniques.

Ventilation is the intentional exchange of air to rid the structure of odors and stuffiness. In order to bring

in fresh air, warm air must be expelled from the structure and cool air is brought into the structure.

Heat loss due to infiltration can be calculated by using the following formula:

$$H = 0.018(T_i - T_o)nV$$

where

H equals the heat loss due to infiltration
(BTU/hr)

n equals the number of air changes per hour

V equals the volume of the building (ft³)

T_i, T_o equals the inside and outside temperature (°F)

0.018 is a factor combining the density and
heat capacity of air

For a normal residence n equals one air change per hour.

Crack estimation can be preformed in place of n using figures taken from the ASHRAE Handbook of Fundamentals.

The formula then becomes:

$$H = 0.018(T_i - T_o)IL$$

where

I equals the tabulated cubic feet/hr of leakage
per ft of crack (ft³/hr-ft)

L equals the linear ft of crack (ft)

HEAT LOSS THROUGH A GIVEN WALL SECTION

Heat loss through a given wall section can be calculated by using the following formula:

$$q = UA (\Delta T)$$

where

q equals the total heat loss (BTU/hr)

U equals the overall coefficient of transmittance

A equals the area (ft²)

ΔT equals (T₁-T₀) overall

Heat loss for the total building can then be calculated.

SEASONAL HEATING REQUIREMENTS

Seasonal heating requirements can be calculated by using the following formula:

$$S = 24Q(\text{Degree Days})$$

where

S equals the season heating requirement (BTU)

Q equals the total heat loss per degree of

temperature difference for a dwelling (BTU/hr-°F)

24 equals the number of hours in a day

A Degree Day happens for every degree the outside temperature is below 65°F during a 24 hour period.

Q is defined as follows:

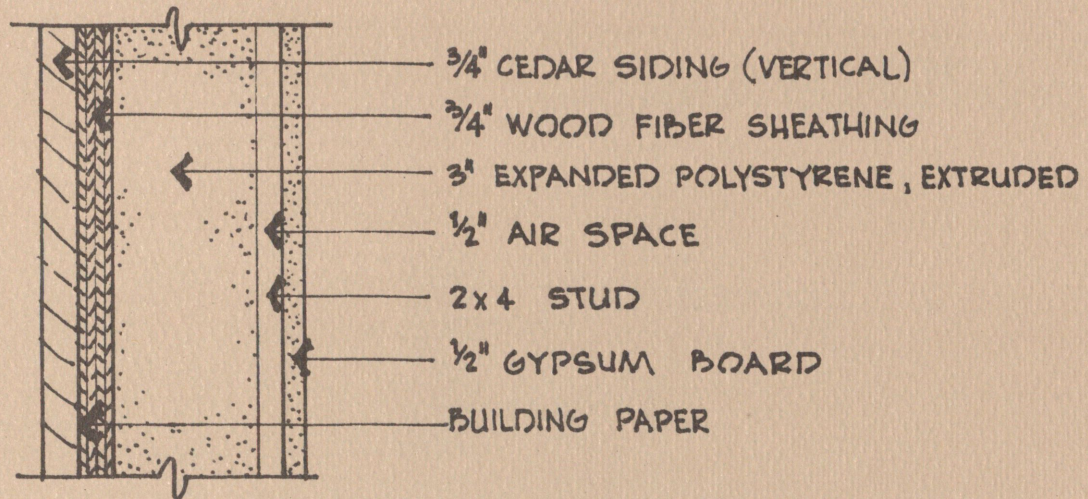
$$Q = \frac{\text{Total Heating Load}}{T_1 - T_0}$$

where

T_1 is the inside design temperature (°F)

T_0 is the outside design temperature (°F)

HEAT LOSS CALCULATIONS



TYPICAL WALL SECTION 3"=1'-0"

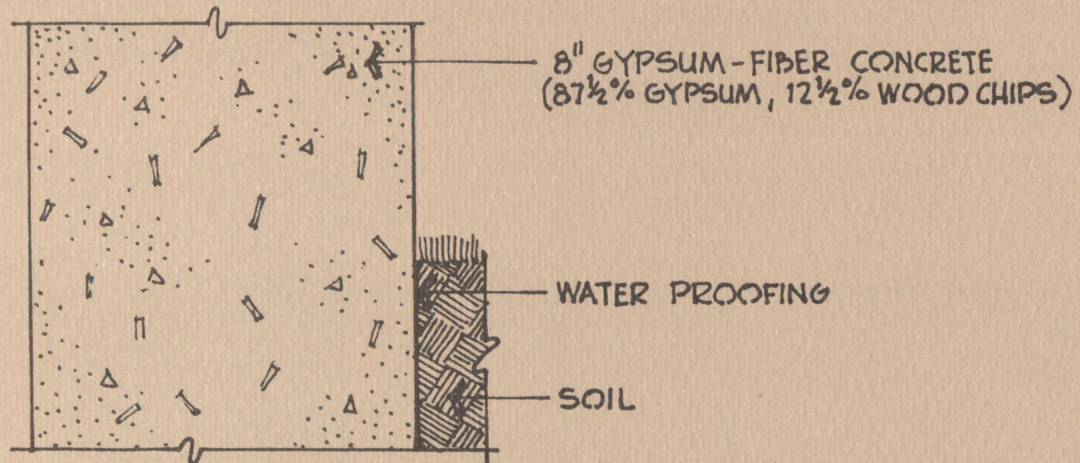
<u>MATERIAL</u>	<u>"R" VALUE</u>
3/4" Cedar wood siding (Vertical, T&G)	0.94
Building paper	0.06
3/4" Wood fiber sheathing	2.06
3" Expanded polystyrene (Extruded)	15.78
1/2" Air space	0.87
1/2" Gypsum board	<u>0.45</u>
Total "R"	20.18

"U" Value

Since the "U" value is equal to $\frac{1}{R}$ then:

$$U = \frac{1}{20.18} = 0.0496$$

HEAT LOSS CALCULATIONS



FOUNDATION WALL SECTION 3"-1'-0"

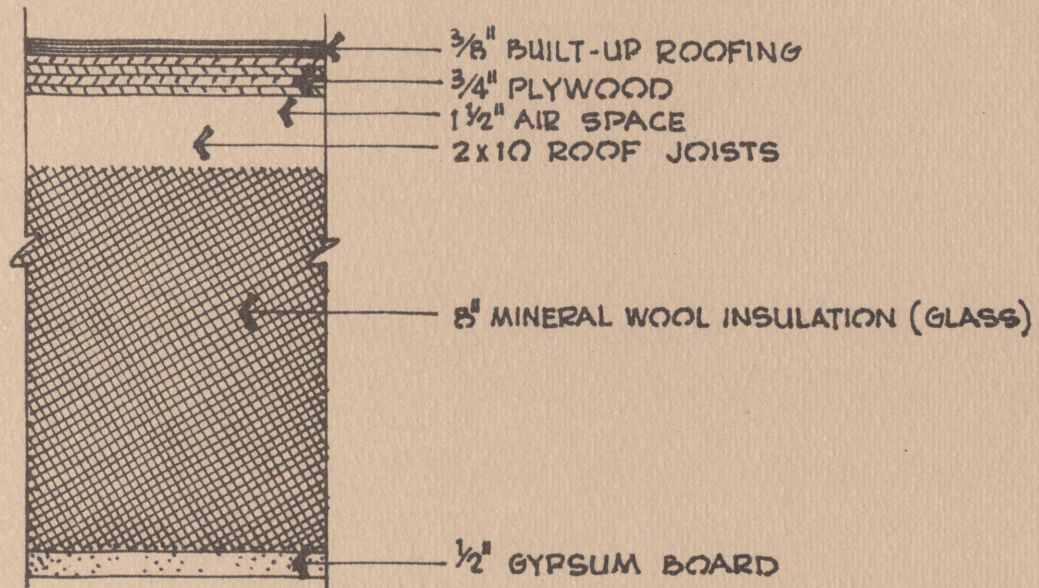
<u>MATERIAL</u>	<u>"R" VALUE</u>
8" Gypsum-fiber concrete	4.80
Water proofing	<u>0.06</u>
Total "R"	4.86

"U" Value

Since the "U" value is equal to $\frac{1}{R}$ then:

$$U = \frac{1}{4.86} = 0.2057$$

HEAT LOSS CALCULATIONS



TYPICAL ROOF SECTION 3"=1'-0"

<u>MATERIAL</u>	<u>"R" VALUE</u>
$\frac{3}{8}$ " Built-up roofing	0.33
$\frac{3}{4}$ " Plywood	0.94
$1\frac{1}{2}$ " Air space	0.87
8" Mineral wool insulation (Glass)	29.60
$\frac{1}{2}$ " Gypsum board	<u>0.45</u>
Total "R"	32.11

"U" Value

Since the "U" value is equal to $\frac{1}{R}$ then:

$$U = \frac{1}{32.11} = 0.0319$$

HEAT LOSS CALCULATIONS

TWO BEDROOM EXTERIOR UNIT

<u>LOCATION</u>		<u>AREA (SQ.FT.)</u>	<u>"U" VALUE</u>	<u>HEAT LOSS (BTU/hr-°F)</u>
Lower floor				
Walls		810	0.0496	40.2
Windows	Double glass	168	0.581	97.6
	Triple glass	24	0.359	8.6
Upper floor				
Walls		741	0.0496	36.8
Windows	Double glass	133	0.581	77.2
	Triple glass	40	0.359	14.4
Roof				
Living room area		202	0.0319	6.4
Upper roof area		768	0.0318	24.4
Doors				
2-3'-0"x6'-8"x14 ³ / ₄ "		20	0.24	4.8
Foundation walls				
Exterior only		194	0.2057	<u>39.9</u>
	Sub total			350.9 BTU/hr-°F

HEAT LOSS PER HOUR

$$\text{Design temperature} = 65^{\circ}\text{F} - 31.1^{\circ}\text{F} = 33.9^{\circ}\text{F}$$

$$\text{Heat loss per hour} = (350.3 \text{ BTU/hr-}^{\circ}\text{F}) \times (33.9^{\circ}\text{F})$$

$$= 11,875.17 \text{ BTU/hr}$$

HEAT LOSS CALCULATIONS

TWO BEDROOM EXTERIOR UNIT

INFILTRATION HEAT LOSS

Wind mean speed = 7.1 mph use 10 mph

Average loss/ft window crack 6 ft³/hr-ft

Average loss/ft door crack 69 ft³/hr-ft

INFILTRATION HEAT LOSS (WINDOWS)

$$H = 0.018(T_i - T_o)IL$$

$$H = 0.018(70 - 31.1)(80)(6\text{ft}^3/\text{hr-ft})$$

$$H = 292.9 \text{ BTU/hr}$$

INFILTRATION HEAT LOSS (DOORS)

$$H = 0.018(T_i - T_o)IL$$

$$H = 0.018(70 - 31.1)(20)(69\text{ft}^3/\text{hr-ft})$$

$$H = 842.0 \text{ BTU/hr}$$

INFILTRATION HEAT LOSS (TOTAL)

Window loss + Door loss = Total loss

$$292.9 \text{ BTU/hr} + 842.0 \text{ BTU/hr} = 1134.9 \text{ BTU/hr}$$

TOTAL HEAT LOSS (TWO BEDROOM EXTERIOR UNIT)

Unit heat loss/hr + Infiltration heat loss/hr = Total heat loss

$$11,875.17 \text{ BTU/hr} + 1134.9 \text{ BTU/hr} = \underline{13,010.1 \text{ BTU/hr}}$$

COMPARISON HEAT LOSS CALCULATIONS (FHA RECOMMENDATIONS)

TWO BEDROOM EXTERIOR UNIT

<u>LOCATION</u>	<u>AREA (SQ.FT.)</u>	<u>"U" VALUE</u>	<u>HEAT LOSS (BTU/hr-°F)</u>
Lower floor			
Walls	810	0.09	72.9
Windows	192	0.65	124.8
Upper floor			
Walls	741	0.09	66.7
Windows	173	0.65	112.5
Roof			
Living room area	202	0.09	18.1
Upper roof area	768	0.09	69.1
Doors			
2-3'-0"x6'-8"x1 $\frac{3}{4}$ "	20	0.65	13.0
Foundation walls			
Exterior only	194	0.3	<u>58.2</u>
	Sub total		535.3 BTU/hr-°F

HEAT LOSS PER HOUR

$$\text{Design temperature} = 65^{\circ}\text{F} - 31.1^{\circ}\text{F} = 33.9^{\circ}\text{F}$$

$$\text{Heat loss per hour} = (535.3 \text{ BTU/hr-}^{\circ}\text{F}) \times (33.9^{\circ}\text{F})$$

$$= 18,146.7 \text{ BTU/hr}$$

INFILTRATION HEAT LOSS

The infiltration heat loss recommended by FHA is equal to one air change per hour. The energy conscious air change is equal to one half air change per hour. The calculated FHA infiltration values are therefore twice the energy conscious values.

INFILTRATION HEAT LOSS (TOTAL)

$$1134.9 \text{ BTU/hr} \times 2 = 2269.8 \text{ BTU/hr}$$

TOTAL HEAT LOSS (TWO BEDROOM EXTERIOR UNIT)

Unit heat loss/hr + Infiltration heat loss/hr = Total heat loss

$$18,146.7 \text{ BTU/hr} + 2269.8 \text{ BTU/hr} = \underline{20,416.5 \text{ BTU/hr}}$$

HEAT LOSS COMPARISON

Total heat loss in the energy conscious two bedroom exterior unit is equal to 13,010.1 BTU/hr.

Total heat loss in the FHA recommended insulation value two bedroom exterior unit is equal to 20,416.5 BTU/hr.

This increased heat saving through the increased insulation value represents a 56% energy savings.

HEAT LOSS CALCULATIONS

THREE BEDROOM EXTERIOR UNIT

<u>LOCATION</u>	<u>AREA (SQ.FT.)</u>	<u>"U" VALUE</u>	<u>HEAT LOSS (BTU/hr-°F)</u>	
Lower floor				
Walls	873	0.0496	43.3	
Windows	Double glass	224	0.581	130.1
	Triple glass	32	0.359	11.5
Upper floor				
Walls	840	0.0496	41.7	
Windows	Double glass	196	0.581	113.9
	Triple glass	36	0.359	12.9
Roof				
Living room area	198	0.0319	6.31	
Upper roof area	1064	0.0318	33.8	
Doors				
2-3'-0"x6'-8"x1 $\frac{3}{4}$ "	20	0.24	4.8	
Foundation walls				
Exterior only	208	0.2057	<u>42.8</u>	
	Sub total		441.1 BTU/hr-°F	

HEAT LOSS PER HOUR

$$\text{Design temperature} = 65^{\circ}\text{F} - 31.1^{\circ}\text{F} = 33.9^{\circ}\text{F}$$

$$\text{Heat loss per hour} = (441.1 \text{ BTU/hr-}^{\circ}\text{F}) \times (33.9^{\circ}\text{F})$$

$$= 14,953.3 \text{ BTU/hr}$$

HEAT LOSS CALCULATIONS

THREE BEDROOM EXTERIOR UNIT

INFILTRATION HEAT LOSS

Wind mean speed = 7.1 mph use 10 mph

Average loss/ft window crack 6 ft³/hr-ft

Average loss/ft door crack 69 ft³/hr-ft

INFILTRATION HEAT LOSS (WINDOWS)

$$H = 0.018(T_1 - T_o)IL$$

$$H = 0.018(70 - 31.1)(80)(6 \text{ ft}^3/\text{hr-ft})$$

$$H = 366.1 \text{ BTU/hr}$$

INFILTRATION HEAT LOSS (DOORS)

$$H = 0.018(T_1 - T_o)IL$$

$$H = 0.018(70 - 31.1)(20)(69 \text{ ft}^3/\text{hr-ft})$$

$$H = 842.0 \text{ BTU/hr}$$

INFILTRATION HEAT LOSS (TOTAL)

Window loss + Door loss = Total loss

$$366.1 \text{ BTU/hr} + 842.0 \text{ BTU/hr} = 1208.1 \text{ BTU/hr}$$

TOTAL HEAT LOSS (THREE BEDROOM EXTERIOR UNIT)

Unit heat loss/hr + Infiltration heat loss/hr = Total heat loss

$$14,953.3 \text{ BTU/hr} + 1208.1 \text{ BTU/hr} = \underline{16161.4 \text{ BTU/hr}}$$

COMPARISON HEAT LOSS CALCULATIONS (FHA RECOMMENDATIONS)

THREE BEDROOM EXTERIOR UNIT

<u>LOCATION</u>	<u>AREA (SQ.FT.)</u>	<u>"U" VALUE</u>	<u>HEAT LOSS (BTU/hr-°F)</u>
Lower floor			
Walls	873	0.09	78.6
Windows	256	0.65	166.4
Upper floor			
Walls	840	0.09	75.6
Windows	232	0.65	150.8
Roof			
Living room area	198	0.09	17.8
Upper roof area	1064	0.09	95.7
Doors			
2-3'-0"x6'-8"x1 $\frac{3}{4}$ "	20	0.65	13.0
Foundation walls			
Exterior only	208	0.3	<u>62.4</u>
Sub total			660.3

HEAT LOSS PER HOUR

$$\text{Design temperature} = 65^{\circ}\text{F} - 31.1^{\circ}\text{F} = 33.9^{\circ}\text{F}$$

$$\text{Heat loss per hour} = (660.3 \text{ BTU/hr-}^{\circ}\text{F}) \times (33.9^{\circ}\text{F})$$

$$= 22,440 \text{ BTU/hr}$$

INFILTRATION HEAT LOSS

The infiltration heat loss recommended by FHA is equal to one air change per hour. The energy conscious air change is equal to one half air change per hour. The calculated FHA infiltration values are therefore twice the energy conscious values.

INFILTRATION HEAT LOSS (TOTAL)

$$1208.1 \text{ BTU/hr} \times 2 = 2416.2 \text{ BTU/hr}$$

TOTAL HEAT LOSS (THREE BEDROOM EXTERIOR UNIT)

Unit heat loss/hr + Infiltration heat loss/hr = Total heat loss

$$22,440 \text{ BTU/hr} + 2416.2 \text{ BTU/hr} = \underline{24,856 \text{ BTU/hr}}$$

HEAT LOSS COMPARISON

Total heat loss in the energy conscious three bedroom exterior unit is equal to 16,161.4 BTU/hr.

Total heat loss in the FHA recommended insulation value three bedroom exterior unit is equal to 24,856 BTU/hr.

This increased heat saving through the increased insulation value represents a 53% energy savings.

HEAT LOSS CALCULATIONS

TWO BEDROOM INTERIOR UNIT

<u>LOCATION</u>	<u>AREA (SQ.FT.)</u>	<u>"U" VALUE</u>	<u>HEAT LOSS (BTU/hr- F)</u>
Lower floor			
Walls	495	0.0496	24.5
Windows	Double glass	168	0.581
	Triple glass	24	0.359
Upper floor			
Walls	459	0.0496	22.7
Windows	Double glass	133	0.581
	Triple glass	40	0.359
Roof			
Living room area	202	0.0319	6.4
Upper roof area	768	0.0318	24.4
Doors			
2-3'-0"x6'-8"x1 $\frac{3}{4}$ "	20	0.24	4.8
Foundation walls			
Exterior only	124	0.2057	<u>25.5</u>
Sub total			306.1 BTU/hr-°F

HEAT LOSS PER HOUR

$$\text{Design temperature} = 65^{\circ}\text{F} - 31.1^{\circ}\text{F} = 33.9^{\circ}\text{F}$$

$$\text{Heat loss per hour} = (306.1 \text{ BTU/hr-}^{\circ}\text{F}) \times (33.9^{\circ}\text{F})$$

$$= 10,376.75 \text{ BTU/hr}$$

HEAT LOSS CALCULATIONS

TWO BEDROOM INTERIOR UNIT

INFILTRATION HEAT LOSS

Wind mean speed = 7.1 mph use 10 mph

Average loss/ft window crack 6 ft³/hr-ft

Average loss/ft door crack 69 ft³/hr-ft

INFILTRATION HEAT LOSS (WINDOWS)

$$H = 0.018(T_1 - T_o)IL$$

$$H = 0.018(70 - 31.1)(80)(6\text{ft}^3/\text{hr-ft})$$

$$H = 366.1 \text{ BTU/hr}$$

INFILTRATION HEAT LOSS (DOORS)

$$H = 0.018(T_1 - T_o)IL$$

$$H = 0.018(70 - 31.1)(20)(69\text{ft}^3/\text{hr-ft})$$

$$H = 842.0 \text{ BTU/hr}$$

INFILTRATION HEAT LOSS (TOTAL)

Window loss + Door loss = Total loss

$$366.1 \text{ BTU/hr} + 842.0 = 1208.1 \text{ BTU/hr}$$

TOTAL HEAT LOSS (TWO BEDROOM INTERIOR UNIT)

Unit heat loss/hr + Infiltration heat loss/hr = Total heat loss

$$10,376.75 \text{ BTU/hr} + 1208.1 \text{ BTU/hr} = \underline{11,511.65 \text{ BTU/hr}}$$

COMPARISON HEAT LOSS CALCULATIONS (FHA RECOMMENDATIONS)

TWO BEDROOM INTERIOR UNIT

<u>LOCATION</u>	<u>AREA (SQ.FT.)</u>	<u>"U" VALUE</u>	<u>HEAT LOSS (BTU/hr- F)</u>
Lower floor			
Walls	495	0.09	44.5
Windows	192	0.65	124.8
Upper floors			
Walls	459	0.09	41.3
Windows	173	0.65	112.5
Roof			
Living room area	202	0.09	18.1
Upper roof area	768	0.09	69.1
Doors			
2-3'-0"x6'-8"x1 $\frac{3}{4}$ "	20	0.65	13.0
Foundation walls			
Exterior only	124	0.3	<u>37.2</u>
Sub total			460.5 BTU/hr-°F

HEAT LOSS PER HOUR

$$\text{Design temperature} = 65^{\circ}\text{F} - 31.1^{\circ}\text{F} = 33.9^{\circ}\text{F}$$

$$\begin{aligned}\text{Heat loss per hour} &= (460.5 \text{ BTU/hr-}^{\circ}\text{F}) \times (33.9^{\circ}\text{F}) \\ &= 15,640 \text{ BTU/hr}\end{aligned}$$

INFILTRATION HEAT LOSS

The infiltration heat loss recommended by FHA is equal to one air change per hour. The energy conscious air change is equal to one half air change per hour. The calculated FHA infiltration values are therefore twice the energy conscious values.

INFILTRATION HEAT LOSS (TOTAL)

$$1208.4 \text{ BTU/hr} \times 2 = 2416.2 \text{ BTU/hr}$$

TOTAL HEAT LOSS (TWO BEDROOM INTERIOR UNIT)

Unit heat loss/hr + Infiltration heat loss/hr = Total heat loss

$$15,640 \text{ BTU/hr} + 2416 \text{ BTU/hr} = \underline{18056 \text{ BTU/hr}}$$

HEAT LOSS COMPARISON

Total heat loss in the energy conscious two bedroom interior unit is equal to 11,511.65 BTU/hr.

Total heat loss in the FHA recommended insulation value two bedroom interior unit is equal to 18,056 BTU/hr.

This increased heat saving through the increased insulation value represents a 56% energy savings.

SOLAR ENERGY USAGE

HEAT GAIN FROM WINDOWS

Mean daily solar radiation in Helena = $170 \text{ langleys/day/ft}^2$
on a vertical surface. Correcting this figure to correspond
to the vertical and 60° window surface the solar radiation
then becomes as follows:

Vertical window with 20° misalignment = $283 \text{ langleys/day/ft}^2$.

60° window with 10° misalignment = $297 \text{ langleys/day/ft}^2$.

One langley is equal to 3.69 BTU/ft^2 .

HEAT GAIN FROM WINDOWS (TWO BEDROOM UNIT)

60° window

Heat gain = $(\text{ft}^2 \text{ window})(\text{langleys})(\text{BTU/ft}^2)(\% \text{ sunshine})$

Heat gain = $(220 \text{ ft}^2)(297 \text{ langleys})(3.69 \text{ BTU/ft}^2)(51\%)$

Heat gain = $122,963 \text{ BTU/day}$

Vertical window

Heat gain = $(63 \text{ ft}^2)(283 \text{ langleys})(3.69 \text{ BTU/ft}^2)(51\%)$

Heat gain = $33,552 \text{ BTU/day}$

TOTAL GAIN = $156,515 \text{ BTU/day}$

HEAT GAIN FROM WINDOWS (THREE BEDROOM UNIT)

60° window

Heat gain = $(322 \text{ ft}^2)(297 \text{ langleys})(3.69 \text{ BTU/ft}^2)(51\%)$

Heat gain = $179,973 \text{ BTU/day}$

Vertical window

Heat gain = $(70 \text{ ft}^2)(283 \text{ langleys})(3.69 \text{ BTU/ft}^2)(51\%)$

Heat gain = $37,280 \text{ BTU/day}$

TOTAL GAIN = $217,253 \text{ BTU/day}$

HEAT LOSS AND HEAT GAIN PER UNIT GROUPING

<u>UNIT GROUPING</u>				<u>UNIT TYPE</u>	<u>HEAT LOSS/day (BTU)</u>	<u>HEAT GAIN/day (BTU)</u>
2BR	2BR	2BR	2BR	2-2BR EXT	624,484 BTU	313,030 BTU
				2-2BR INT	552,558 BTU	313,030 BTU

TOTAL 1,177,042 BTU 626,060 BTU

DIFFERENCE = 550,982 BTU/day Heat loss

3BR	2BR	2BR	3BR	2-3BR EXT	775,746 BTU	434,506 BTU
				2-2BR INT	552,558 BTU	313,030 BTU

TOTAL 1,328,304 BTU 747,536 BTU

DIFFERENCE = 580,768 BTU/day Heat loss

2BR	2BR
-----	-----

2-2BR EXT 624,484 BTU 313,030 BTU

TOTAL 624,484 BTU 313,030 BTU

DIFFERENCE = 311,454 BTU/day Heat loss

3BR	3BR
-----	-----

2-3BR EXT 775,746 BTU 434,506 BTU

TOTAL 775,746 BTU 434,506 BTU

DIFFERENCE = 341,454 BTU/day Heat loss

2BR	3BR
-----	-----

1-2BR EXT 312,242 BTU 156,515 BTU

1-3BR EXT 387,873 BTU 217,253 BTU

TOTAL 700,115 BTU 373,768 BTU

DIFFERENCE = 326,347 BTU/day Heat loss

ENERGY DEMAND AT COLLECTOR STATIONS (NEIGHBORHOOD CENTERS)

<u>UNITS SERVED</u>	<u>ENERGY NEEDED PER UNIT</u>	<u>ADDITIONAL ENERGY NEEDS</u>
<u>STATION ONE</u>		
4 groups of (2-3BR, 2-2BR)	580,768 BTU/day	2,323,072 BTU/day
	TOTAL	<u>2,323,072 BTU/day</u>
<u>STATION TWO</u>		
3 groups of (2-3BR, 2-2BR)	580,768 BTU/day	1,742,304 BTU/day
1 group of (1-3BR, 1-2BR)	326,347 BTU/day	326,247 BTU/day
	TOTAL	<u>2,068,651 BTU/day</u>
<u>STATION THREE</u>		
2 groups of (2-3BR)	341,454 BTU/day	682,480 BTU/day
3 groups of (2-2BR)	326,347 BTU/day	652,694 BTU/day
	TOTAL	<u>1,335,174 BTU/day</u>
<u>STATION FOUR</u>		
2 groups of (2-3BR, 2-2BR)	580,768 BTU/day	1,161,536 BTU/day
1 group of (2-2BR)	311,454 BTU/day	311,454 BTU/day
	TOTAL	<u>1,428,311 BTU/day</u>
<u>STATION FIVE</u>		
2 groups of (4-2BR)	326,347 BTU/day	1,101,964 BTU/day
1 group of (2-3BR, 2-2BR)	580,768 BTU/day	580,768 BTU/day
	TOTAL	<u>1,428,311 BTU/day</u>

ENERGY DEMAND AT COLLECTOR STATIONS (NEIGHBORHOOD CENTERS)

<u>UNITS SERVED</u>	<u>ENERGY NEEDED PER UNIT</u>	<u>ADDITIONAL ENERGY NEEDS</u>
<u>STATION SIX</u>		
2 groups of (2-3BR, 2-2BR)	580,768 BTU/day	1,161,536 BTU/day
1 group of (4-2BR)	550,982 BTU/day	550,982 BTU/day
1 group of (2-3BR)	341,240 BTU/day	341,240 BTU/day
	TOTAL	<u>2,053,758 BTU/day</u>

CONCENTRATING COLLECTOR EFFICIENCY

The amount of solar energy falling on the collector surface
can be determined by the following formula:

$$I_o = (302 \text{ langleys/day})(3.69 \text{ BTU/ft}^2)$$

$$I_o = 1114.4 \text{ BTU/ft}^2/\text{day}$$

$$\text{Efficiency} = (1114.4 \text{ BTU/ft}^2/\text{day})(51\% \text{ available sunshine})$$

$$\text{Efficiency} = 568.3 \text{ BTU/ft}^2/\text{day}$$

$$\text{Collector flow rate} = 8 \text{ gal/min. @ } 210^\circ\text{F} \text{ (160 ft}^2 \text{ collector)}$$

$$\text{One gallon of 210 F water} = 498 \text{ BTU/hr.}$$

$$\text{Collector output} = (8 \text{ gal min.})(498 \text{ BTU})$$

$$\text{Collector output} = (3984 \text{ BTU/min})(60 \text{ min/hr})$$

$$\text{Collector output} = (239,040 \text{ BTU/hr})(8 \text{ hr/day})$$

$$\text{Collector output} = 1,912,320 \text{ BTU/day}$$

$$\text{Efficiency} = (1,912,320 \text{ BTU/day})(51\% \text{ available sunshine})$$

$$\text{Efficiency} = 975,283 \text{ BTU/day/160 ft}^2$$

COLLECTOR SIZING FOR COLLECTOR STATIONS (NEIGHBORHOOD CENTERS)

STATION ONE

$$\frac{975,283 \text{ BTU/day}}{2,323,072 \text{ BTU/day}} \times \frac{160 \text{ ft}^2}{\text{SIZE}}$$

$$\text{Collector size} = 381 \text{ ft}^2$$

STATION TWO

$$\frac{975,283 \text{ BTU/day}}{2,068,651 \text{ BTU/day}} \times \frac{160 \text{ ft}^2}{\text{SIZE}}$$

$$\text{Collector size} = 339 \text{ ft}^2$$

STATION THREE

$$\frac{975,283 \text{ BTU/day}}{1,335,174 \text{ BTU/day}} \times \frac{160 \text{ ft}^2}{\text{SIZE}}$$

$$\text{Collector size} = 219 \text{ ft}^2$$

STATION FOUR

$$\frac{975,283 \text{ BTU/day}}{1,472,990 \text{ BTU/day}} \times \frac{160 \text{ ft}^2}{\text{SIZE}}$$

$$\text{Collector size} = 241 \text{ ft}^2$$

STATION FIVE

$$\frac{975,283 \text{ BTU/day}}{1,428,311 \text{ BTU/day}} \times \frac{160 \text{ ft}^2}{\text{SIZE}}$$

$$\text{Collector size} = 234 \text{ ft}^2$$

STATION SIX

$$\frac{975,283 \text{ BTU/day}}{2,053,758 \text{ BTU/day}} \times \frac{160 \text{ ft}^2}{\text{SIZE}}$$

$$\text{Collector size} = 337 \text{ ft}^2$$

STORAGE SIZING FOR COLLECTOR STATIONS (NEIGHBORHOOD CENTERS)

Design information:

Degree days in January = 1454 Degree days

Design for two days storage = $\frac{2}{30}$ month

Design degree days = 96.9 Degree days

Storage = (Heat loss/day)(Design degree days)

STATION ONE

$$S_{2\text{-day}} = (2,323,072 \text{ BTU/day})(96.9 \text{ degree day})$$

$$S_{2\text{-day}} = 225,105,670 \text{ BTU}$$

$$\text{Volume} = \frac{225,105,670}{(62.4)(80)} = 45,093 \text{ gal}$$

$$\text{Volume} = (45,093 \text{ gal})(7.48 \text{ gal/ft}^3) = 6028 \text{ ft}^3$$

$$\text{Volume} = \pi r^2 h \quad \text{Let } h = 35 \text{ ft}$$

$$6028 \text{ ft}^3 = (3.14)(r^2)(35 \text{ ft})$$

$$r = 7.5 \text{ ft}$$

$$\text{Tank size} = 15 \text{ ft dia.} \times 35 \text{ ft}$$

STATION TWO

$$S_{2\text{-day}} = (2,068,651 \text{ BTU/day})(96.9 \text{ degree day})$$

$$S_{2\text{-day}} = 200,452,280 \text{ BTU}$$

$$\text{Volume} = \frac{200,452,280}{(62.4)(80)} = 40,154.7 \text{ gal}$$

$$\text{Volume} = (40,154.7 \text{ gal})(7.48 \text{ gal/ft}^3) = 5368.2 \text{ ft}^3$$

$$\text{Volume} = \pi r^2 h \quad \text{Let } h = 35 \text{ ft}$$

$$5368.2 \text{ ft}^3 = (3.14)(r^2)(35 \text{ ft})$$

$$r = 7 \text{ ft}$$

$$\text{Tank size} = 14 \text{ ft dia.} \times 35 \text{ ft}$$

STATION THREE

$$S_{2\text{-day}} = (1,335,174 \text{ BTU/day})(96.9 \text{ degree day})$$

$$S_{2\text{-day}} = 129,378,360 \text{ BTU}$$

$$\text{Volume} = \frac{129,378,360}{(62.4)(80)} = 25,917 \text{ gal}$$

$$\text{Volume} = (25,917 \text{ gal})(7.48 \text{ gal/ft}^3) = 3464 \text{ ft}^3$$

$$\text{Volume} = \pi r^2 h \quad \text{Let } h = 20 \text{ ft}$$

$$3464 \text{ ft}^3 = (3.14)(r^2)(20 \text{ ft})$$

$$r = 7.5 \text{ ft}$$

$$\text{Tank size} = 15 \text{ ft dia.} \times 20 \text{ ft}$$

STATION FOUR

$$S_{2\text{-day}} = (1,472,990 \text{ BTU/day})(96.9 \text{ degree day})$$

$$S_{2\text{-day}} = 142,732,730 \text{ BTU}$$

$$\text{Volume} = \frac{142,732,730}{(62.4)(80)} = 28,592 \text{ gal}$$

$$\text{Volume} = (28,592 \text{ gal})(7.48 \text{ gal/ft}^3) = 3822 \text{ ft}^3$$

$$\text{Volume} = \pi r^2 h \quad \text{Let } h = 22 \text{ ft}$$

$$3822 \text{ ft}^3 = (3.14)(r^2)(22 \text{ ft})$$

$$r = 7.5 \text{ ft}$$

$$\text{Tank size} = 15 \text{ ft dia.} \times 22 \text{ ft}$$

STATION FIVE

$$S_{2\text{-day}} = (1,428,311 \text{ BTU/day})(96.9 \text{ degree day})$$

$$S_{2\text{-day}} = 138,403,330 \text{ BTU}$$

$$\text{Volume} = \frac{138,403,330}{(62.4)(80)} = 27,725 \text{ gal}$$

$$\text{Volume} = (27,725 \text{ gal})(7.48 \text{ gal/ft}^3) = 3706 \text{ ft}^3$$

$$\text{Volume} = \pi r^2 h \quad \text{Let } h = 22 \text{ ft}$$

$$3706 \text{ ft}^3 = (3.14)(r^2)(22 \text{ ft})$$

$$r = 7.5 \text{ ft}$$

$$\text{Tank size} = 15 \text{ ft dia.} \times 22 \text{ ft}$$

STATION SIX

$$S_{2\text{-day}} = (2,053,758 \text{ BTU/day})(96.9 \text{ degree day})$$

$$S_{2\text{-day}} = 199,009,150 \text{ BTU}$$

$$\text{Volume} = \frac{199,009,150}{(62.4)(80)} = 39,865 \text{ gal}$$

$$\text{Volume} = (39,865 \text{ gal})(7.48 \text{ gal/ft}^3) = 5329 \text{ ft}^3$$

$$\text{Volume} = \pi r^2 h \quad \text{Let } h = 35 \text{ ft}$$

$$5329 \text{ ft}^3 = (3.14)(r^2)(35 \text{ ft})$$

$$r = 7 \text{ ft}$$

$$\text{Tank size} = 14 \text{ ft dia.} \times 35 \text{ ft}$$

SUN CACHE OVERALL PERFORMANCE

For this overall performance calculation a unit grouping with two-three bedroom exterior units and two-two bedroom interior units was used.

The FHA control house insulated to the FHA insulation values had a heat loss of 85,824 BTU/hr. This compares with a heat loss in the energy conscious house of 55,346 BTU/hr. This represents an energy saving of 35%.

By grouping the units in the manner in which they are arranged an additional energy saving of 5873 BTU/hr can be gained.

This represents an additional energy saving of about 7%.

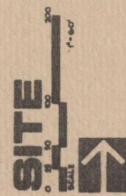
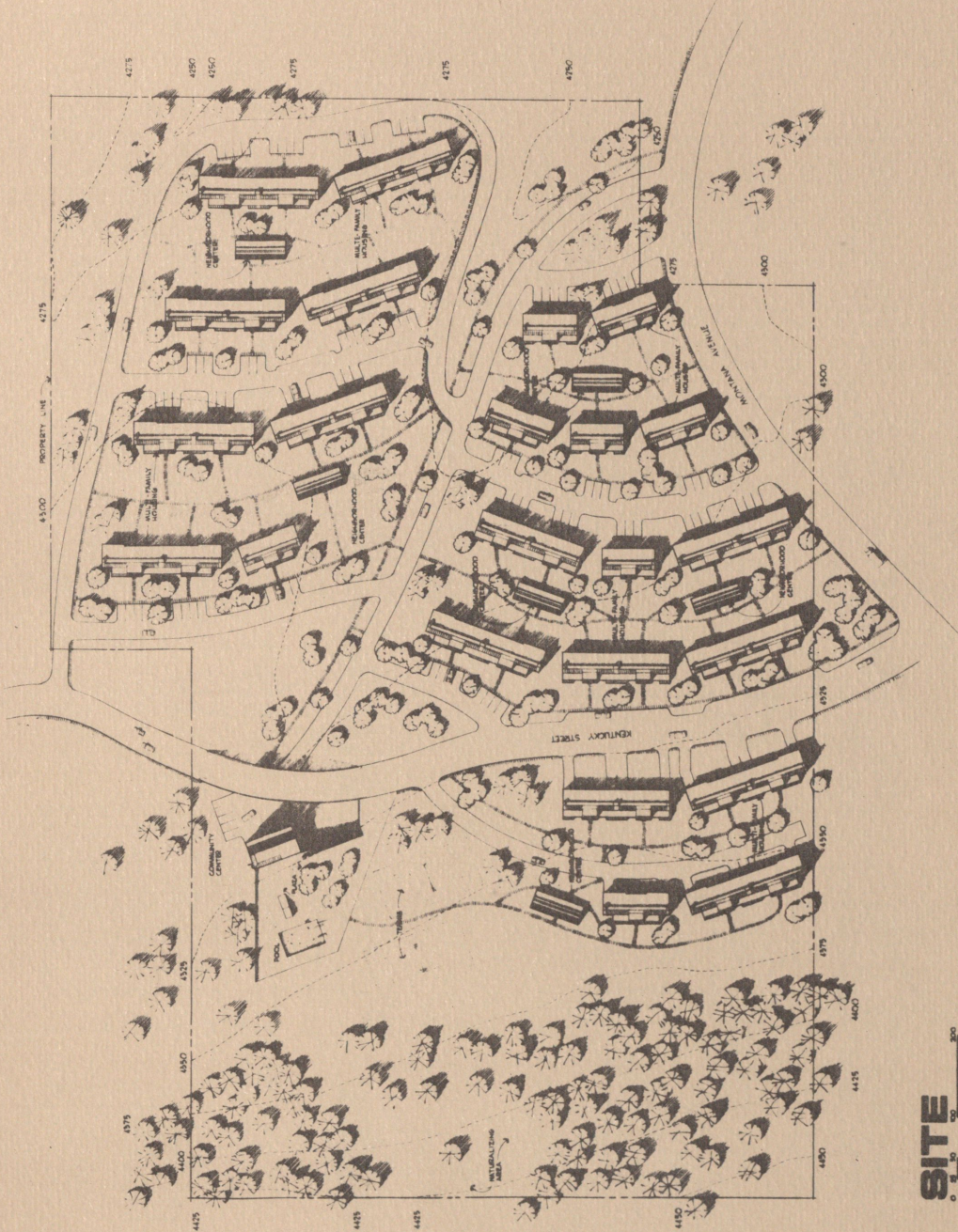
Through proper orientation and maximum window area an additional heat gain of 31,147 BTU/hr can be attained. This represents a 36% energy saving.

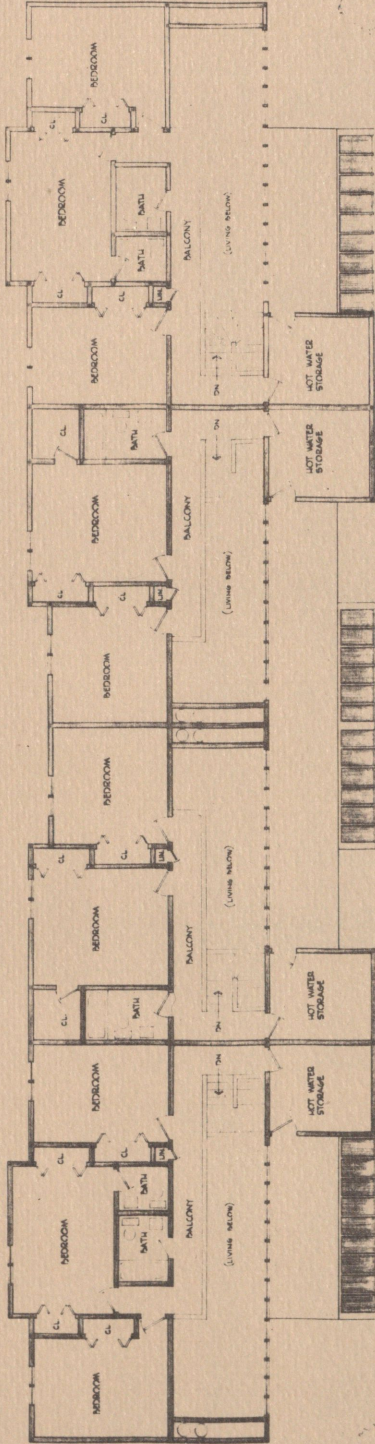
DRAWINGS

THESIS

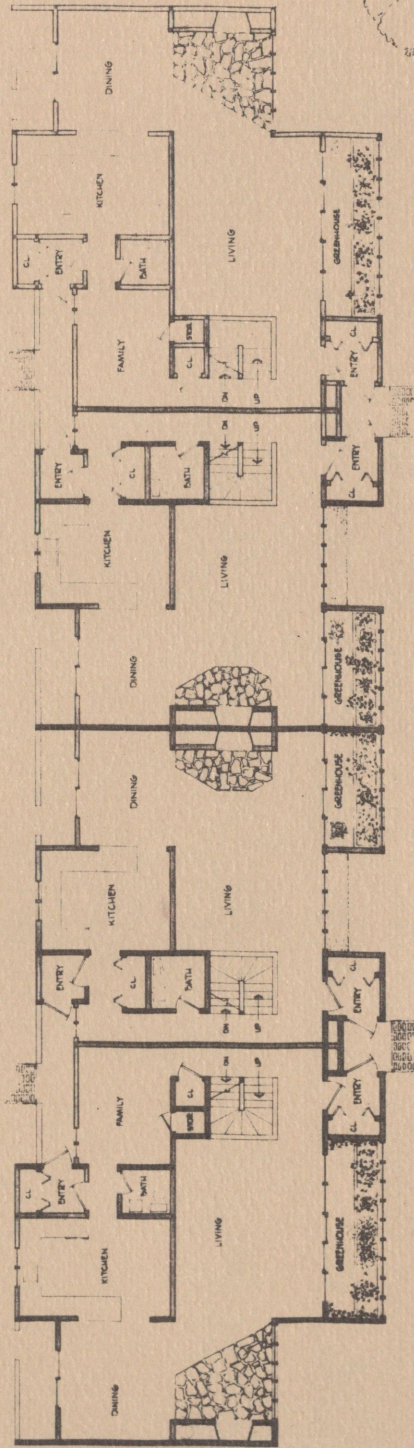
THE INTEGRATION OF SOLAR
MECHANICAL SYSTEMS AND
ENERGY CONSERVATION
MEASURES, WITH MULTIPLE
FAMILY DWELLINGS, HAS A
PROFOUND EFFECT ON THE
RESULTING ARCHITECTURAL
FORM, AS WELL AS THE
EXPERIENCE OF SUCH
ENVIRONMENTS



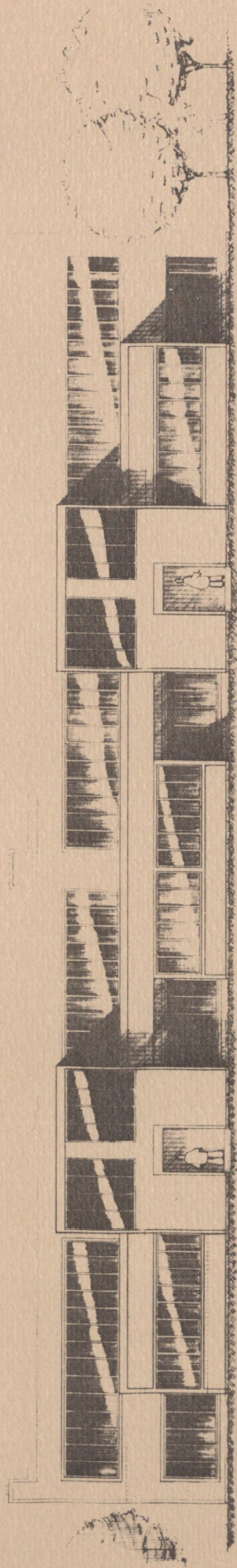




LEVEL 2
SCALE 0 10 20 FEET

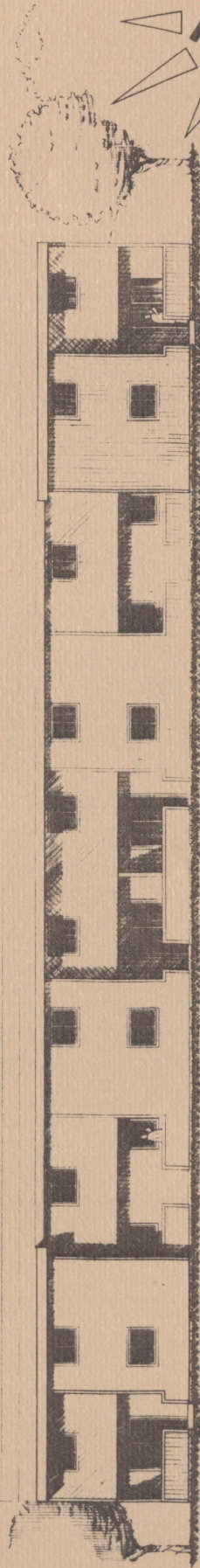


LEVEL 1
SCALE 0 10 20 FEET



SOUTH

0 1 2 3 4 5 6 7 8 9 10
feet



NORTH

0 1 2 3 4 5 6 7 8 9 10
feet



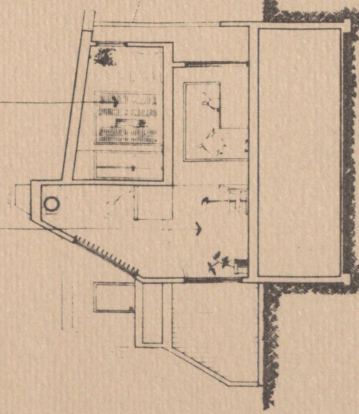
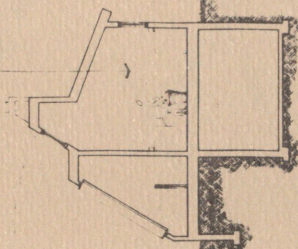
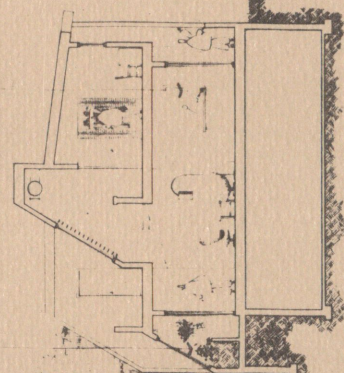
DINING

GREENHOUSE

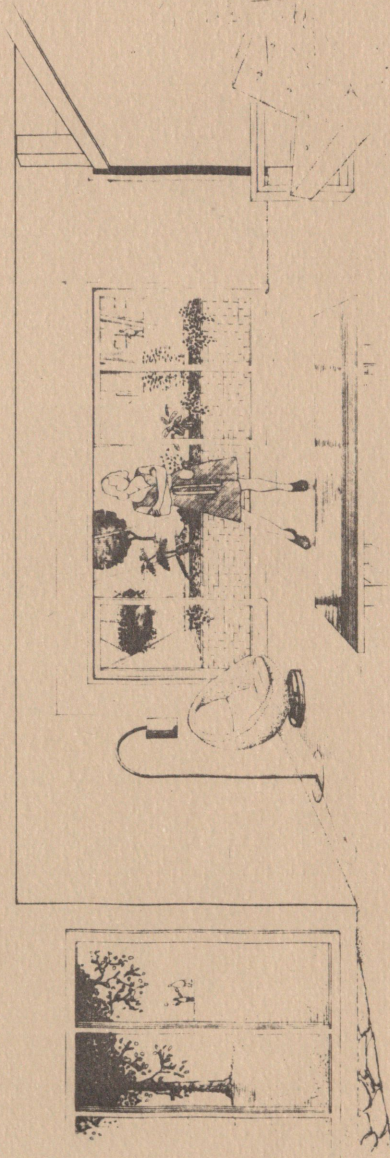
LAUNDRY

BEDROOM

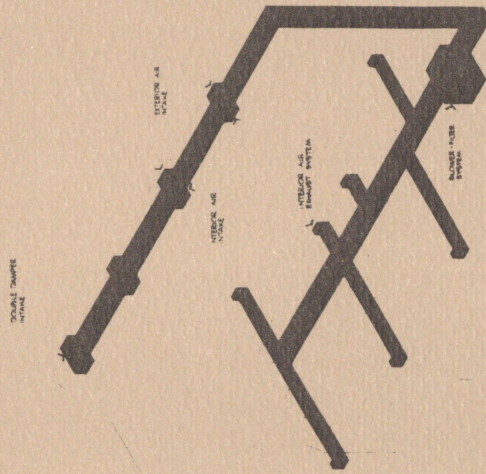
LIVING



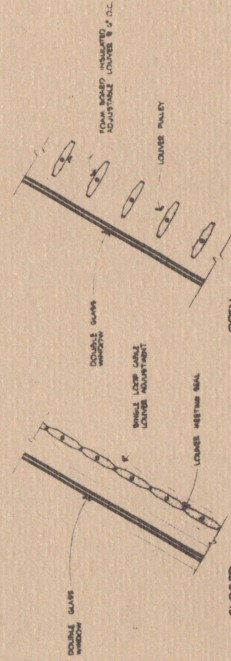
SECTION



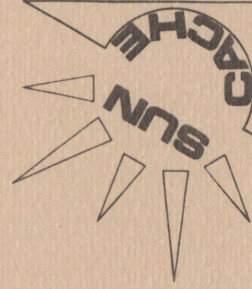
INTERIOR

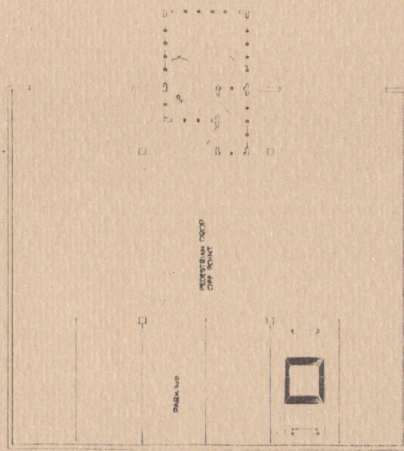
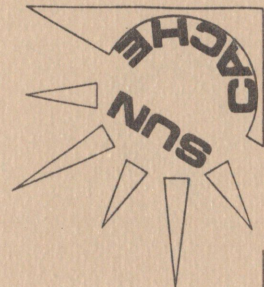


UNIT GROUPING

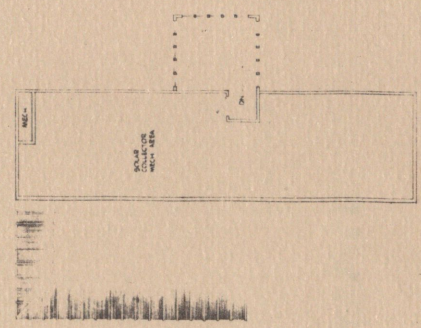


LOUVER

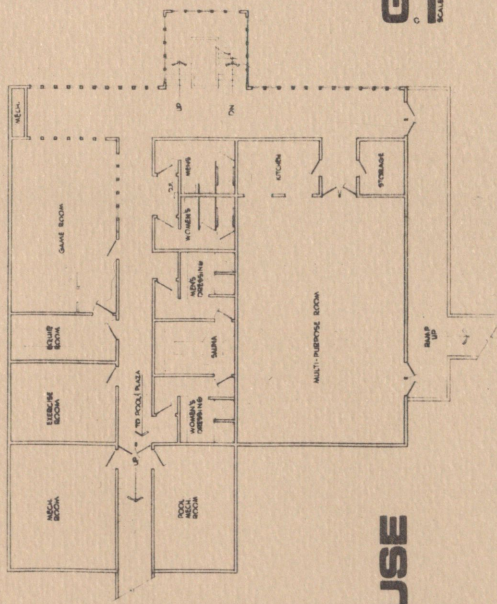




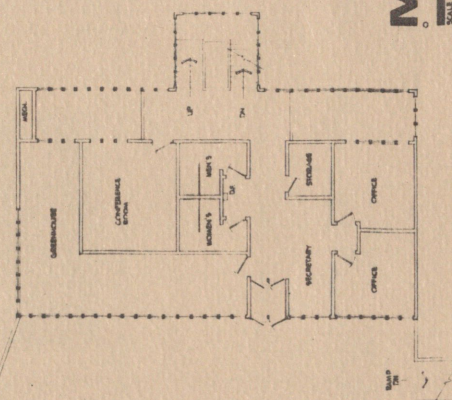
GROUND



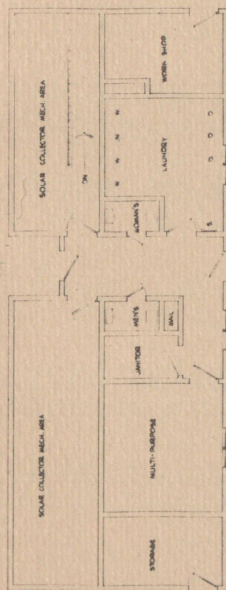
MECHANICAL



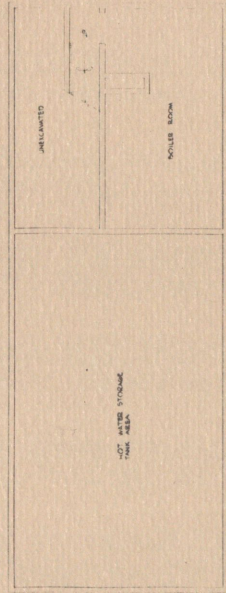
MULTI-USE



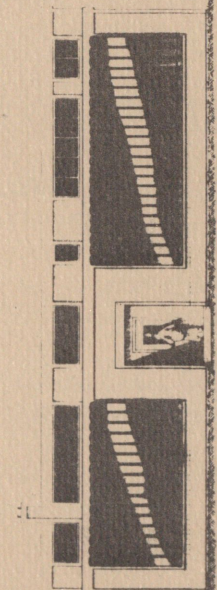
PLAZA



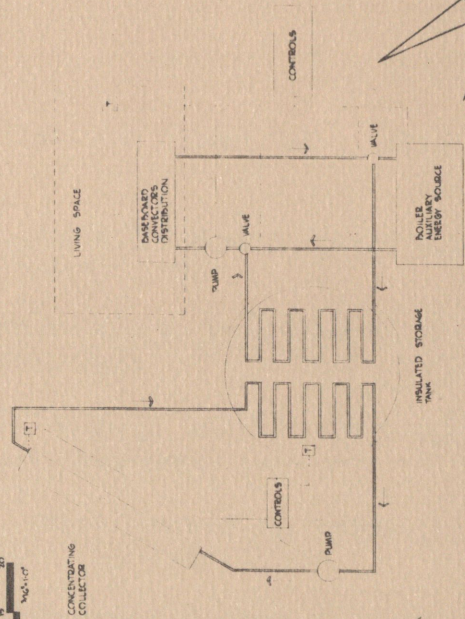
MAIN
0 10 20
feet
SCALE



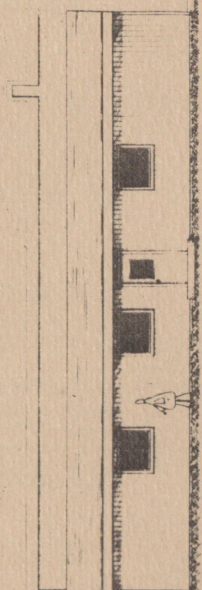
LOWER
0 10 20
feet
SCALE



SOUTH



SCHEMATIC



NORTH



BIBLIOGRAPHY

The Autonomous House, Brenda and Robert Vale: Universe Books; New York, 1975

Design and Evaluation Criteria for Energy Conservation in New Buildings, A.S.H.R.A.E., 1974

Design with Climate, Victor Olgyay: Princeton University Press; Princeton, New York, 1973

Design with Nature, Ian L. McHarg: Doubleday/Natural History Press; Garden City, New York, 1969

Here Comes the Sun 1981, Joint Venture and Friends: Joint Venture Inc.; Boulder, Colorado, 1975

Housing, Macsai, Holland, Nachman, Yacker: John Wiley and Sons; New York, 1976

Manual of Housing Planning and Design Criteria, Joseph DeChiara and Lee Koppelman: Prentice-Hall; Englewood Cliffs, New Jersey, 1975

Mechanical and Electrical Equipment for Buildings, William J. McGuinness and Benjamin Stein: John Wiley and Sons; New York, 1971

Other Homes and Garbage, Leckie, Masters, Whitehouse, Young: Sierra Club Books; San Francisco, 1975

Solar Energy and Building, S.V. Szokolay: The Architecture Press; London, England, 1975

Solar Energy and Housing, Giffels Associates, Inc.: A.I.A. Research Corporation; 1975

Solar Energy Home Design, Total Environmental Action: The Wallace Press; Harrisville, New Hampshire, 1975

Solar Dwelling Design Concepts, A.I.A. Research Corporation: U.S. Government Printing Office; Washington, D.C., 1976

Your Energy-efficient House, Anthony Adams: Garden Way Publishing; Charlotte, Vermont, 1975

MONTANA STATE UNIVERSITY LIBRARIES
stks 720.6.M76M193
Energy conscious multiple family housing CA



3 1762 00158134 5

~~AD. USE ONLY~~

~~NA 7540~~

~~4206~~

~~m76~~

m193

