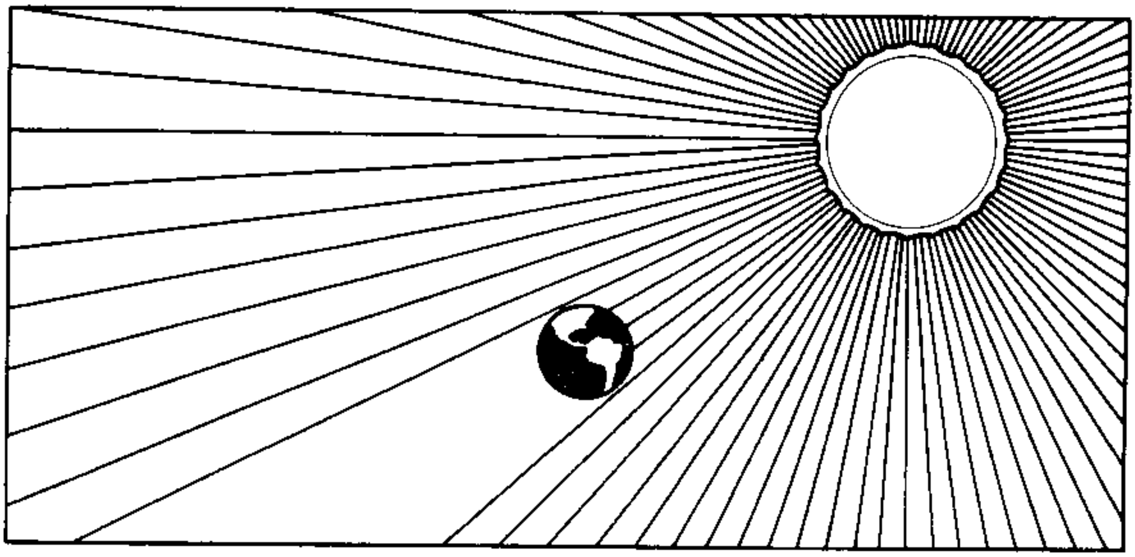
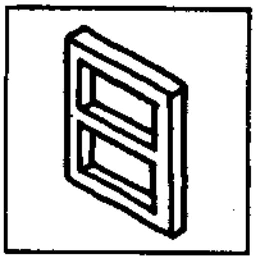
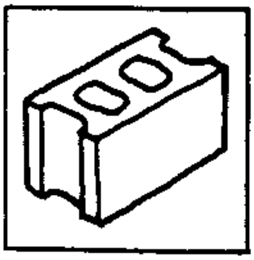
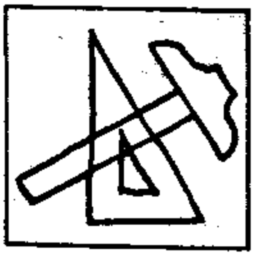
Path to Passive



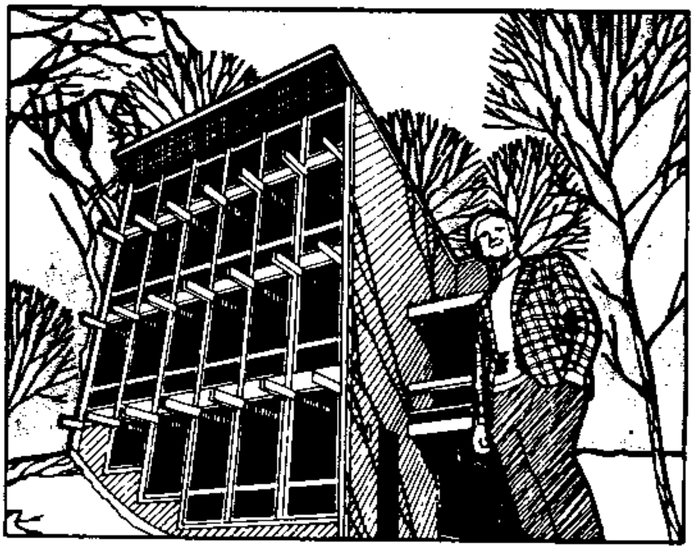




Nebraska's Passive Solar Primer



by
Solar
Energy
Associates



Path to Passive

Nebraska's Passive Solar Primer

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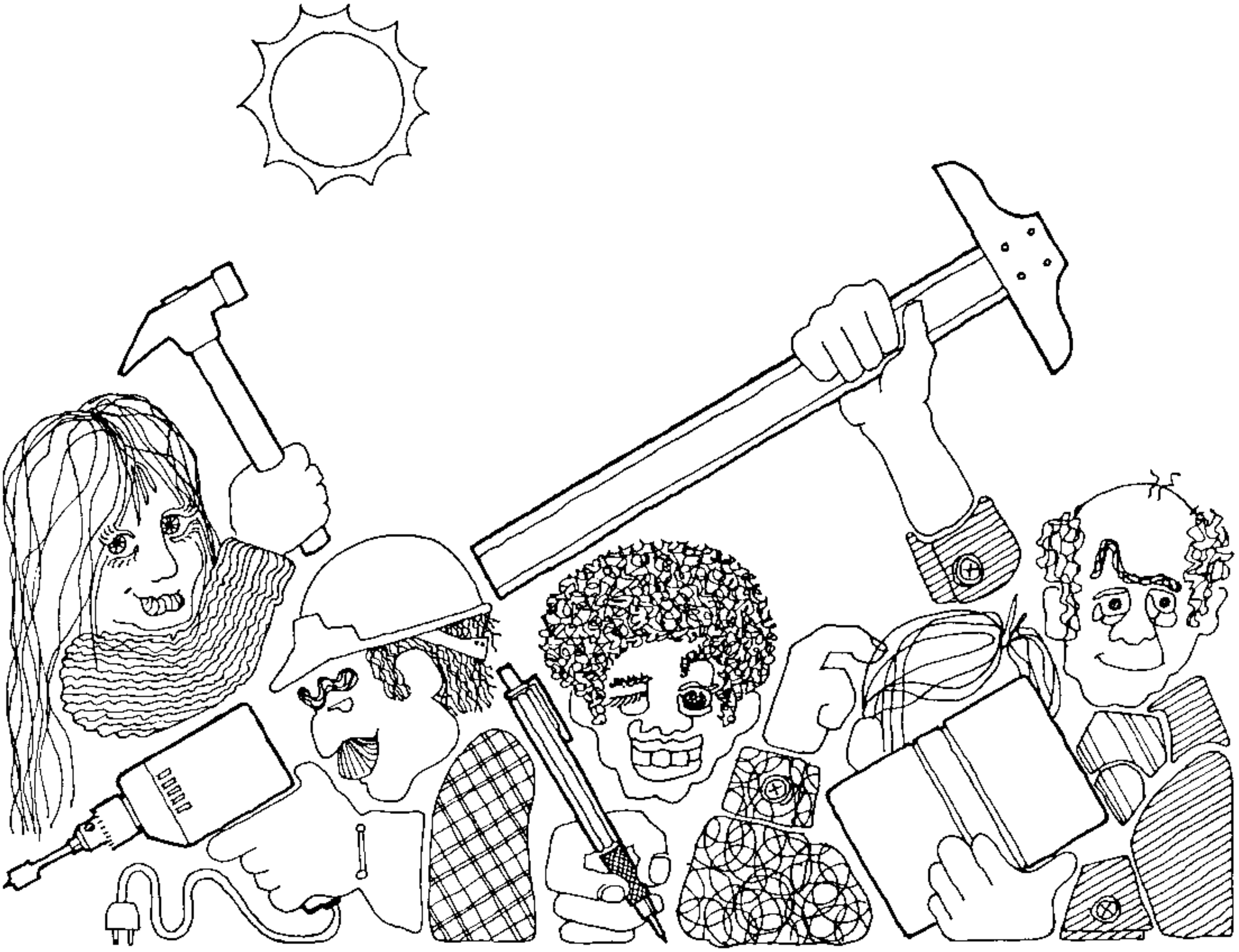
"Destiny is not a matter of chance,
it is a matter of choice;
it is not a thing to be waited for,
it is a thing to be achieved."

William Jennings Bryan

NEBRASKA'S PASSIVE SOLAR PRIMER IS A TESTAMENT TO THE DEDICATION AND EFFORT OF A SMALL BAND OF FACULTY AND STUDENTS FROM THE UNIVERSITY OF NEBRASKA. KNOWN COLLECTIVELY AS THE PASSIVE SOLAR RESEARCH GROUP (PSRG), THEY HAD A VISION OF THE FUTURE AND THE ROLE THAT PASSIVE SOLAR ENERGY COULD PLAY IN RESHAPING IT. TO THE PAST AND PRESENT MEMBERS OF THE PASSIVE SOLAR RESEARCH GROUP, IS THIS BOOK DEDICATED.



A BOOK FOR THE ARCHITECT, ENGINEER, BUILDER-CONTRACTOR AND THE HOMEOWNER

HOW TO USE THIS BOOK

The purpose of this Primer is to provide the reader with information required to make a decision on an important issue: whether or not to build an energy efficient passive solar heated home. As fossil fuel energy becomes more scarce and costly, the number of energy source options available to a homebuilder becomes limited as far as the conventional sources of energy are concerned. However, the possible variations for energy conservation and passive solar energy techniques are limited only by the imagination of the homebuilder. The Primer should be used as an introductory guide to stimulate new ideas and to avoid pitfalls which have been common to this newly emerging field. The Primer should not be regarded as the final treatise. It will undergo revisions and evolve as new knowledge enters the mainstream of passive solar energy.

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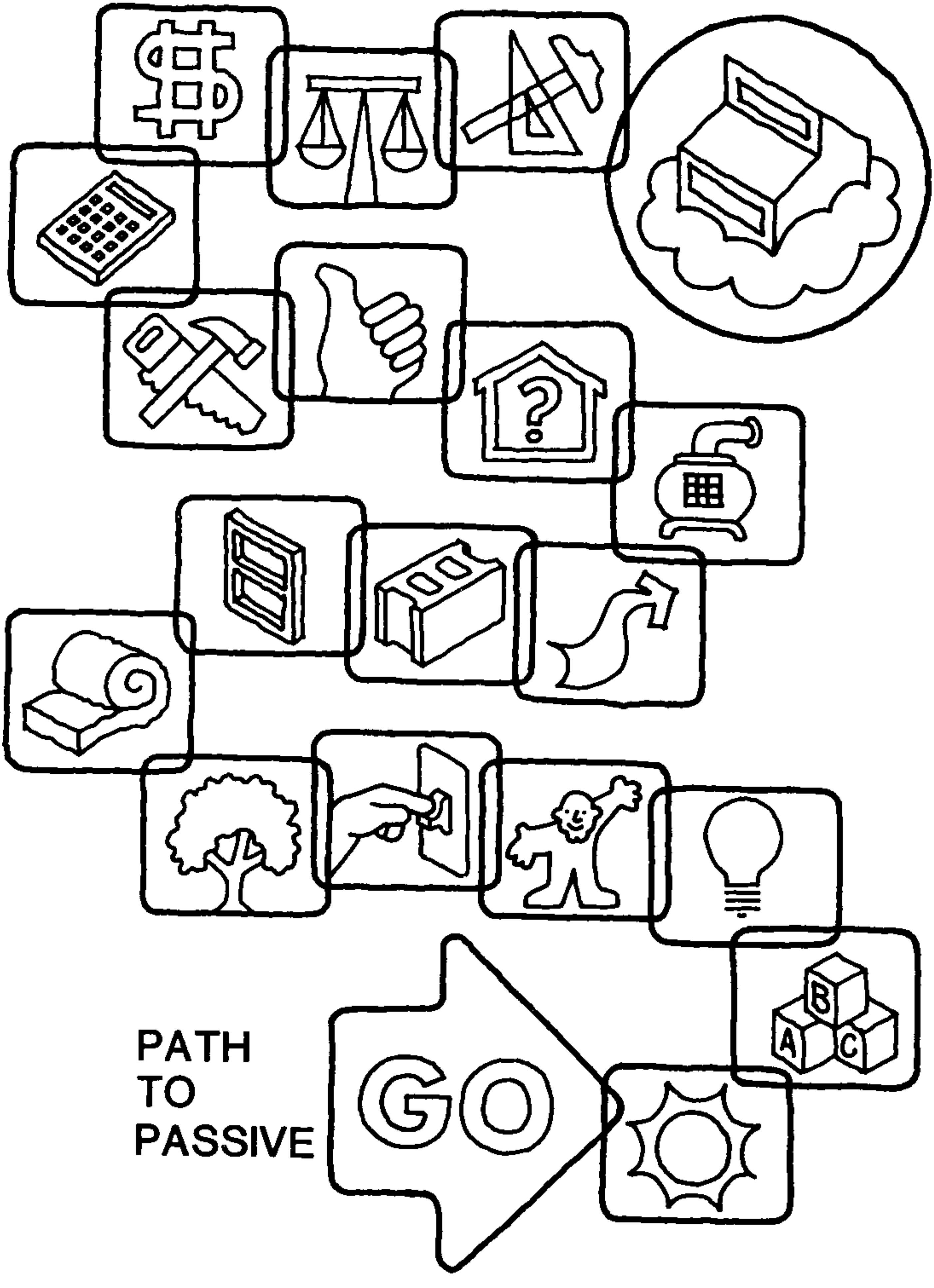
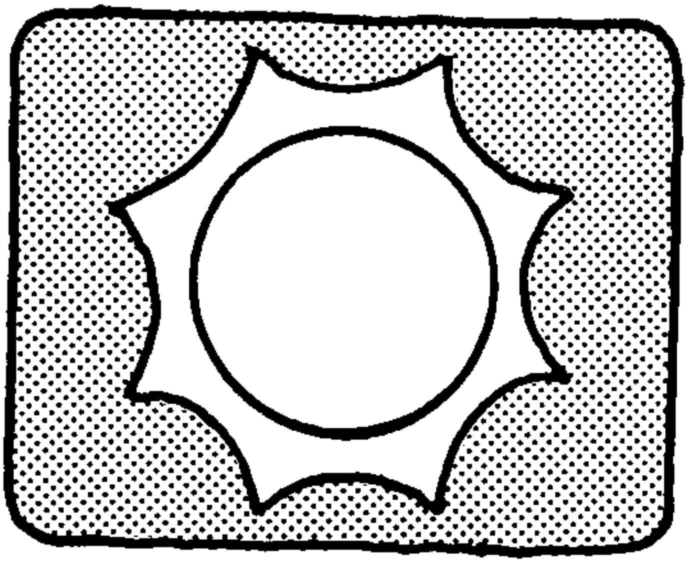


PATH
TO
PASSIVE

CHAPTER 0
INTRODUCTION

This chapter is a brief philosophical and historical perspective of passive solar energy.

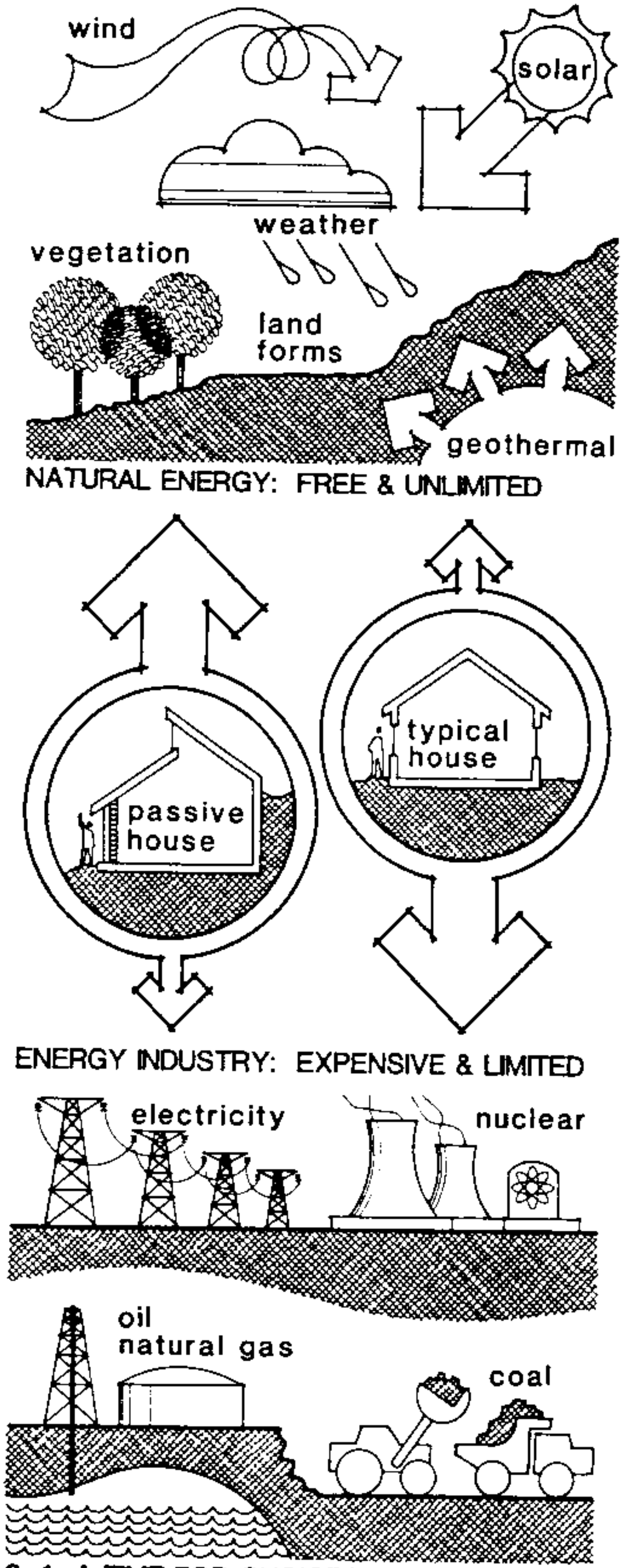


INTRODUCTION

The sun is the principal source of energy for all life on this planet: the complex interwoven web of life on this planet is dependent upon the sun for its survival. For example, the sun drives the weather patterns; it controls the various oxygen, nitrogen and carbon dioxide cycles. Man is the only species which has been able to substantially alter the environment, although only in the recent past have such actions been questioned. Our long term survival may very well rest upon our ability to temper this Promethean power endowed to us. We have yet to fully understand the lack of wisdom inherent in brokering our future with short-sighted, short-term economic gain at the expense of our environment. The "balance due in full" account with nature may be more than our heirs can pay.

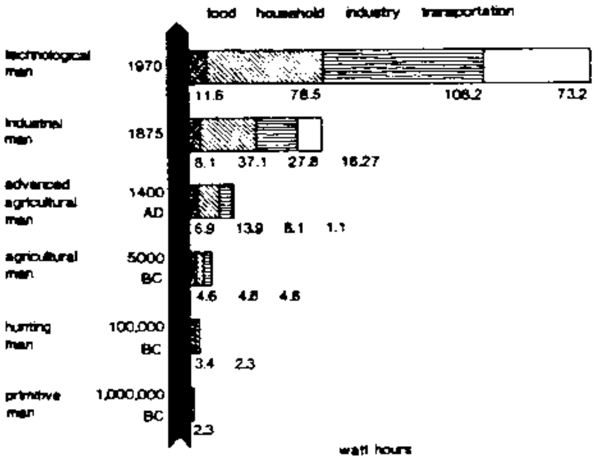
In the decades ahead, a number of fundamental decisions will have to be made with respect to our lifestyles and our responsibilities as the pre-eminent life form on Earth (FIG 0-1). The passive solar heated home is indicative of a choice made in favor of utilizing a plentiful and renewable energy source -- the sun. No other source of energy can make the claim of being unending or of being in harmony with nature.

At the beginning of this century, coal was the principal source of heat for most homes . Coal was to be supplanted by the newer and, at the time, seemingly inexhaustible reserves of oil and, later, natural gas. Generous government subsidies allowed the gas and oil industries to grow and proliferate; America grew and prospered. Our homes grew larger and their energy appetites for fossil fuels kept pace. An entire generation was nurtured on "cheap" fossil and nuclear fuels. The first storm clouds warning of energy problems gathering on the horizon were ignored in the "happy days" of the 50's. Economics has not tallied the true cost exacted

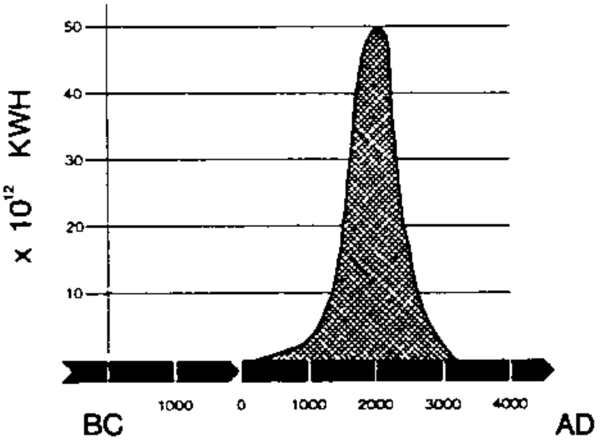


0-1 A TIME FOR CHOICES

INTRODUCTION



0–2 ENERGY CONSUMPTION HISTORY



0–3 FOSSIL FUELS: A LIMITED FUTURE

0–4 THE TAMING OF ENERGY

upon our environment. As a result, we are faced with the following questions: Can future generations pay the balance due? Has the environment's maximum stress point been exceeded?

Per capita energy consumption of primitive man, whose energy needs were principally concerned with food, was modest (FIG 0-2). Energy consumption did not increase significantly until the Agricultural Revolution. The Industrial Revolution, about 1875, brought about a quantum leap in consumption and the inclusion of a new sector -- transportation.

Each fossil energy resource is finite. At the initial stages of exploitation, supplies appear to be inexhaustible. Successful marketing increases the rate at which the fuel is consumed, and this process continues until the ease of discovery and extraction diminishes. Prices of the fuel then escalate as the resource base is depleted (FIG 0-3). At this point, threat of depletion may lead planners to consider substitution strategies such as coal gassification or shale oil for petroleum. The problem with this approach is that one is led to believe that a permanent solution has been found. However, if the substitution is another fossil fuel, the problem is only delayed, not solved. At best the substitution can only buy time until a permanent solution is developed.

Each stage in the ascent of man has involved fundamental changes in how the world is perceived and what role man plays in the scheme of life. Among our early ancestors, Peking Man had learned to use fire for cooking food and keeping warm during inclement weather (FIG 0-4). Wood was the chief source of fuel. In many parts of the world today, wood is still the principal source of energy.

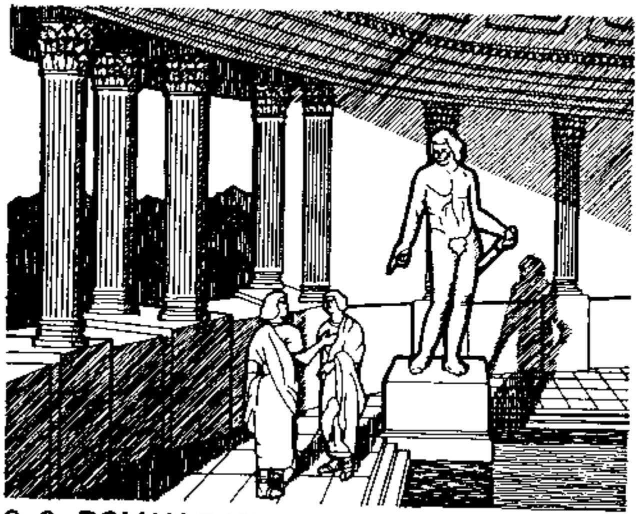
SOLAR ENERGY: A HISTORICAL OVERVIEW

Energy crises are not unique to our times. Rather, throughout history man has repeatedly been faced with the problem of finding sufficient energy supplies for warmth, to cook food, to power machines, etc. The first recorded energy crisis occurred in Greece about 500 B.C. (FIG 0-5). Wood was the principal energy source for heating, cooking, shipbuilding, and smelting. The competition for wood led to the denuding of many forests, resulting in higher prices as well as regulations to control consumption of wood. Olynthus, the first solar community using passive solar heating techniques, was built. Homes were built to capture the sun's heat through south-facing courtyards. Windowless north walls and common east-west walls completed the energy conservation package.

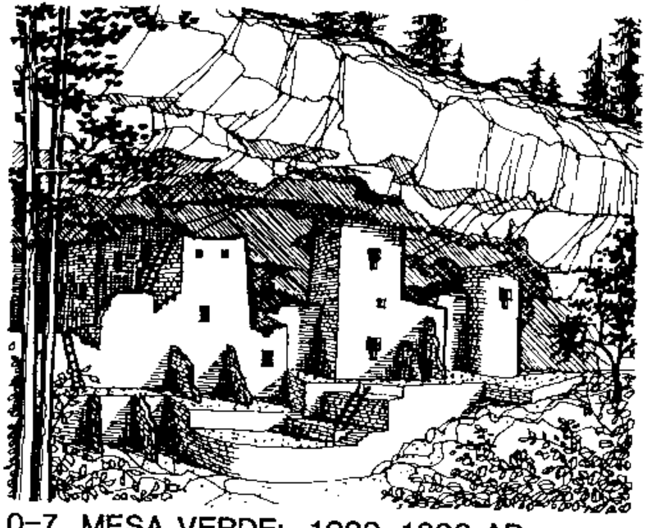
The scene for the next energy crisis shifts to ancient Rome (FIG 0-6). Demand for wood came from industry, shipping, and residential heating -- central heating systems in some homes consumed up to 280 pounds of wood per day. Heavily forested areas near Rome disappeared and wood was imported from as far as 1000 miles away. To extend wood resources, passive solar heating techniques were refined to include south-facing glass and the use of water as thermal mass to store the solar energy. As passive solar heating became commonplace in public baths, residences, and greenhouses, the first solar access, or "right to light", laws were enacted.

During the eleventh and twelfth centuries A.D., the Pueblo Indian culture developed the first American solar communities (FIG 0-7). Every residence had a south-facing exposure to permit sunlight to enter through doors and windows, and entire communities were planned to provide maximum solar access. Adobe construction assured sufficient thermal mass to store the heat during winter and to moderate temperatures

0-5 OLYNTHUS, GREECE: 500 BC
FIRST SOLAR COMMUNITY

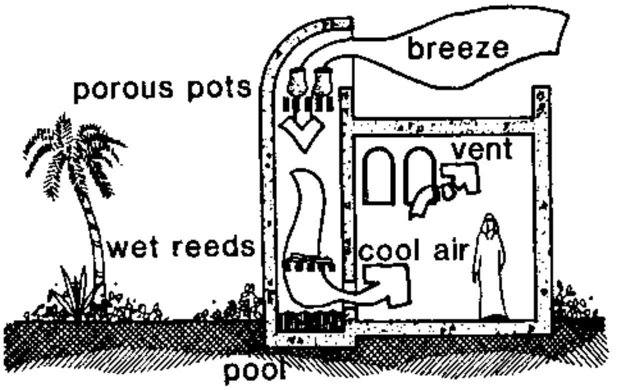


0-6 ROMAN BATH: ca. 100 AD
FIRST SOLAR ACCESS RIGHTS

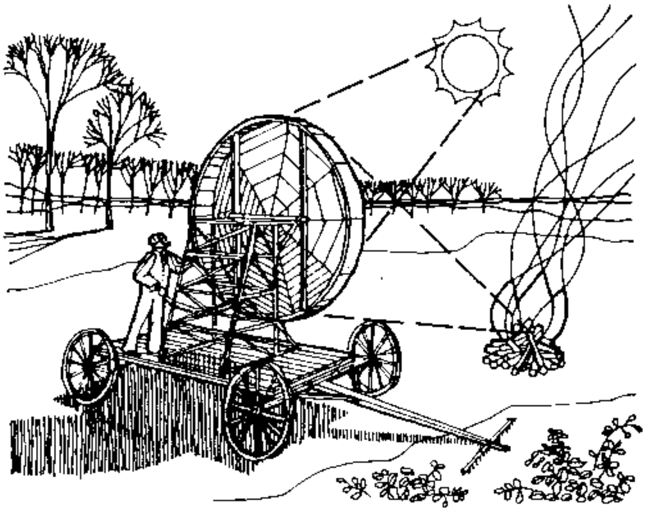


0-7 MESA VERDE: 1000-1200 AD
NATIVE AMERICAN SOLAR DWELLINGS

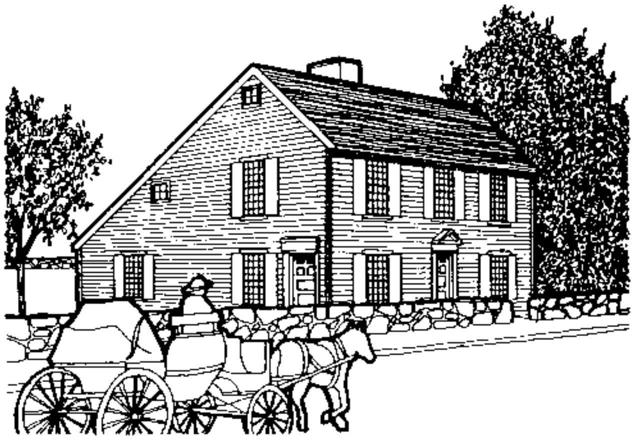
INTRODUCTION



0-8 PERSIA: 900 AD TO PRESENT
COOLING TOWER



0-9 GERMANY: 1700'S
EARLY CONCENTRATING COLLECTORS



0-10 NEW ENGLAND: 1700'S
EARLY AMERICAN SALTBOX

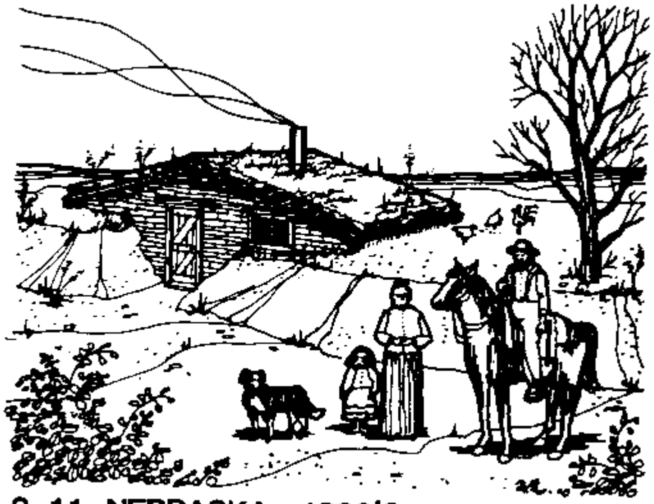
during the hot summer months. Shutters and roof insulation helped retain heat in the winter, and eaves were used to shade the sun in the summer.

The sun's energy can be used to cool as well as to heat. All wind currents are sun driven, and the Persians took advantage of this fact to keep their interior spaces cool during summer months (FIG 0-8). Breezes are ducted from roof openings down through porous pots and wet reeds and over a pool at the bottom of the chimney. In picking up moisture, the air current is cooled so air entering the living space is cooler than indoor air temperatures.

The use of the sun's energy is not limited to heating and cooling applications alone. Ancient Chinese, Greek, and Roman civilizations developed curved mirrors to concentrate the sun's rays onto a single point. Archimedes is said to have used mirrors in 221 B.C. to destroy an enemy fleet attacking Syracuse. Da Vinci conceptualized the idea of using mirrors to supply industrial hot water. In place of single piece mirror fabrication, Peter Hoesen fabricated his mirrors with brass-covered wood sections that were fitted together (FIG 0-9). The power of the mirrors was such that copper metal would melt in one second.

Early American settlers built the New England "saltbox" (FIG 0-10). The buildings were two-story with most of the rooms facing south. Only one floor faced north. Sloping roofs carried cold northern winds up and over the building. Vines above the doors and windows kept summer sun out of the home, but would permit sunlight to pass through the windows when the leaves fell in autumn.

Each environment has unique characteristics. The prairie pioneers of a century ago faced cold winters with fierce north winds (FIG 0-11) and hot, unpleasant summers. Wood was not in abundance to serve as a primary fuel. The solution was the sod house. Earth berms on the north kept out winter winds. South-facing doors and windows permitted solar gain. Dirt and sod provided roof insulation year round. The thick walls moderated temperatures, and the earth floor contact provided the additional bonus of summer cooling.



0-11 NEBRASKA: 1800'S
EARTH SHELTERED SODDY

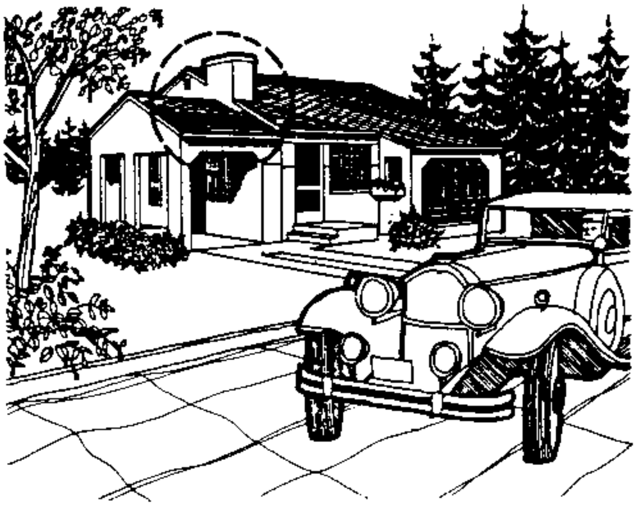
In 16th century Holland, greenhouses were utilized for horticultural purposes, which resulted in the perfection of window angles and thermal storage techniques. It was not until Victorian England, however, that the idea of the glassed-in garden, or conservatory, gained popularity . Sun-warmed and plant-moistened air could be drawn into homes which otherwise were usually cold and gloomy (FIG 0-12).

0-12 LONDON: 1890'S
VICTORIAN GREENHOUSE

Although personal bathing was popular in Rome, the practice was discontinued in Europe , primarily because heating water was a laborious and tedious process. However, in 1891, Clarence Kemp marketed the "Climax", the first commercial solar hot water heater unit. It consisted of a hot box with exposed bare metal tanks operating under city water pressure. Bathing became practical again. In 1911, the "Day and Night" solar hot water heater by William Bailey revolutionized the industry (FIG 0-13). Its insulated storage tank was separated from the collector, and the collector included a metal absorber plate operating on thermosiphon principles.

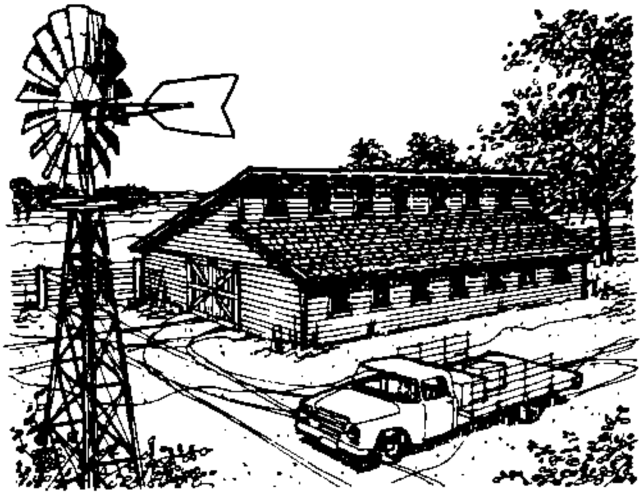
0-13 SOUTHERN CALIFORNIA: 1911
SOLAR WATER HEATER

INTRODUCTION



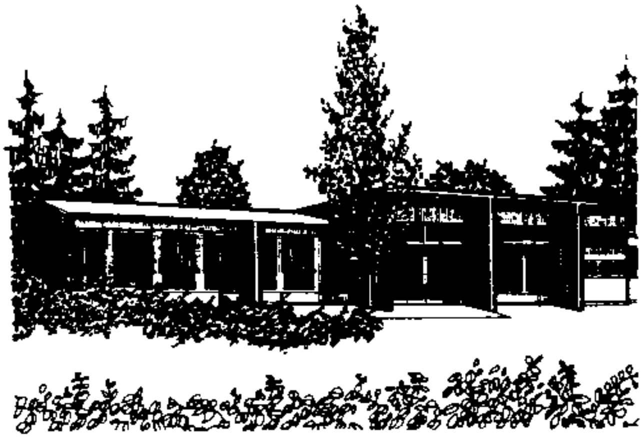
0-14 FLORIDA: 1930'S
IMPROVED SOLAR WATER HEATER

Florida's population grew rapidly during the Roaring 20's and by 1941 more than half of Miami's population was using solar heated hot water (FIG 0-14). A popular model of solar hot water heater was the "Duplex", an improved version of the "Day and Night". Soft copper replaced steel tubing, the spacing between tubing was reduced, and the collector box was insulated and further improved by switching to steel construction.



0-15 NEBRASKA: 1940'S
LIVESTOCK SHELTER

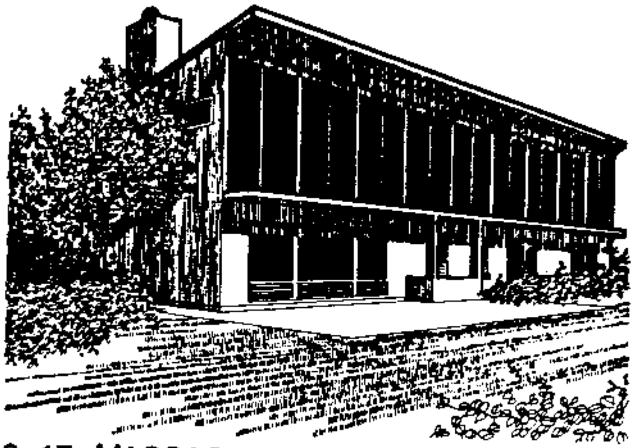
In the midst of the great Depression, a number of programs were instituted to benefit farmers, including one by the Farm Security Administration, in which an existing design of an animal facility was altered to reduce energy consumption (FIG 0-15). These alterations included windows and clerestories facing south to maximize solar gain and a long roof line pitched to deflect the cold winter winds up and over the building. Many of these animal barns dotted the prairie landscape of the 30's and 40's. The famous architect Saarinen is said to have commented: "Kids should be able to live as well as these chickens".



0-16 ILLINOIS: 1941
PASSIVE DESIGN BY KECK

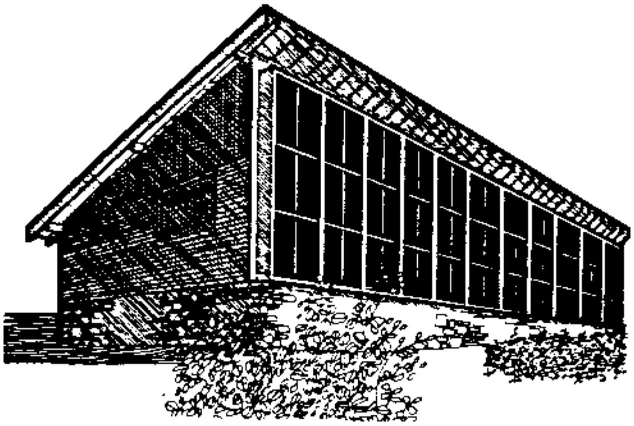
The modern passive solar era began in the 1930's and 1940's with George Fred Keck, who designed homes with a southern orientation. Keck used double paned glass which allowed the home to retain more heat in winter and overhangs to prevent overheating in summer (FIG 0-16). In 1940 the first modern passive solar heated home with a complete south wall of glass was built for Howard Sloan, a real estate developer in Chicago, who, in 1941, built Solar Park, the first American solar development.

In 1948, Maria Telkes, then a research associate at MIT, worked with Amelia Peabody to design a 100% solar home without backup furnace. Called the Dover House (FIG 0-17) the structure had a vertical collector with 180 square feet of south-facing glass. Hot air was ducted from the air collector to a 470 cubic foot storage unit comprised of glaubers salt in five gallon steel cans. The storage capacity was 5 million btus, enough to heat the house through a week of cloudy days. Unfortunately, the system was only successful for 2-1/2 winters, after which problems developed in the salts.



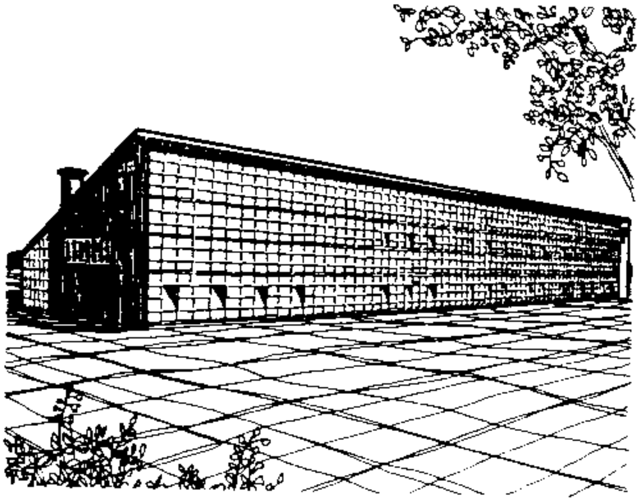
0-17 MASSACHUSETTS: 1948
DOVER HOUSE BY MARIA TELKES

In 1956 in the mountains of southern France, Felix Trombe built the first of a series of solar buildings (FIG 0-18). Today Trombe is recognized as one of the modern pioneers of passive solar energy, and the concept of placing thermal mass directly behind south-facing glass is frequently referred to as a Trombe wall. Concrete one-foot thick and painted black serves two purposes: it provides thermal storage and acts as a structural element. Heat absorbed by the concrete migrates to the inner wall and radiates into the living space during the evening.



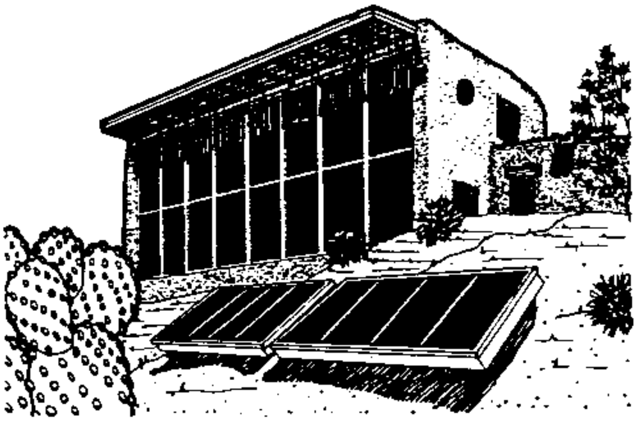
0-18 PYRENEES, FRANCE: 1956
FELIX TROMBE HOUSE

The Wallasey school in Liverpool, England is another early example of passive solar energy design (FIG 0-19). Built in 1961, the school's entire 230' by 27' south facade is in two glass layers. The inner layer diffuses the impact of direct sunlight. This diffused light strikes concrete floors, ceilings, and brick walls directly and these contain sufficient mass to limit the daily temperature swing to 6^{o}F. The school has yet to require auxiliary heating.



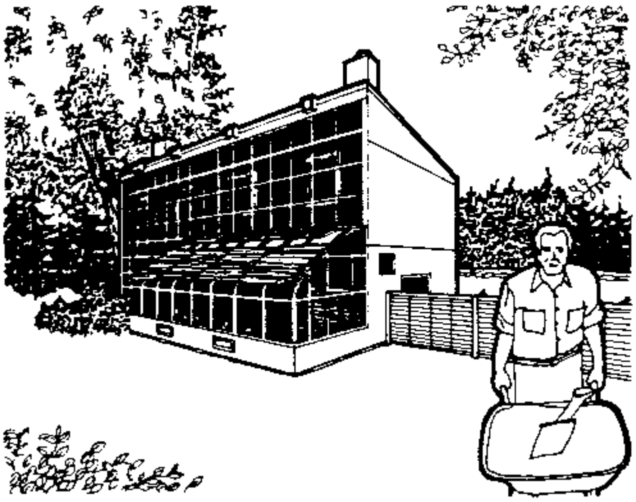
0-19 WALLASEY, ENGLAND: 1961
SOLAR HEATED SCHOOL

INTRODUCTION



0–20 NEW MEXICO: ca. 1970'S
DAVID WRIGHT DESIGN

The sun provides 90% of the annual energy requirements of a home built in 1974 by David Wright (FIG 0-20). Most of the nearly 500,000 btus collected each day are stored in the 2' thick adobe floor and 13" to 17" thick adobe wall, insulated with 2" of polyurethane foam, and enough heat can be stored to provide heat to the house for three to four sunless days. The interior space fluctuates between 58°F and 80°F during the winter.



0–21 PRINCETON, NEW JERSEY: 1975
DOUG KELBAUGH HOUSE

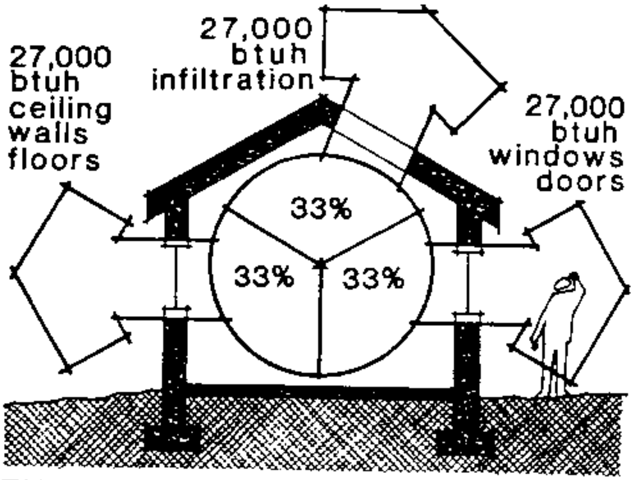
The Doug Kelbaugh home, (FIG 0-21) built in 1975 in Princeton, N.J., combines a Trombe wall with greenhouse. It overcomes the chief objection to placing thermal mass between the living space and the south-facing view by providing for windows to be installed in the Trombe wall. During 1976-77, the average temperature was 63°F downstairs and 67°F upstairs.

0–22 OMAHA, NEBRASKA: 1978
UNO PASSIVE SOLAR TEST PROJECT

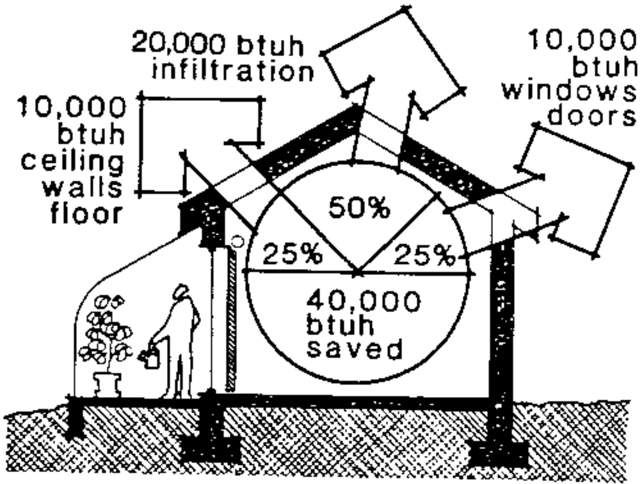
Begun in 1978, the Passive Solar Energy Test Facility, located at the University of Nebraska at Omaha, now ranks as one of the largest passive solar test facilities in the world (FIG 0-22). The study of different passive solar heating techniques has been heavily emphasized, especially those that are suited to northern climates. Greenhouse, earth sheltered, and super-insulated test rooms have been built at the test site. The only double shell or continuous thermal envelope test room known to be in existence has been undergoing monitoring since 1979. Experiments with cooling tubes and testing of commercial products are planned. The Passive Solar Research Group (PSRG), consisting of volunteer faculty and students, manages the test facility.

WHY PASSIVE SOLAR ENERGY?

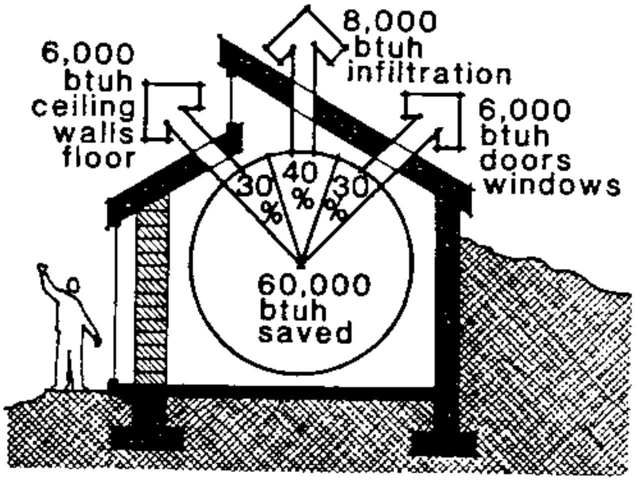
Passive solar heating technology has been proven to be a viable, cost-effective, maintenance-free, low technology, and almost universally applicable strategy in the field of energy efficient house design (FIG 0-23). Because conservation is a cornerstone of any passive solar energy strategy, a solar-conscious home will reduce energy consumption by 50% or more. For those solar structures which have been optimally designed, the savings can amount to 80% or better compared to a conventionally-designed home. It appears that passive solar energy is one of the principal strategies which will be utilized by the homeowner to combat the inevitable upward spiral of home energy costs.



TYPICAL HOUSE IN JANUARY
(80,000 btuh loss)



SOLAR CONSCIOUS HOUSE
(40,000 btuh loss)

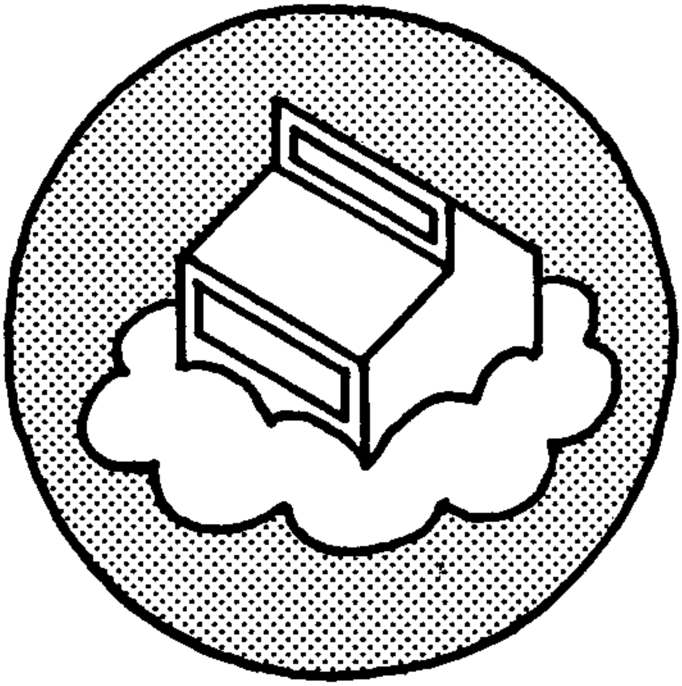


OPTIMUM SOLAR HOUSE
(20,000 btuh loss)

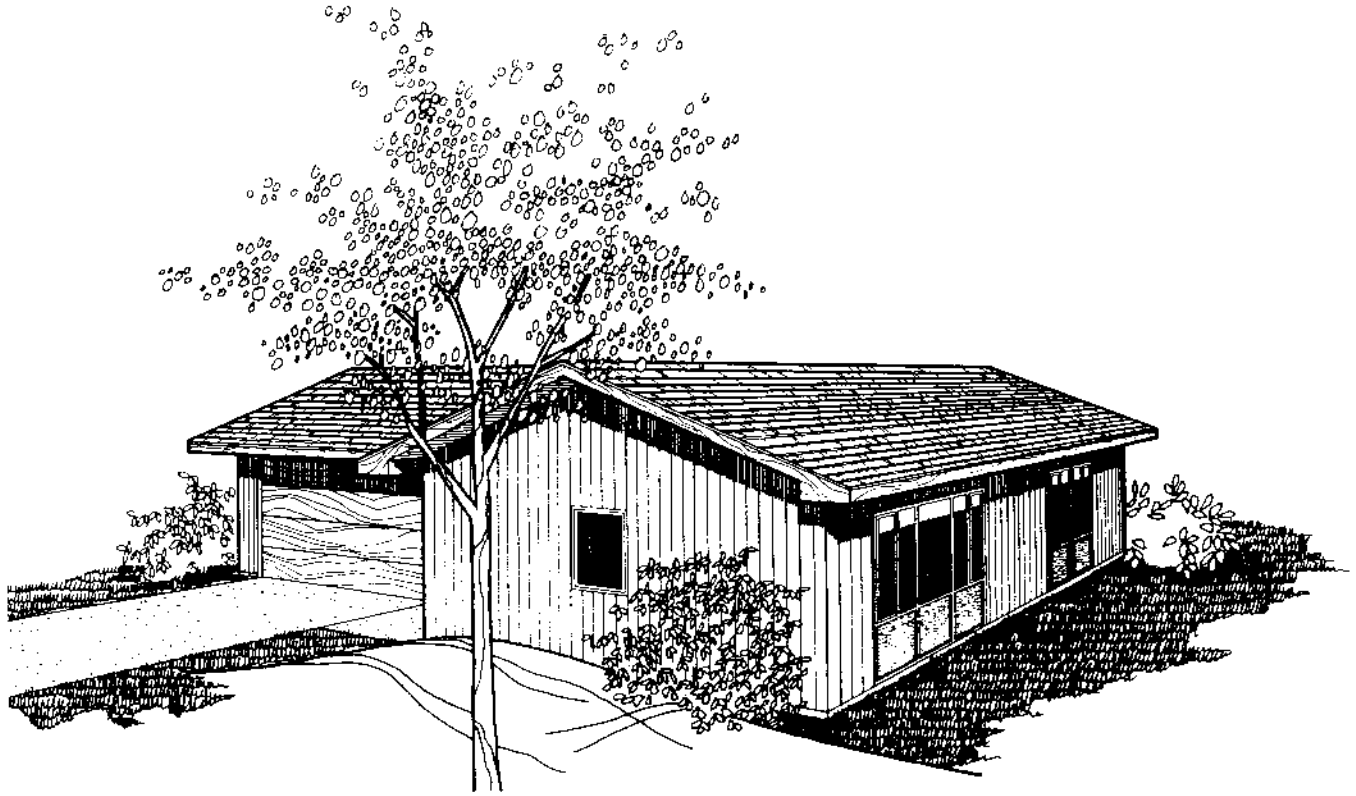
0-23 WHY SOLAR?

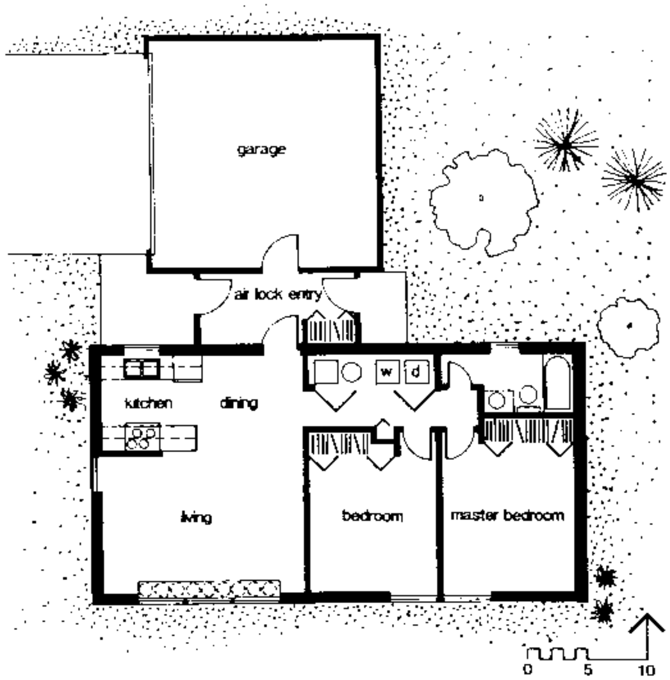
CHAPTER 9
EXAMPLE PROJECTS

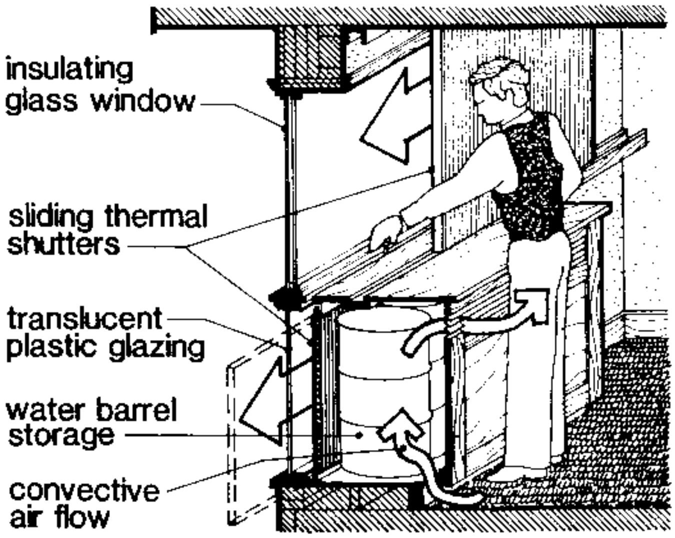
A number of projects involving passive solar heating techniques are presented in this chapter as examples which have succeeded in achieving a certain measure of energy self sufficiency.



EXAMPLE PROJECTS







EXAMPLE PROJECTS

GRANDVIEW AND ISLANDER

ENERGY KEYWORDS: DIRECT GAIN, WATERWALL MASS, SUPER INSULATION, UNIVERSAL SITING

DESIGN PARAMETERS: Develop plans that could be built for competitive prices and fit on a standard 60 x 100 city lot.

ENERGY CONCEPTS: Reduce energy consumption by 80% in comparison to the conventional tract home. This is achieved through the use of either of two variations: 1) a double 2x4 stud wall construction with a small amount of glass area or 2) greater glass area with a single 2x6 stud wall construction.

DESIGN SPECIFICS: The Islander is a single-story dwelling and the Grandview is a two-story dwelling. Both can be regarded as "typical" designs which on the surface are no different than any other standard tract home.

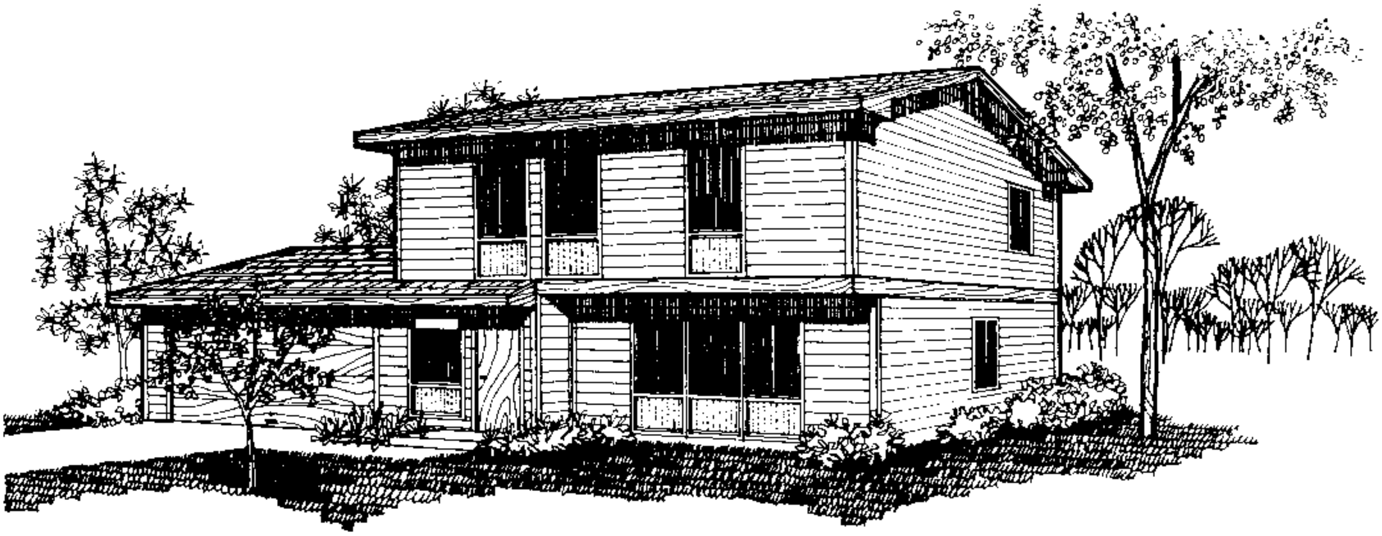
GRANDVIEW
(on the previous page)

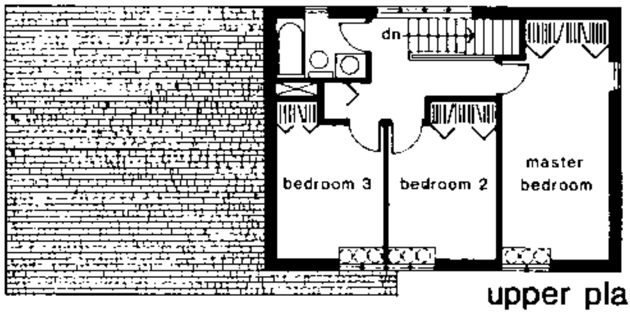
FLOOR AREA: 1100 sq ft
with garage and optional basement
SOUTH GLAZING: 108 sq ft
R VALUES: Walls R-38, Roof R-60
OTHER COMMENTS:

1. Optional master bath upstairs.
2. Optional domestic solar hot water heater.
3. Optional entry vestibule.
4. Optional vestibule on first floor.
5. Optional fireplace and vent openings for attic turbine.
6. Optional water storage beneath first floor windows with sliding insulating panel. Transluscent Lexan panels below windows to admit sunlight to heat storage.

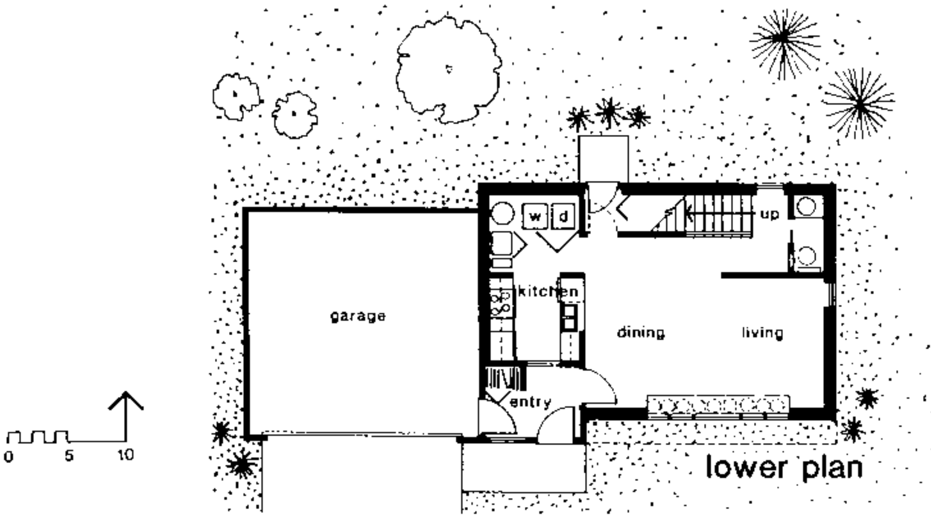
ISLANDER
(on opposite page)

FLOOR AREA:
living 924 sq ft
vestibule 84 sq ft
garage 400 sq ft
SOUTH GLAZING: 90 sq ft or 160 sq ft
OTHER SPECIFICATIONS SIMILAR TO THE GRANDVIEW



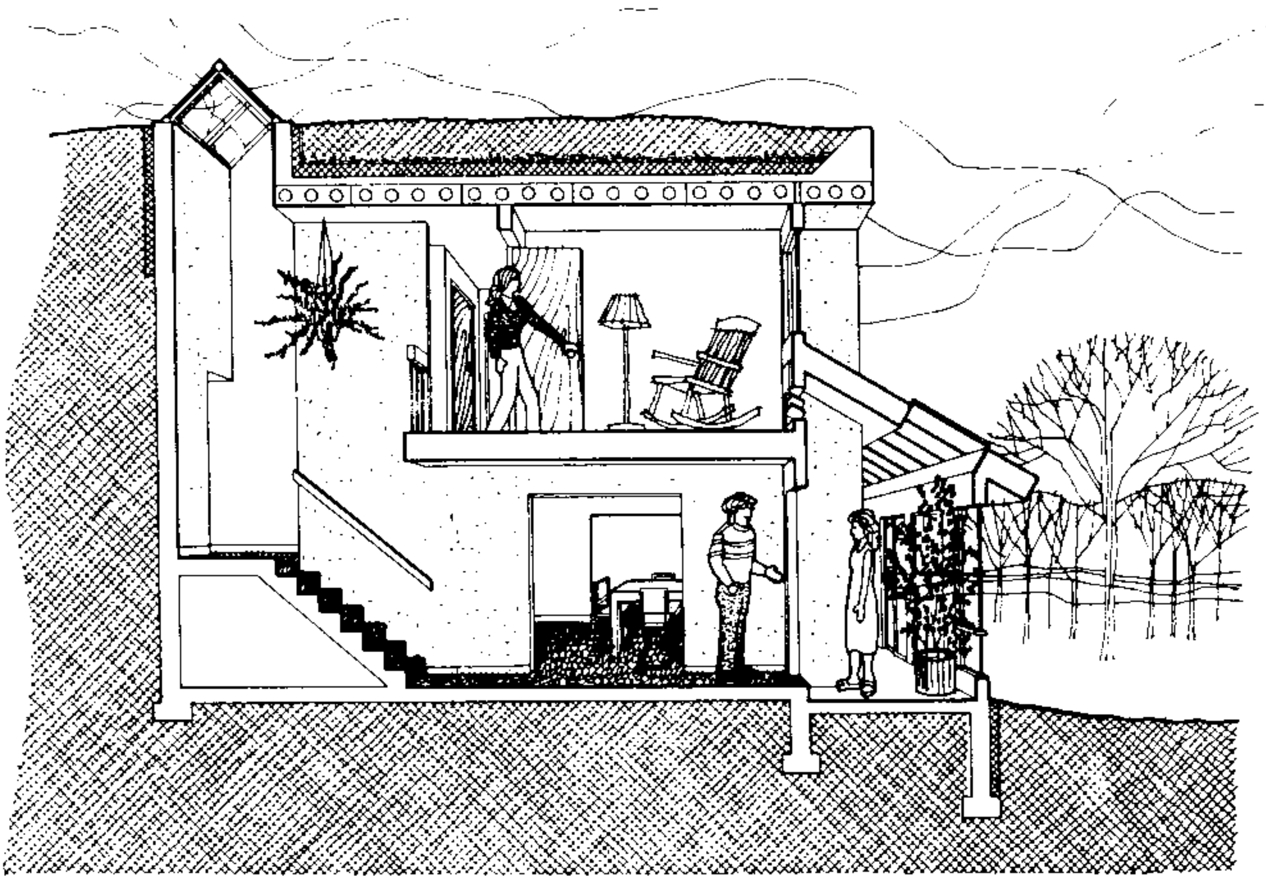


upper plan



lower plan

EXAMPLE PROJECTS



NELSON RESIDENCE KEARNEY, NEBRASKA

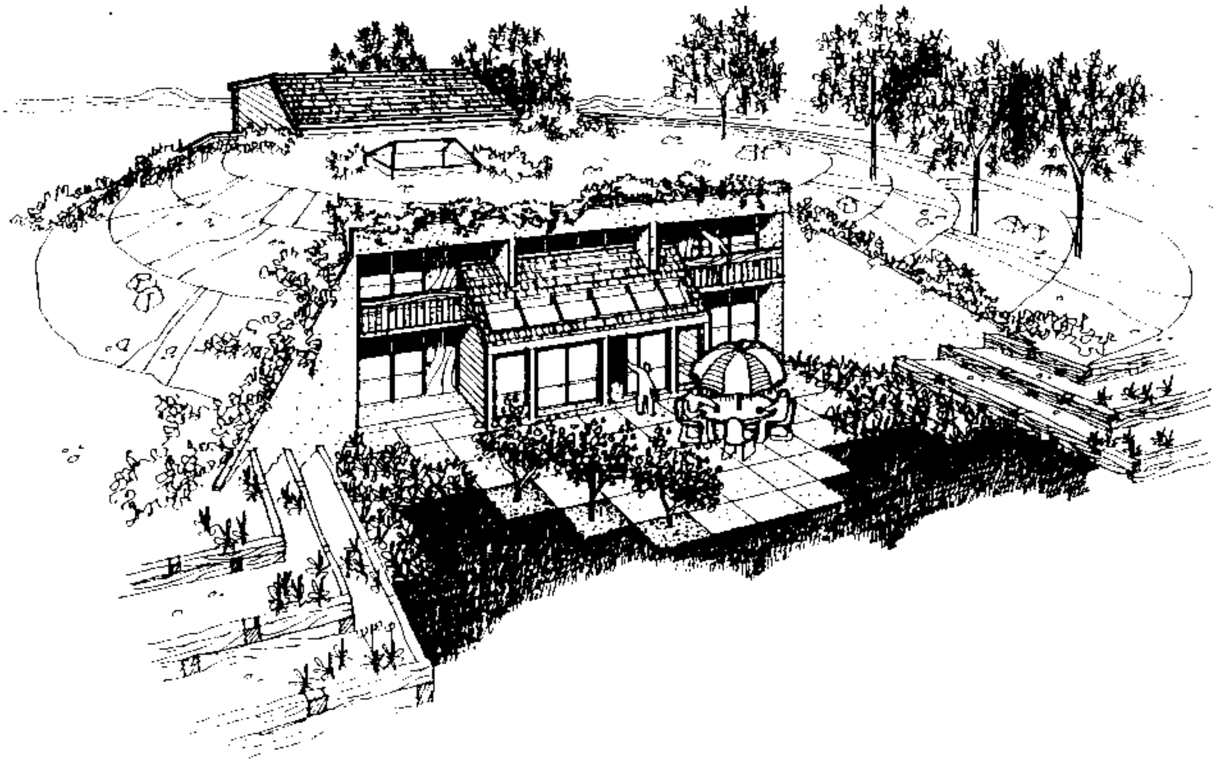
ENERGY KEYWORDS: DIRECT GAIN, THERMAL WALLS, GREENHOUSE, LIGHT WELL, SOLAR CONTROL, EARTH SHELTERING, AIRLOCK ENTRY, NATURAL COOLING

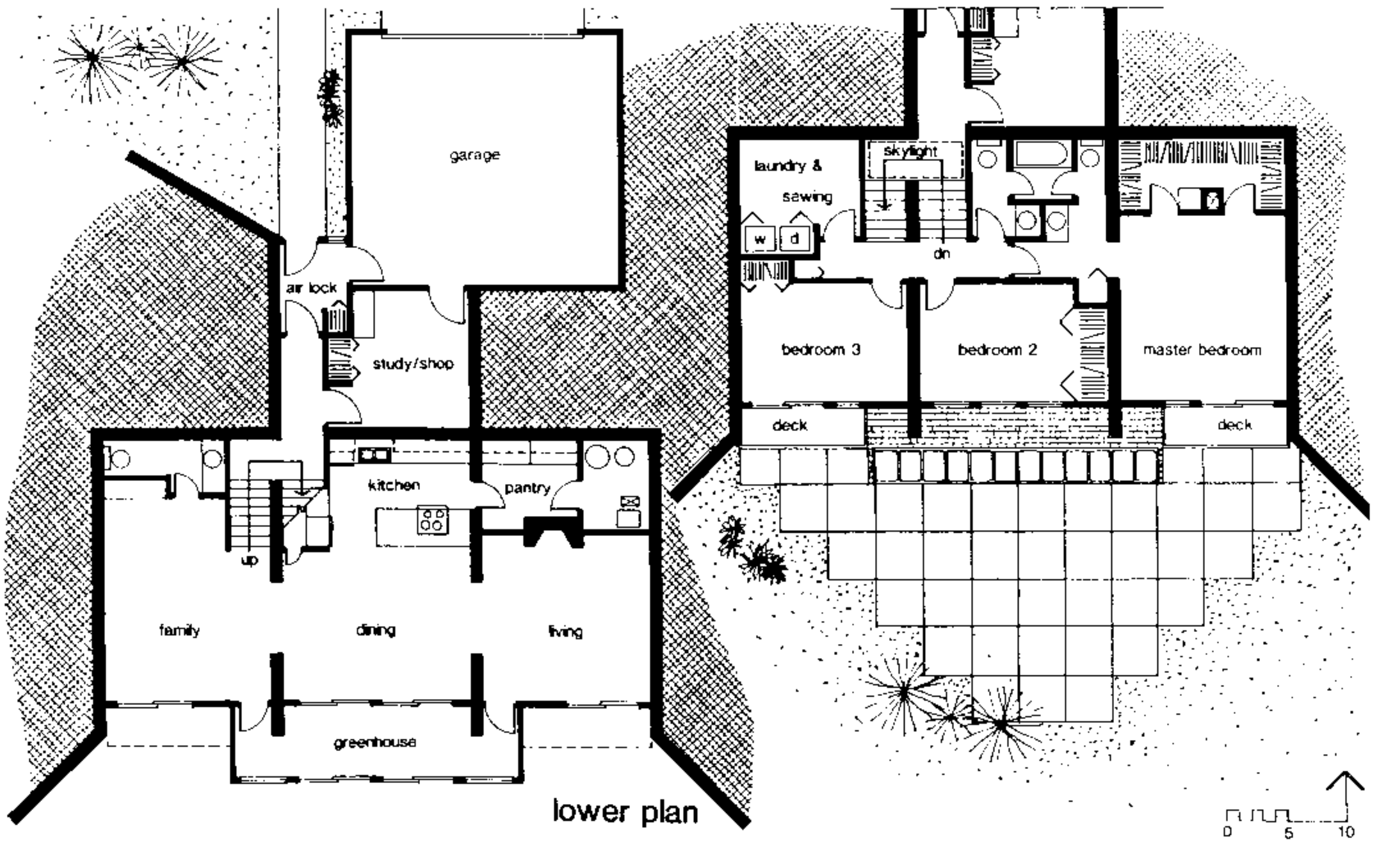
DESIGN PARAMETERS: Design a 3 bedroom residence to be compatible with its surroundings.

ENERGY CONCEPT: Earth sheltering, natural cooling, and passive solar design techniques were specified by the owner/builder team.

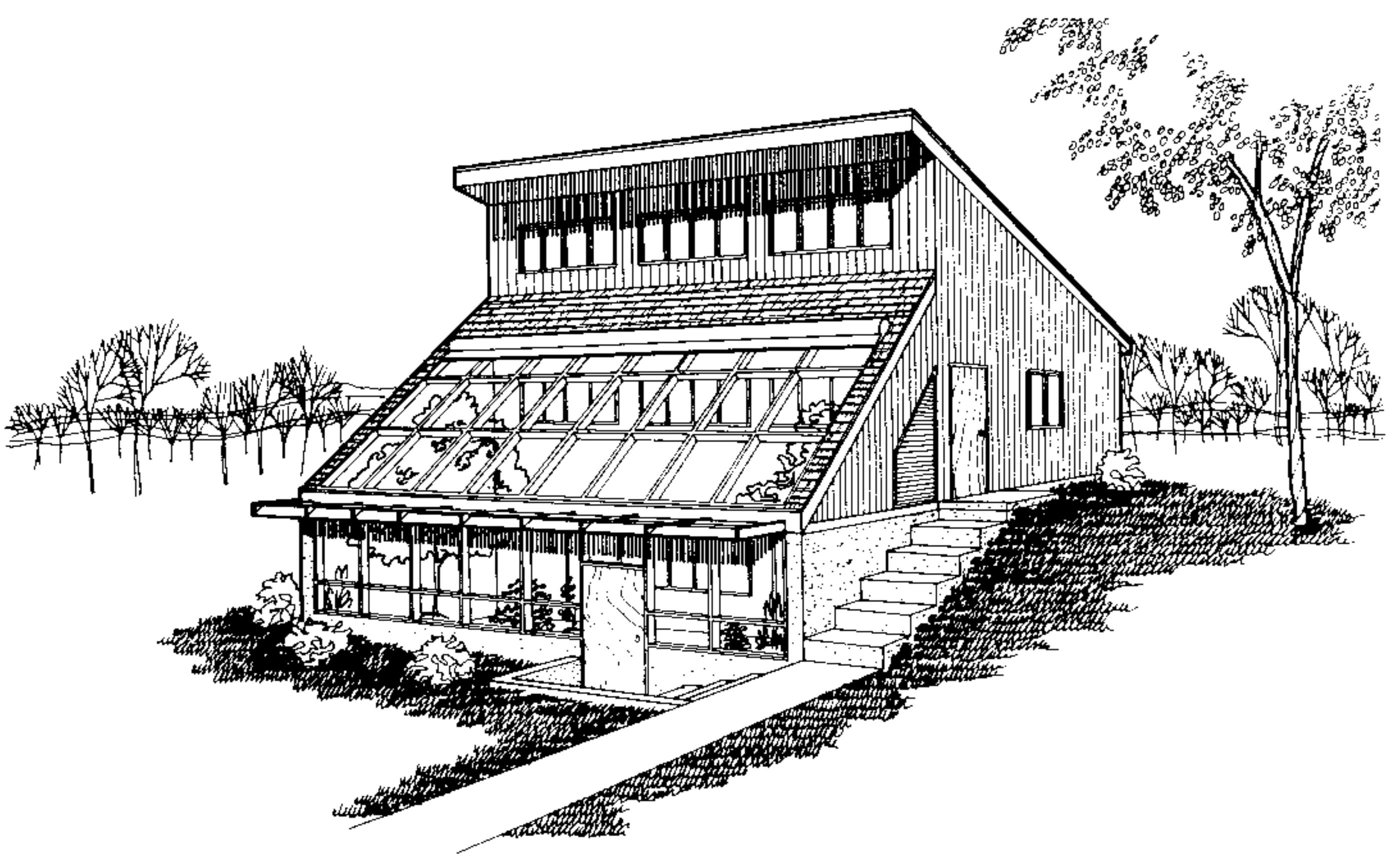
DESIGN SPECIFICS: The 2 story structure was designed to take advantage of a sloping site. The solar greenhouse integrates all six major living spaces. Bearing walls divide the house into three bays, defined by the ends of the solar greenhouse. The structure is poured concrete with precast horizontal roof slabs.

FLOOR AREA:	1st floor 1310 sq ft
	2nd floor 903 sq ft
	greenhouse 175 sq ft
	garage 433 sq ft
SOUTH GLAZING:	1st floor 64 sq ft
	2nd floor 86 sq ft
	greenhouse 130 sq ft
INSULATION:	Roof R-36
	South wall R-27
	Other walls R-34 for 1st 4 feet, R-2 for rest




garage
air lock
study/shop
kitchen
pantry
up
family
dining
living
greenhouse
lower plan
laundry &
sewing
skylight
w
d
dn
bedroom 3
bedroom 2
master bedroom
deck
deck
0
5
10

EXAMPLE PROJECTS



MORAN RESIDENCE AUBURN, NEBRASKA

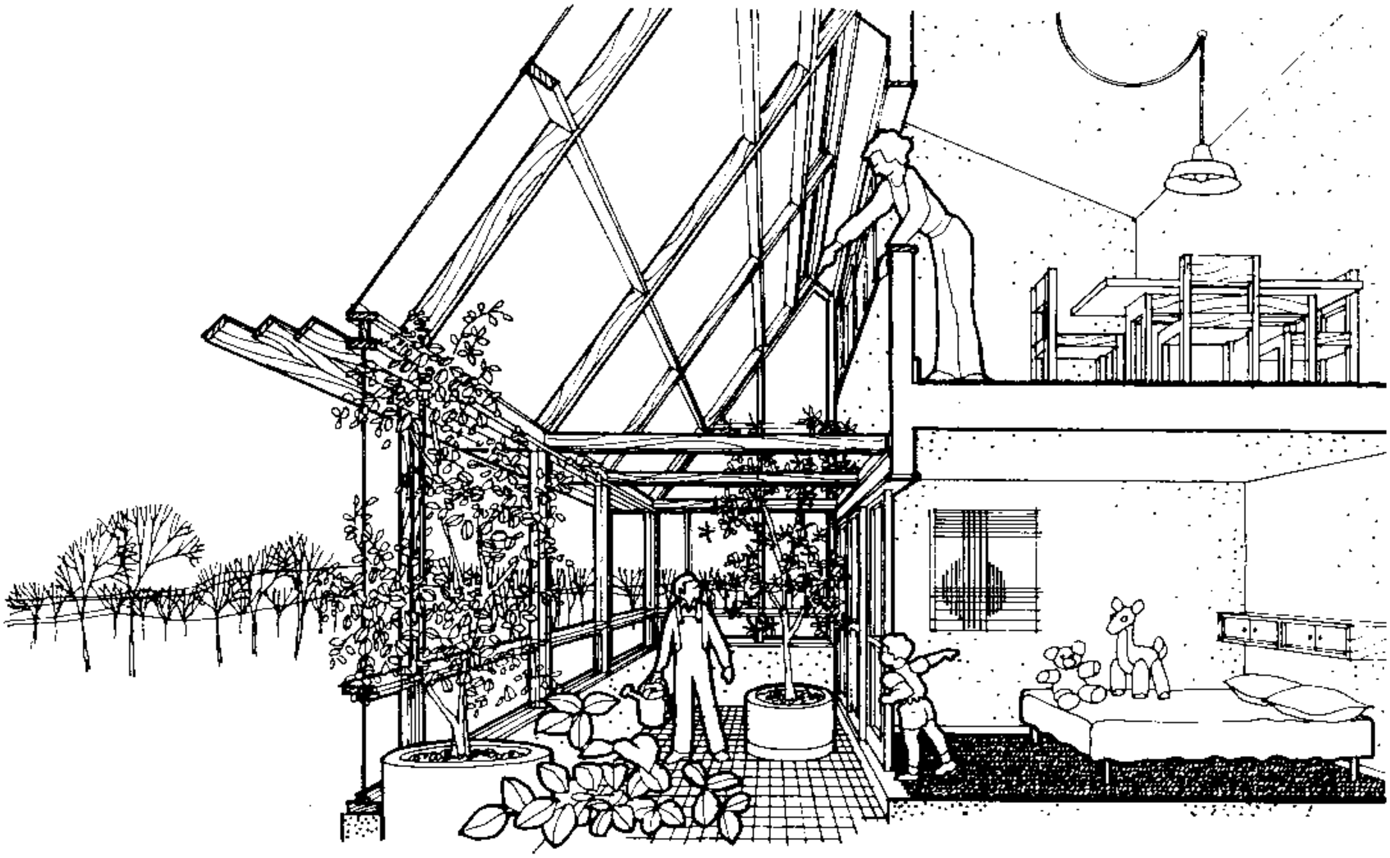
ENERGY KEYWORDS: DIRECT GAIN, GREENHOUSE, CLERESTORY, EARTH BERM

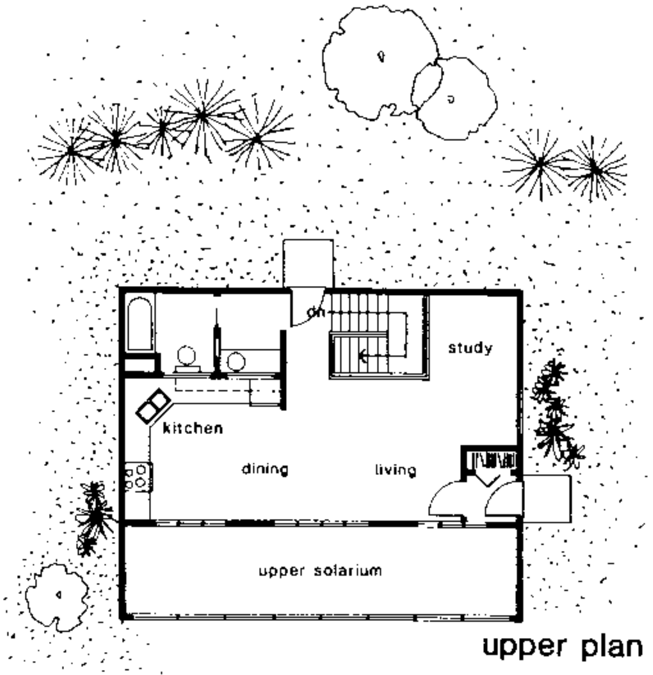
DESIGN PARAMETERS: Develop a solar-conscious home on a budget under $40,000.

ENERGY CONCEPTS: A greenhouse (solarium) was incorporated as the major passive solar energy system. A clerestory provides some direct gain to the upper level living areas.

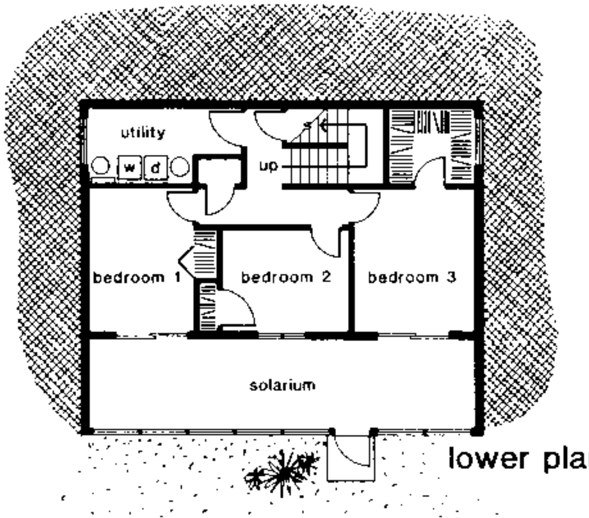
DESIGN SPECIFICS: There are three bedrooms located on the lower level. A full bath would have been desireable but was not adopted for the lower level. The floor plan exudes economy of space and has an airlock entry.

FLOOR AREA: Upper Living 572 sq ft
Lower Bedroom 537 sq ft
Greenhouse 239 sq ft
SOUTH GLAZING: Clerestory 45 sq ft
Sloped area 320 sq ft
with double filon
Bedroom 111 sq ft
INSULATION: WALLS R-19
ROOF R-32

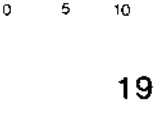




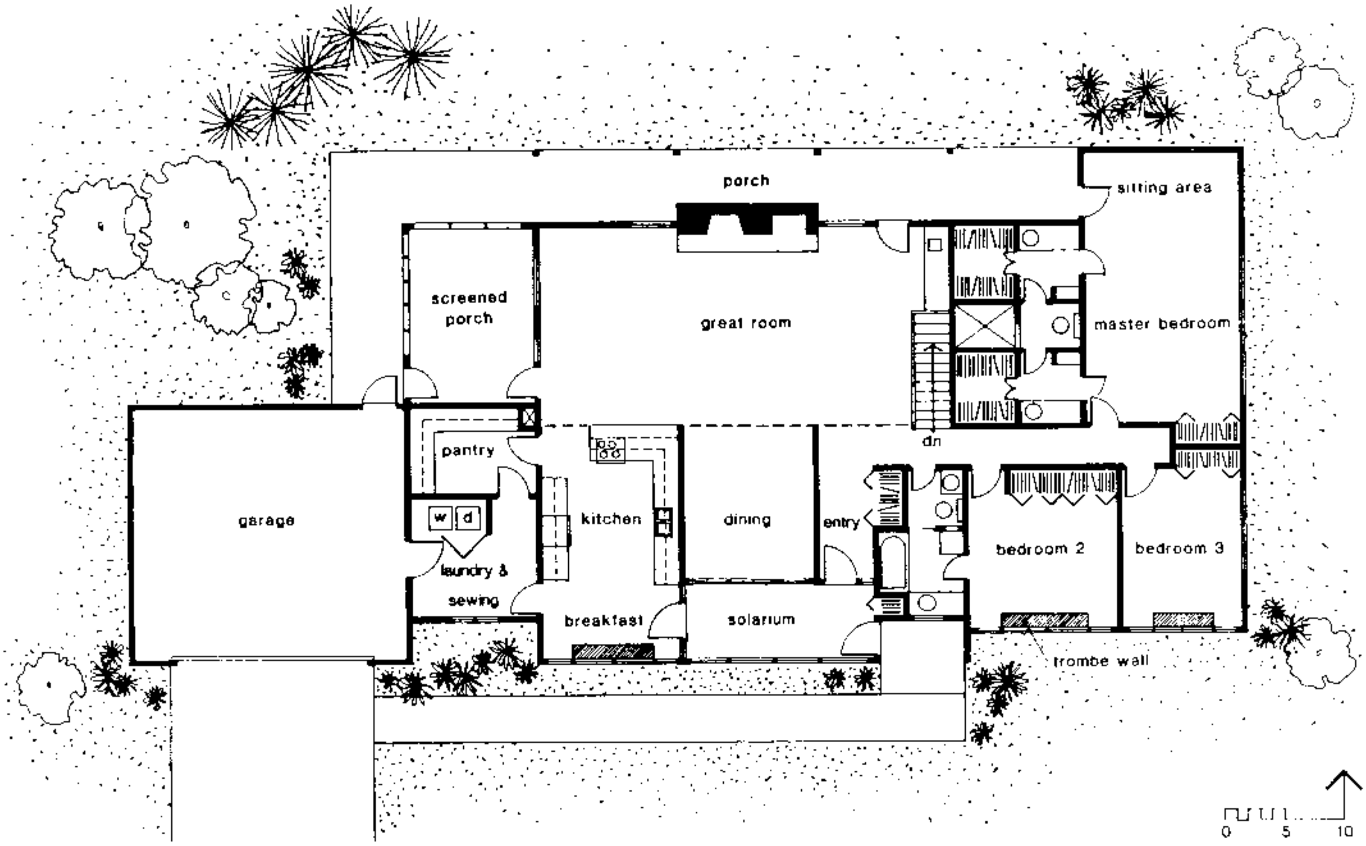
upper plan



lower plan



EXAMPLE PROJECTS



RANCH STYLE OMAHA, NEBRASKA

ENERGY KEYWORDS: DIRECT GAIN, TROMBE WALL, GREENHOUSE, CLERESTORY AND SOLARIUM VESTIBULE

DESIGN PARAMETERS: Create an open and airy solar home with the great room as central focus.

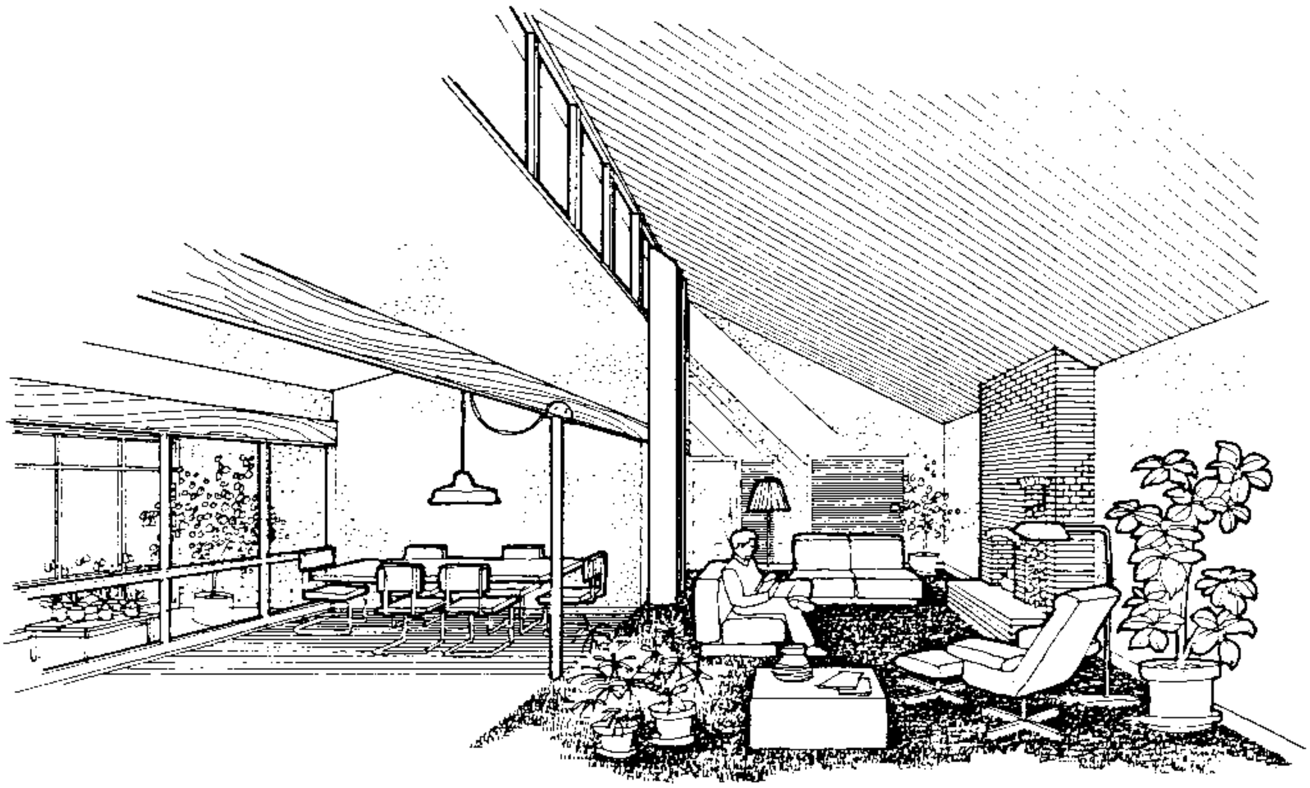
ENERGY CONCEPTS: Clerestory windows serve to admit sunlight to master bedroom and great room. The solarium provides an airy and sunny aspect to the dining area. Trombe walls provide delayed heat to two bedrooms and kitchen area and provide additional privacy.

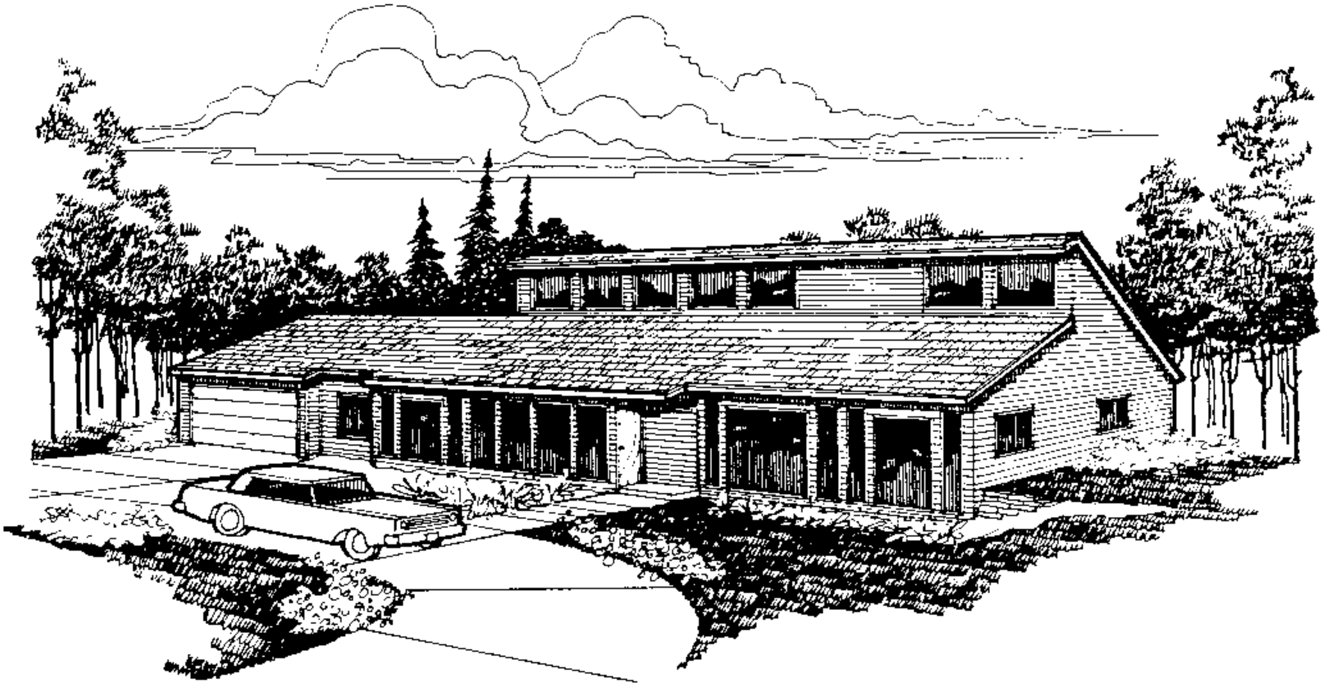
DESIGN SPECIFICS: The home is a single story ranch style with three bedrooms and two baths. Airlock vestibule entries are cleverly disguised as a solarium for the main entry and as a laundry room for the garage entry point. A clerestory window area provides a vaulted space for the great room. A screened porch is located off the great room. The great room contains a large central fireplace. A porch surrounds both the great room and screened-in porch. In the summer, the western part of this porch provides shading to the west of the screened in porch. Thus the porch serves as a continuous tie-in from the master bedroom on the east side of the home all the way to the garage which anchors the west side.

FLOOR AREA: Living 1925 sq ft
Solarium 110 sq ft
Screened porch 110 sq ft
Garage 480 sq ft

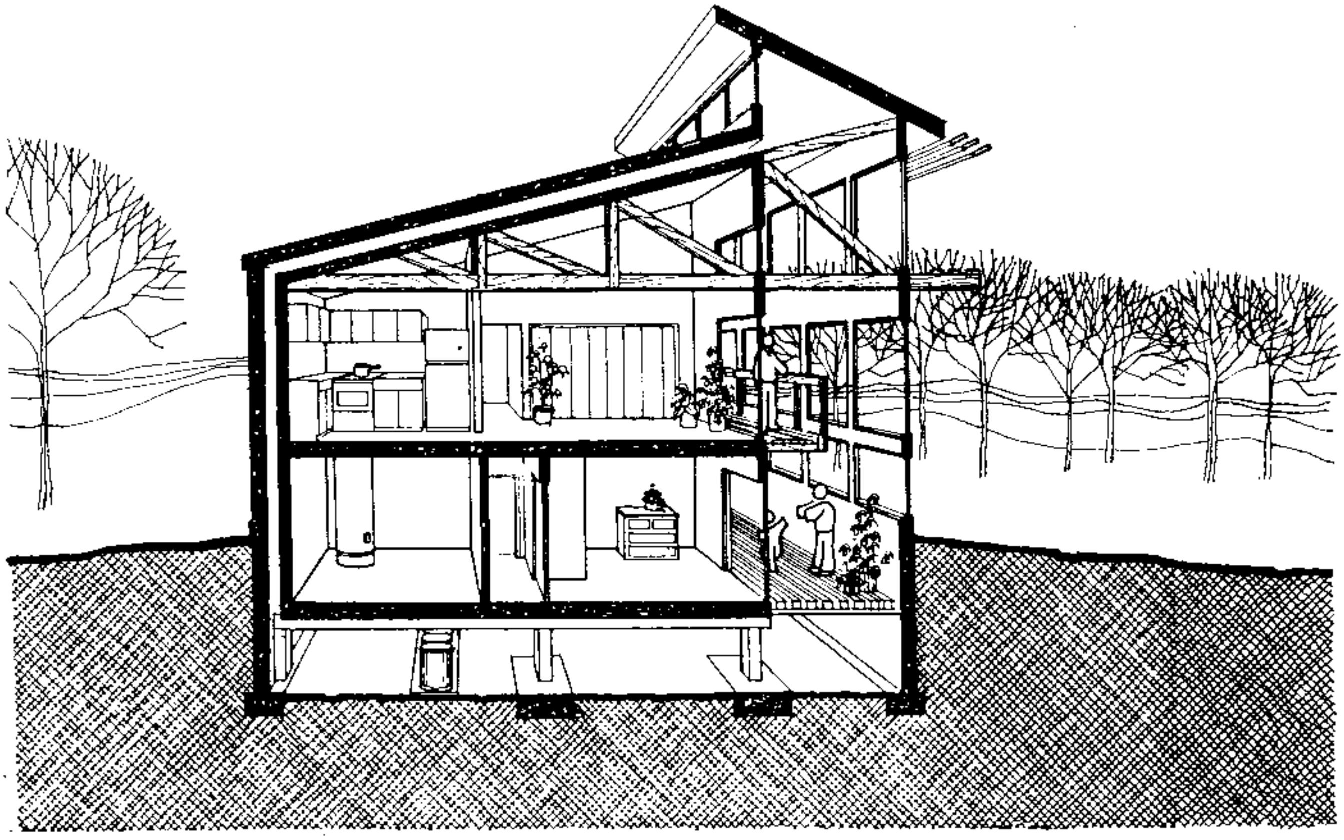
SOUTH GLAZING:
Clerestory window 140 sq ft
Trombe walls 125 sq ft
Remaining 200 sq ft

INSULATION:
WALLS R-27
CEILING R-38





EXAMPLE PROJECTS



DOUBLE SHELL HOME COLUMBUS, NEBRASKA

ENERGY KEYWORDS: DOUBLE SHELL, GREENHOUSE, NORTH-FACING CLERESTORY VENTILATION

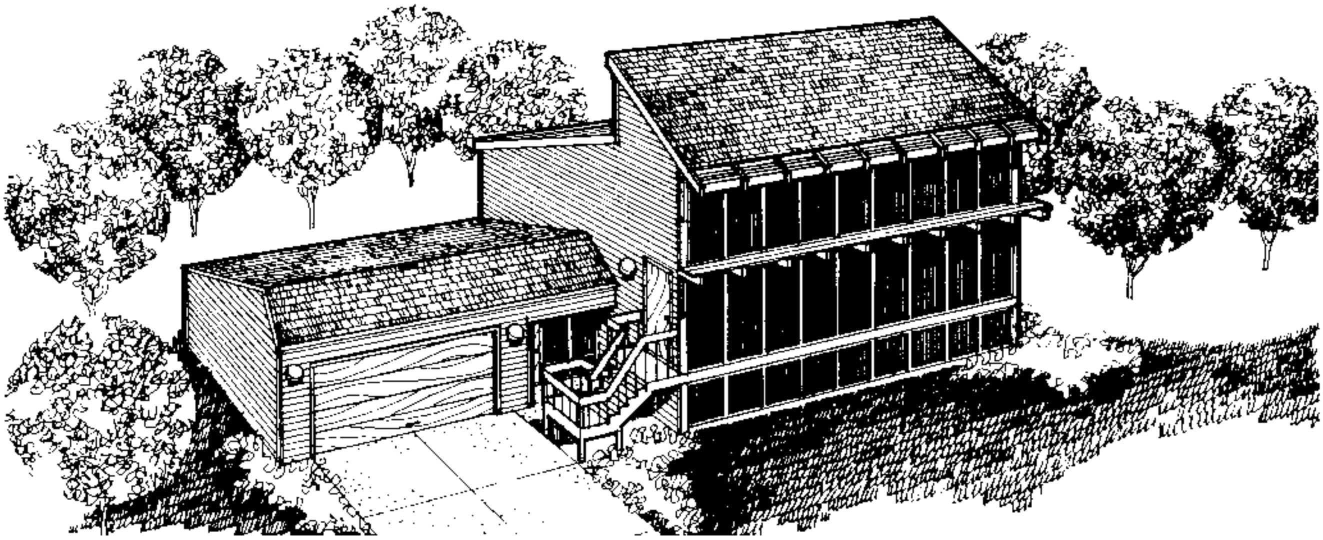
DESIGN PARAMETERS: Develop a 2-story double shell home utilizing the upper story as primary living space.

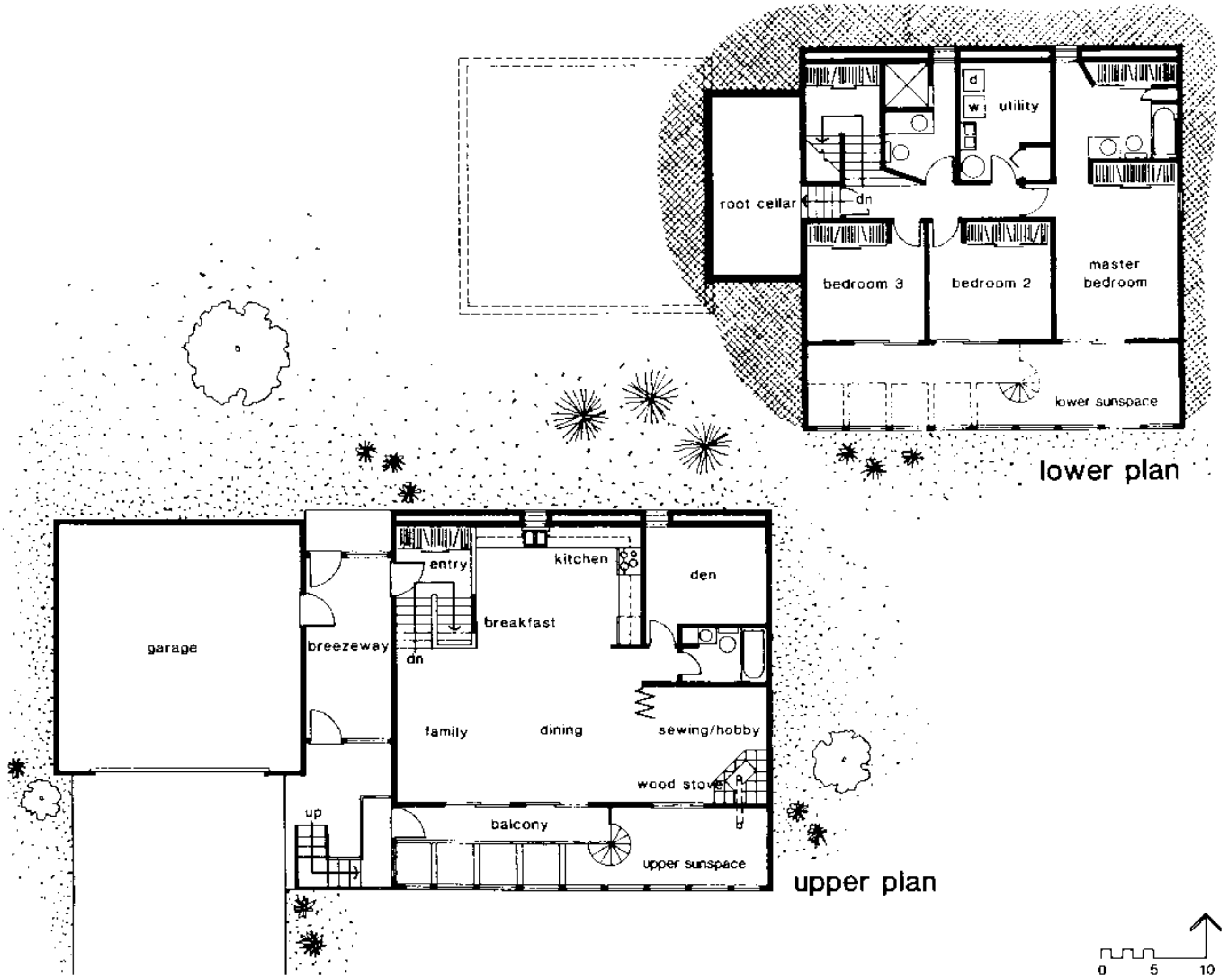
ENERGY CONCEPT: This double shell design includes a greenhouse which bathes the roof and north wall area with warm air. The crawl space provides additional storage of excess heat.

DESIGN SPECIFICS: The bedrooms are on the lower floor in this floor plan to take advantage of the way the space is utilized -- as the family tends to congregate in the living areas, which have been designed with cathedral ceilings, during the daylight hours. In a double shell the warmest daylight locations are in the upper floors.

FLOOR AREA:
Lower Level: Living 758 sq ft
Sunspace 283 sq ft
Upper Level: Living 855 sq ft
Balcony 60 sq ft
Breezeway 136 sq ft
Garage 544 sq ft
SOUTH GLASS: 500 sq ft
INSULATION:
Exterior East & West Walls R-27
Exterior South Wall R-19
Exterior North Wall R-27
Roof R-18
Inner Walls R-11 (R-18 in ceiling)
OTHER COMMENTS

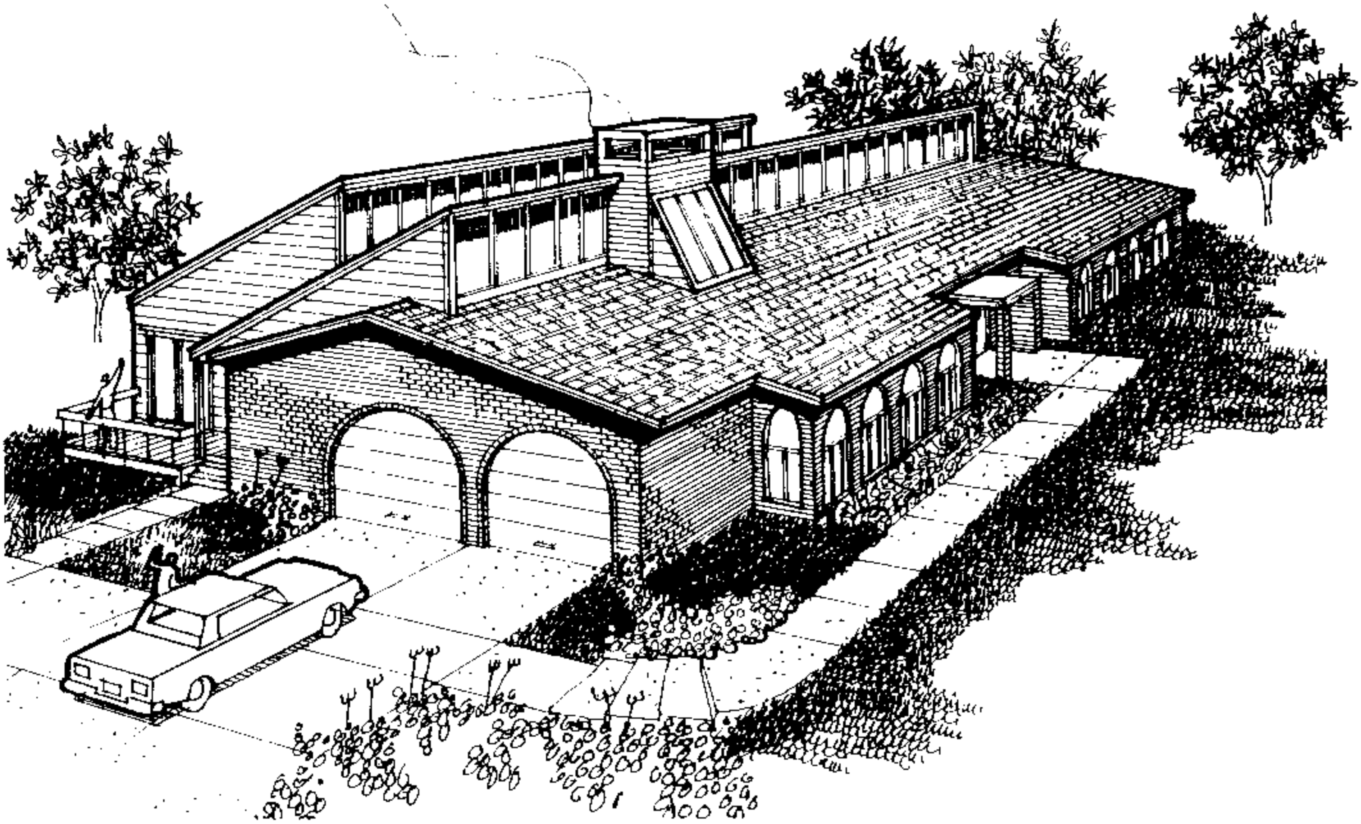
1. Crawl space designed for 2" slab.
2. No night shutter system.
3. Water barrels in crawl space for additional storage.
4. Air envelope between walls is 8" thick.
5. Operable north-facing clerestory windows take advantage of prevailing summer winds.





root cellar
dn
d
w
utility
bedroom 3
bedroom 2
master bedroom
lower sunspace
lower plan
garage
breezeway
entry
kitchen
den
breakfast
dn
family
dining
sewing/hobby
wood stove
up
balcony
upper sunspace
upper plan
0
5
10

EXAMPLE PROJECTS



VOLLERTSEN RESIDENCE HAMBURG, IOWA

ENERGY KEYWORDS: DIRECT GAIN, CLERESTORY, GREENHOUSE, ACTIVE FLAT PLATE DOMESTIC HOT WATER HEATER, POOL WATER HEATER, AIR TO AIR HEAT EXCHANGER

DESIGN PARAMETERS: Develop an energy-conscious, spacious home centered about the indoor swimming pool and whirlpool.

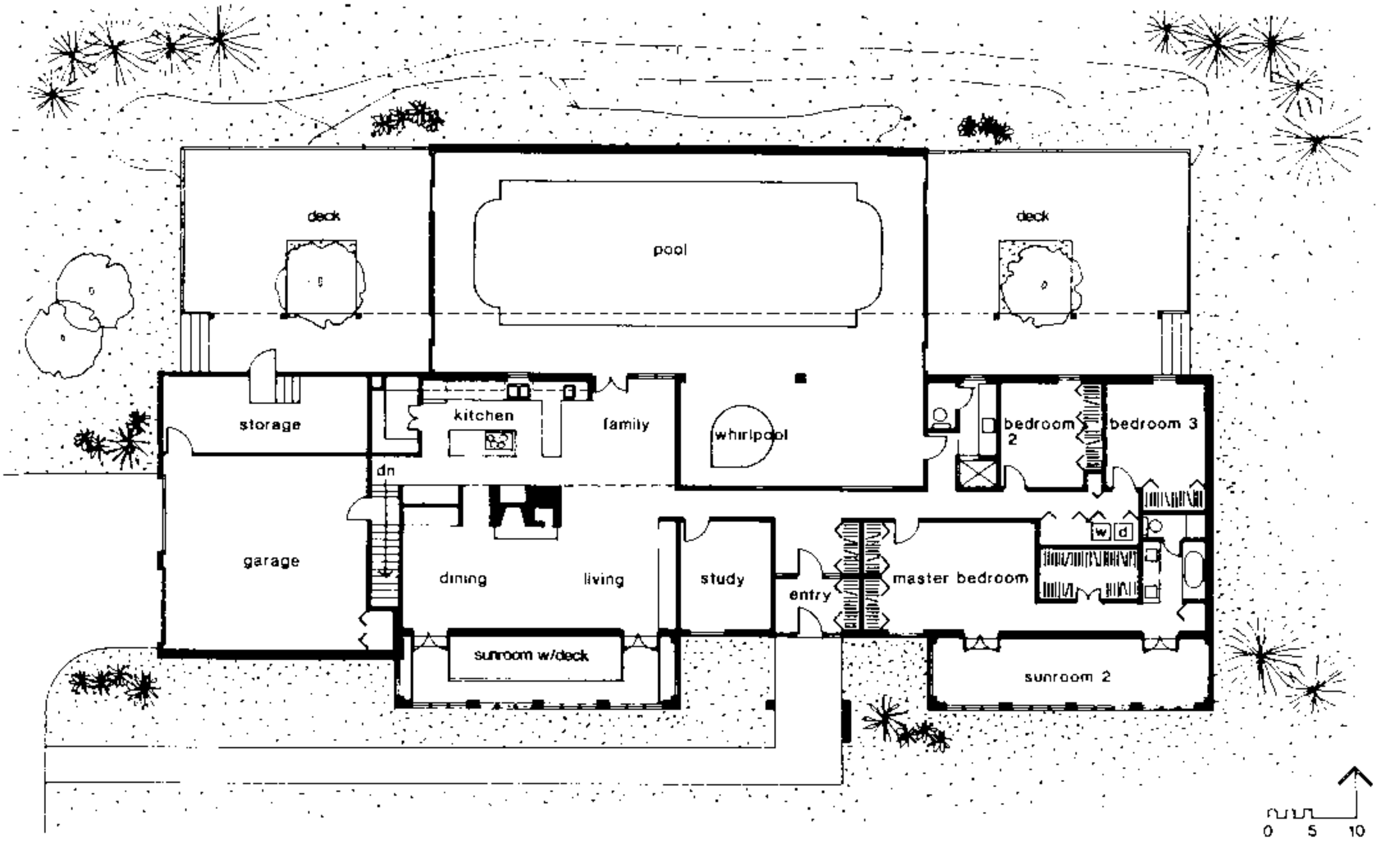
ENERGY CONCEPT: The greenhouse passive solar heating technique is utilized along the south side of the home by the master bedroom and the living room - dining room area. For the bedrooms and kitchen area there is a direct gain passive solar collection system using a clerestory window concept. A second clerestory is used for the swimming pool area. Air must be vented from the pool area in order to maintain acceptable humidity levels. An air to air heat exchanger captures most of the heat from the vented air. Flat plate collectors are used to provide domestic hot water heating.

DESIGN SPECIFICS: The living-dining room and bedroom are anchored by sunspaces. Dark indoor brick located throughout the home serves as thermal mass. The north wall of the swimming pool consists of 12" of concrete which serves as additional thermal mass to store solar energy.

FLOOR AREA:	House 2254 sq ft
	Pool 1792 sq ft
	Sunrooms 512 sq ft
	Basement 1008 sq ft
	Garage 764 sq ft
INSULATION:	Roof R-38 to R-44
	Walls R-20
GLAZING:	Greenhouse 215 sq ft
	Clerestory: 700 sq ft (293 sq ft pool and 407 sq ft in living areas)

Special features:

1. 320 sq ft active flat plate collector for pool water heating.
2. Active solar domestic hot water heater with 82 gallon storage.
3. Air to air heat exchanger for exhausting humid pool air.


deck
pool
deck
storage
kitchen
family
whirlpool
bedroom 2
bedroom 3
dn
garage
dining
living
study
entry
master bedroom
w
d
sunroom w/deck
sunroom 2
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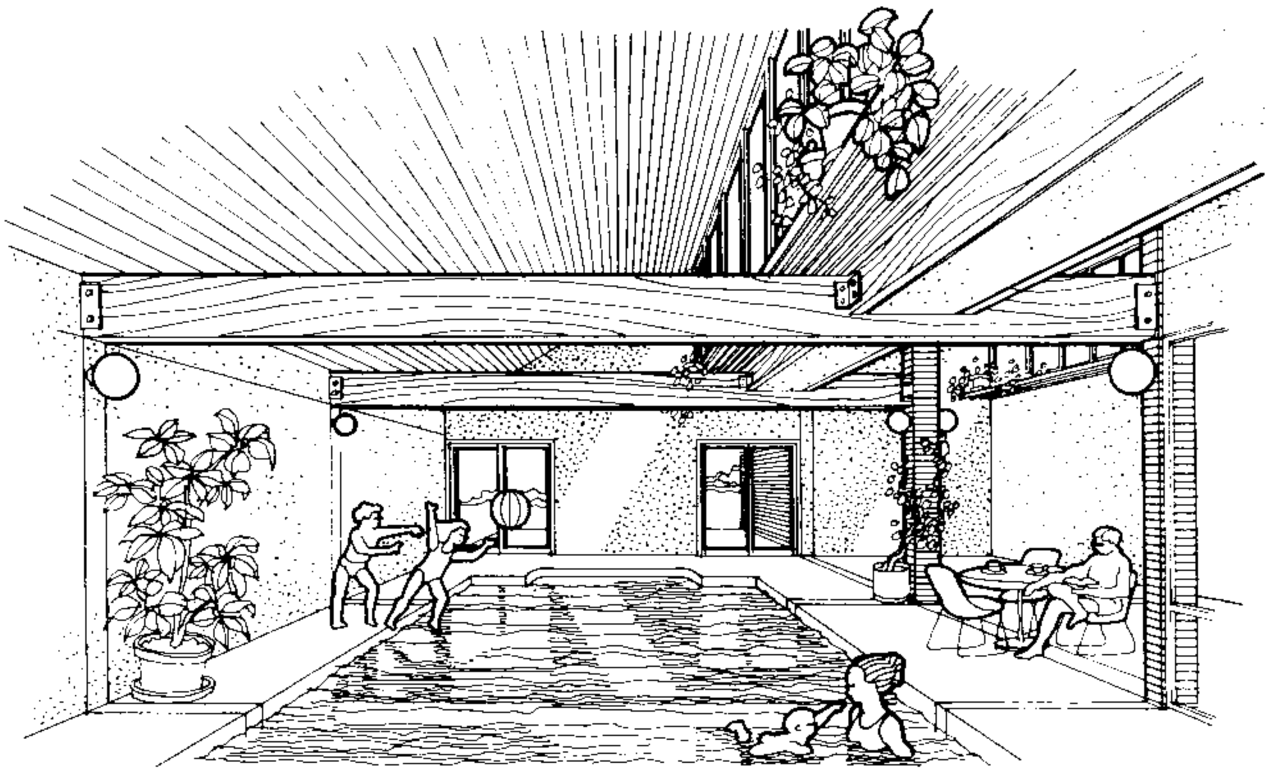
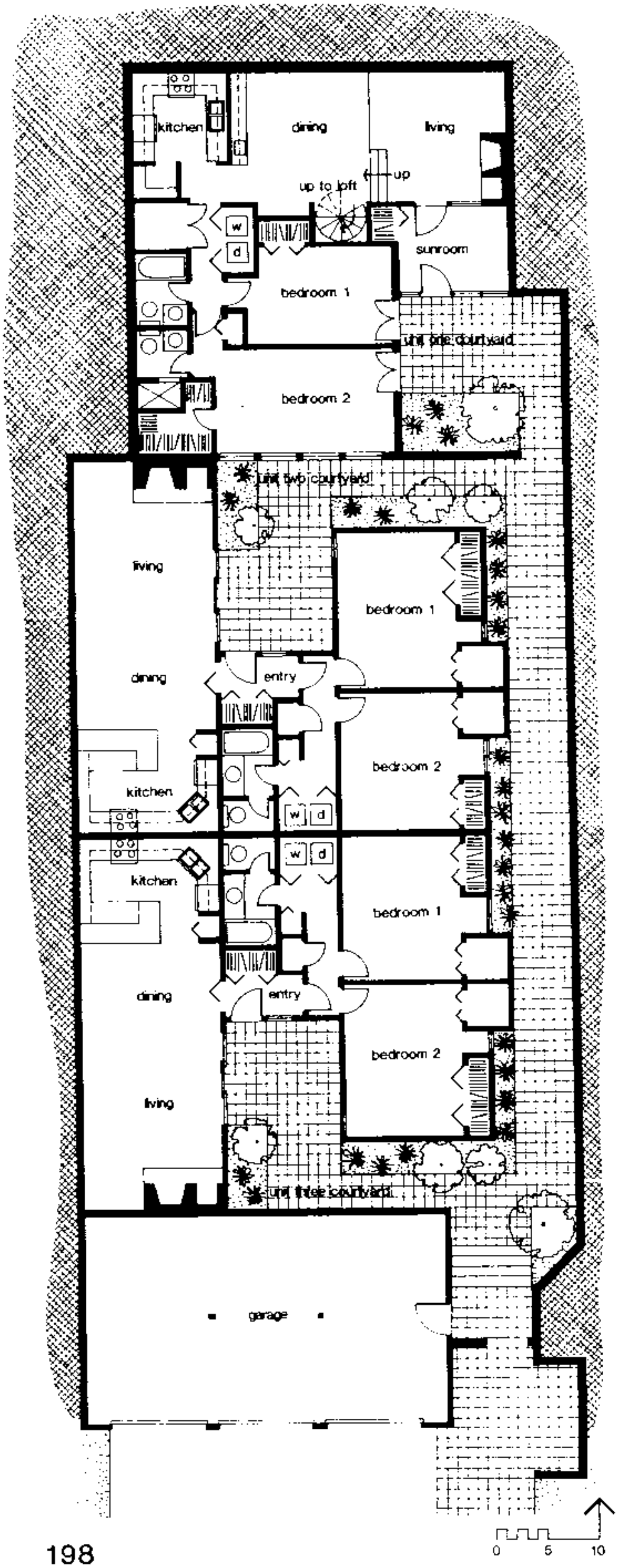
5
10





TRIPLEX OMAHA, NEBRASKA

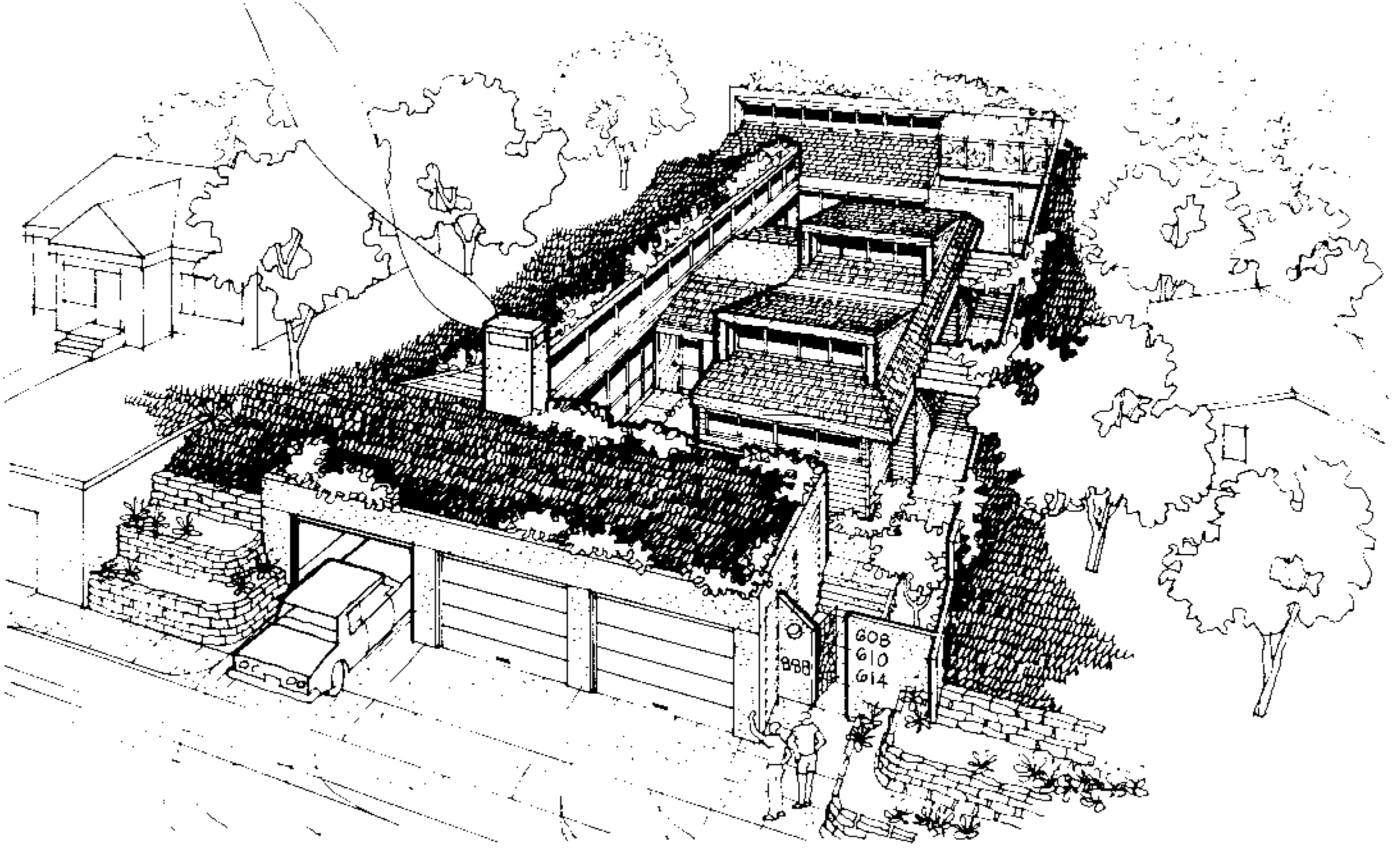
ENERGY KEYWORDS: DIRECT GAIN, GREENHOUSE, CLERESTORY, EARTH SHELTERING

DESIGN PARAMETERS: Create an earth sheltered, energy efficient multi-family urban residence that makes optimum use of the entire lot.

ENERGY CONCEPT: Earth sheltering, natural cooling, and passive solar heating for multi-family housing are utilized in this design. Electric downflow furnaces will provide the back-up heating for the minimal load. Fireplaces in each of the units can be used to raise interior space temperatures.

DESIGN SPECIFICS: The triplex is sited on a single house site in an urban setting. Because of the earth sheltering, zero lot line was utilized. Each unit has two bedrooms and two bathrooms. South-facing clerestories have been incorporated to capture solar energy. Losses are partially offset by the use of night shutters. The north unit contains a greenhouse entry and a loft space which is directly lit by its own clerestory. Private courtyards are employed to provide a means to draw the outside into the living spaces. A cathedral ceiling is incorporated in each of the three units.

FLOOR AREAS:
Middle and south unit 1025 sq ft
North unit 1050 sq ft main floor
and 425 sq ft in loft space
Garage 710 sq ft
SOUTH GLAZING:
Middle and south units 90 sq ft
North unit clerestory 80 sq ft
greenhouse 150 sq ft



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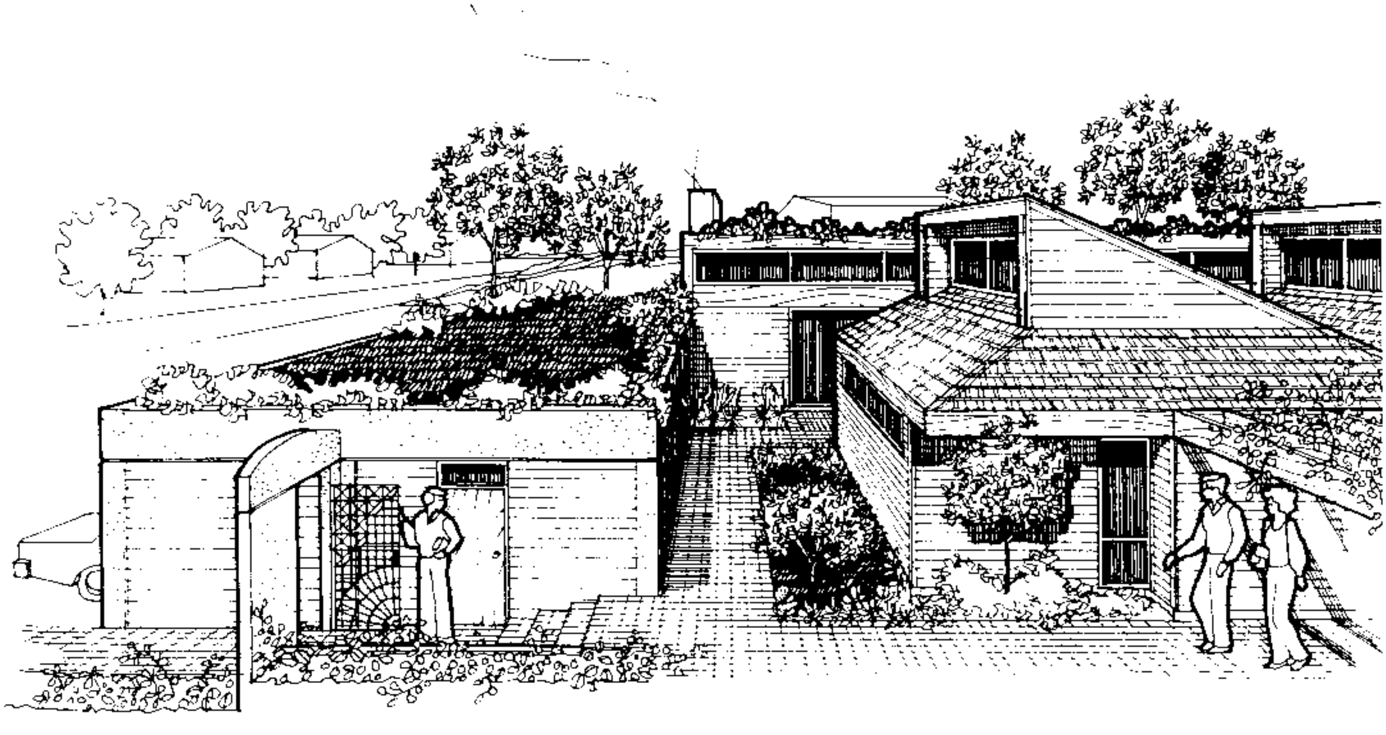
614



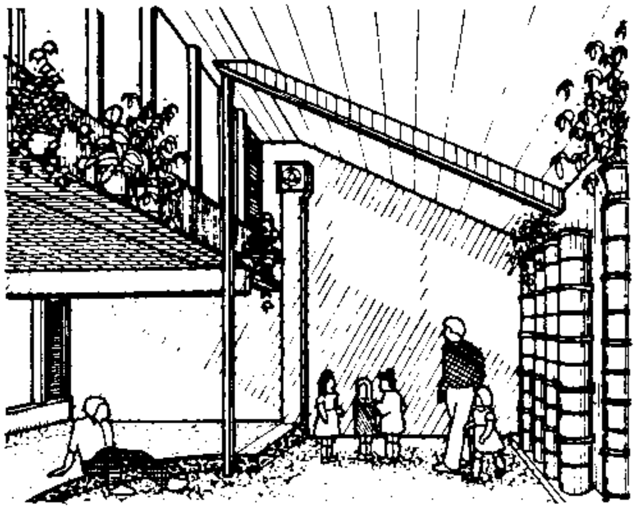
PRESCHOOL OMAHA, NEBRASKA

ENERGY KEYWORDS: DIRECT GAIN, CLERESTORY, WATER MASS, FLOOR MASS, INSULATION, MOVABLE INSULATION, RADIANT ELECTRIC AUXILIARY

DESIGN PARAMETERS: Create a one-room open plan schoolhouse that exemplifies the strengths of early American schooolhouses: self-sufficiency, energy common sense, academic teamwork, simplicity, human sensitivity, construction economy and low operational cost.

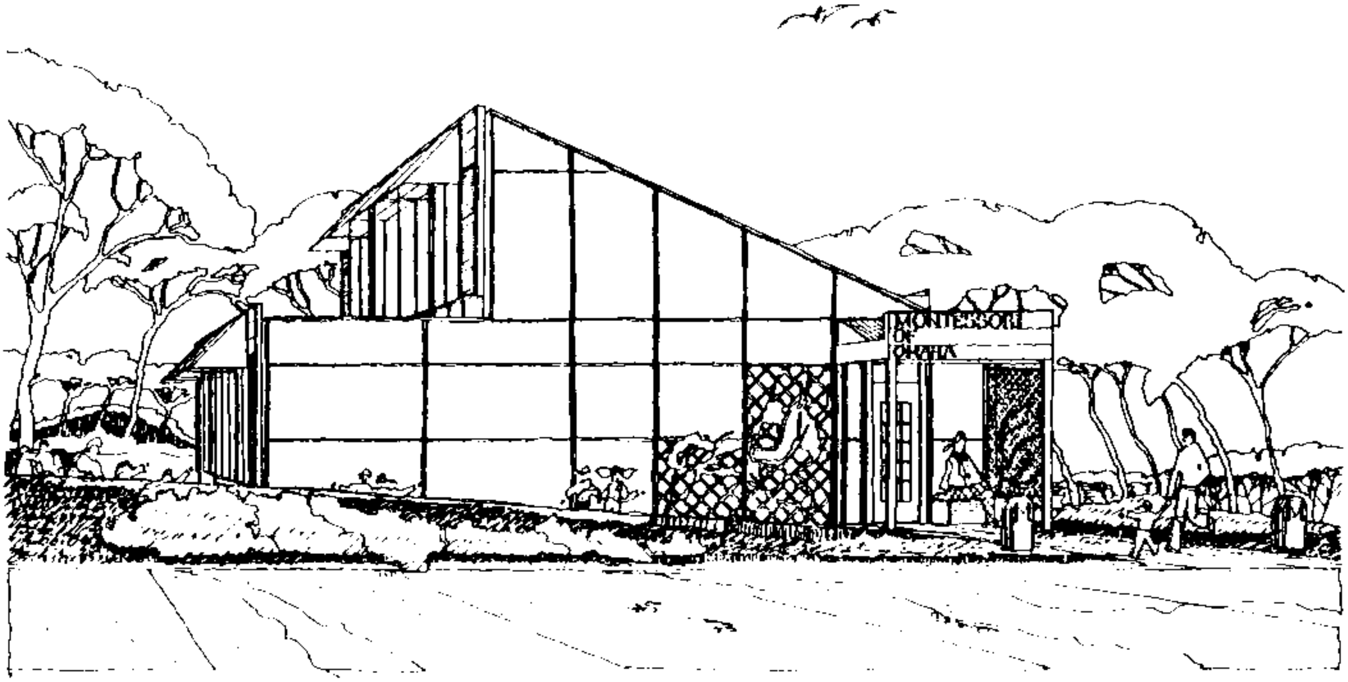
ENERGY CONCEPT: Mandated to minimize energy consumption and yet be as low-cost as possible. Natural gas was not to be used due to the high hookup costs relative to the building size. South-facing louvered ventilation openings capture south winds in the summer to provide a cooling path. North dormer windows help move the air. Except for small window units, air conditioning was to be kept to a minimum. Daylighting would be utilized as an energy conservation strategy to minimize the electric consumption due to lights, yet the problem of glare had to be considered at the same time. Natural cooling and space heating plus daylighting were the three main considerations for the design with a severe constraint on cost.

DESIGN SPECIFICS: The building wall consists of 6" of blanket insulation plus 1" of foil-faced "thermax" board. The ceiling consists of 12" of batt insulation plus the "thermax" board. The window area of 448 sq ft is evenly divided between a clerestory and lower floor. Because of this large expanse of window area, movable insulation at night was required. As a result of the large glazing area and the high vertical space there is a tendency toward over-heating and stratification. Water stored in civil defense cans absorbs solar energy from the clerestory windows. Two fans located in the clerestory area move hot air through ducts to storage in the thermal mass in the concrete floor.



FLOOR AREA: 1465 sq ft
SOUTH GLAZING: 448 sq ft
Clerestory: 224 sq ft double acrylic sheet
Lower level:224 sq ft double pane clear glass
R VALUES: Walls R-27, Roof R-36
OTHER COMMENTS:

1. No night shutters.
2. Adjustable and demountable canvas awning system.
3. Civil defense water barrels in back wall of main room which are stacked and held in place by nylon ropes.
4. 30' of 3" pvc pipe buried in slab on main floor in direct sun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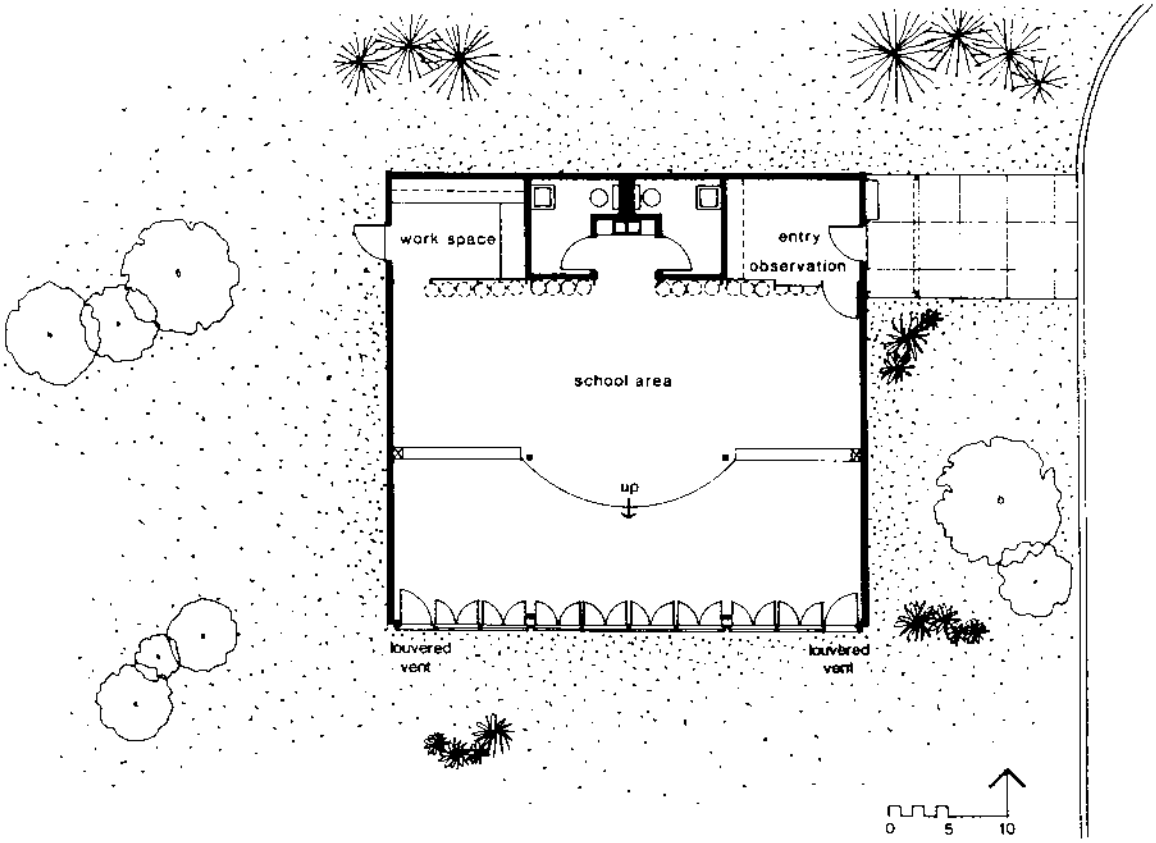

work space
entry
observation
school area
up
louvered vent
louvered vent
0
5
10

APPENDICES

HOUSE DIMENSION TAKEOFF FORM 1

LOCATION OF HOUSE ______________________ LATITUDE __________

SITE - FLAT OR SLOPING? ______ IF SLOPING GIVE PERCENTAGE GRADE AND

DIRECTION OF SLOPE ______ (10% = 1' rise in 10' & 5% = 0.5' in 10')

DEGREE DAYS HEATING PER YEAR _____ INDOOR DESIGN TEMPERATURE ______

FLOOR AREA ______ PERIMETER ______ AVERAGE CEILING HEIGHT ______

WALL AREAS		INSULATION TYPE AND THICKNESS	R VALUE OF THE WALL
EAST	_____	______________________	__________
WEST	_____	______________________	__________
NORTH	_____	______________________	__________
SOUTH	_____	______________________	__________
DOORS: #1	_____	______________________	__________
#2	_____	______________________	__________

WINDOW AREA		SINGLE, DOUBLE, TRIPLE GLAZING	NIGHT INSULATION TYPE AND R VALUE	HOURS IN PLACE AT NIGHT
EAST	____	__________	______________	__________
WEST	____	__________	______________	__________
NORTH	____	__________	______________	__________
SOUTH	____	__________	______________	__________

ROOF AREA ______ ROOF INSULATION TYPE & THICKNESS __________

ROOF R VALUE ______ IF EARTH SHELTERED GIVE DEPTH OF DIRT ______

BELOW GRADE

Is there a basement? ____ If YES what is the height? __________

Specify insulation type and thickness ______ R Value below grade ____

If slab on grade give exterior insulation specs __________

Exposed Perimeter ______________ R Value ______________

HOUSE DIMENSION TAKEOFF FORM 2

PASSIVE SOLAR SPECIFICATIONS

PASSIVE SOLAR TYPE	WINDOW AREA	LOCATION
1. ________	________	________
2. ________	________	________
3. ________	________	________

IF HOME IS A DOUBLE SHELL PROVIDE THE FOLLOWING INFORMATION:

Interior wall area: North ____ South ____ Roof ____ R Value ________

Exterior glazing area greenhouse _____ Interior wall glazing area ___

Specify fans if used ____ Specify type of night shutter ________

R Value of night shutters _____ Location of shutters ________

IF A TROMBE WALL IS EMPLOYED IS THERE A SELECTIVE SURFACE? ________

IF A SUNSPACE IS USED WHAT WILL BE THE MINIMUM TEMPERATURE ALLOWED? ___

Describe location and type of glazing ________ Glazing area ________

Specify night shutter type ______ R value ____ Hours in place _______

Sunspace floor area _____ Describe mass (brick, water, etc.) ________

Glazing area between sunspace and house ________

Wall area and R value betwen sunspace and house ________

IS SOLAR DOMESTIC HOT WATER HEATING DESIRED? ________ YES ________ NO

ARE SOLAR COVENANTS IN FORCE? ______ YES _____ NO _____ NOT APPLICABLE

ARE THERE LEGAL GUARANTEES TO SOLAR ACCESS? ________ YES ________ NO

BACKUP

BACKUP SYSTEM DESIRED (gas, electricity, oil, etc.) ________

COST OF FUEL (consult fuel dealer or utility) ________

WOOD STOVES TO BE USED? ___YES ___NO HOW MANY? ____ LOCATION ________

________ HEATING CAPACITY (btuh)

FIREPLACES TO BE USED? ____YES ___NO HOW MANY? ____ LOCATION ________

________ HEATING CAPACITY)btuh)

SKIN FORM

construction

(circle one) wall window roof door

describe location

____

diagram (optional)

components	thickness	R value
outside air film		
inside air film		

R_t = total R value = ☐

U = $1/R_{total}$ = ______

A = skin area = ______

UA (U x A) btu/° F = ☐

DESIGN HEAT LOSS FORM (DHL) 1

$\Delta T = t_{\text{indoor desired}} - t_{\text{outdoor design temperature}} =$ ______

1.1 SKIN LOSSES: UA PRODUCT (from skin form)

1. Walls

   UA_{North} ______

   UA_{South} ______

   UA_{East} ______

   UA_{West} ______

2. Windows

   UA_{North} ______

   UA_{South} ______

   UA_{East} ______

   UA_{West} ______

3. Roof UA ______

4. Doors UA ______

5. UA Total Sum of All Above ______

   ΔT (from above) x ______

   Total Skin Loss (btuh) = ______ 1.1

1.2 AIR INFILTRATION LOSSES

Volume (Average ceiling height X floor area) ______

ΔT x ______

ACH (from table 5.3) x ______

CONSTANT (.018) x .018

AIR INFILTRATION (btuh) = ______ 1.2

1.3 BELOW GRADE & BASEMENT LOSSES

(Choose one of below) (A or B)

A) BASEMENT:

WALLS: Perimeter ________
Sum of values from Table 5.4 x ________
54 (constant) x 54

Total basement wall loss = ________ walls

FLOOR: Floor Area ________
Table 5.5 value x ________
54 (constant) x 54

Total basement floor losses = ________ floor

Total Basement Losses (add walls and floors) = ☐ 1.3

B) SLAB ON GRADE:

Perimeter (in feet) ________
Table 5.6 or 5.7 value x ________

SLAB ON GRADE LOSS = ☐ 1.3

1.4 DHL

Total Design Heat Loss = Total Skin Loss + Air Infiltration + Below Grade or Basement

DHL = (Sum of 1.1 + 1.2 + 1.3) = ☐ DHL

SOLAR SAVINGS FRACTION FORM (SSF)

PRELIMINARY DATA ENTRY

UA south (from DHL form) ____________

ΔT (from DHL form) x ____________

SOUTH WINDOW LOSSES = ____________

- -

DHL, Design Heat Loss (from DHL form) ____________

South Window Losses (from above) -

dhl (little DHL without south losses) = ☐ dhl

Constant 24 x 24

ΔT (from DHL form) ÷ ____________

BLC (building load coefficient) = ☐ BLC

South Window Area (from House Dimensions Take Off Form) ____________

LCR (load collector ratio) = ☐ LCR

Use LCR Value to find SSF Value from SSF Graph of your Locale in the Appendix **2** - Read SSF of your passive solar type and enter here

SOLAR SAVINGS FRACTION = ☐ SSF

THERMAL INTEGRITY FACTOR FORM (TIF)

PRELIMINARY DATA

TOTAL FLOOR AREA ________ DHL ________ SSF ________

DDy (degree days per year) ____________ ΔT ________

$Q_{GROSS} = \dfrac{DHL \times DDY \times 24}{\Delta T}$

DHL (from data above) ________

DDy (from data above) x ________

24 (constant) x 24

ΔT (from data above) ÷ ________

GROSS ANNUAL HEAT LOSS = ☐ Q_{GROSS}

$Q_{INTERNAL}$ = NUMBER OF INHABITANTS x 3 MILLION BTU

NUMBER OF INHABITANTS ________

3 MILLION (constant) x 3,000,000

INTERNAL HEAT GAIN = ☐ $Q_{INTERNAL}$

$Q_{NET} = Q_{GROSS} - Q_{INTERNAL}$

Q_{GROSS} (from above) ________

$Q_{INTERNAL}$ (from above) - ________

NET ANNUAL HEATING REQUIREMENTS = ☐ Q_{NET}

$Q_{SOLAR} = Q_{NET} \times SSF$

Q_{NET} (from above) ________

SSF (from data above) x ________

ANNUAL SOLAR CONTRIBUTION = ☐ Q_{SOLAR}

$Q_{AUXILIARY} = Q_{NET} - Q_{SOLAR}$

Q_{NET} (from above) ________

Q_{SOLAR} (from above) - ________

TOTAL AUXILIARY HEAT REQUIRED = ☐ $Q_{AUXILIARY}$

TIF = ($Q_{AUXILIARY}$) / (DDY x FLOOR AREA)

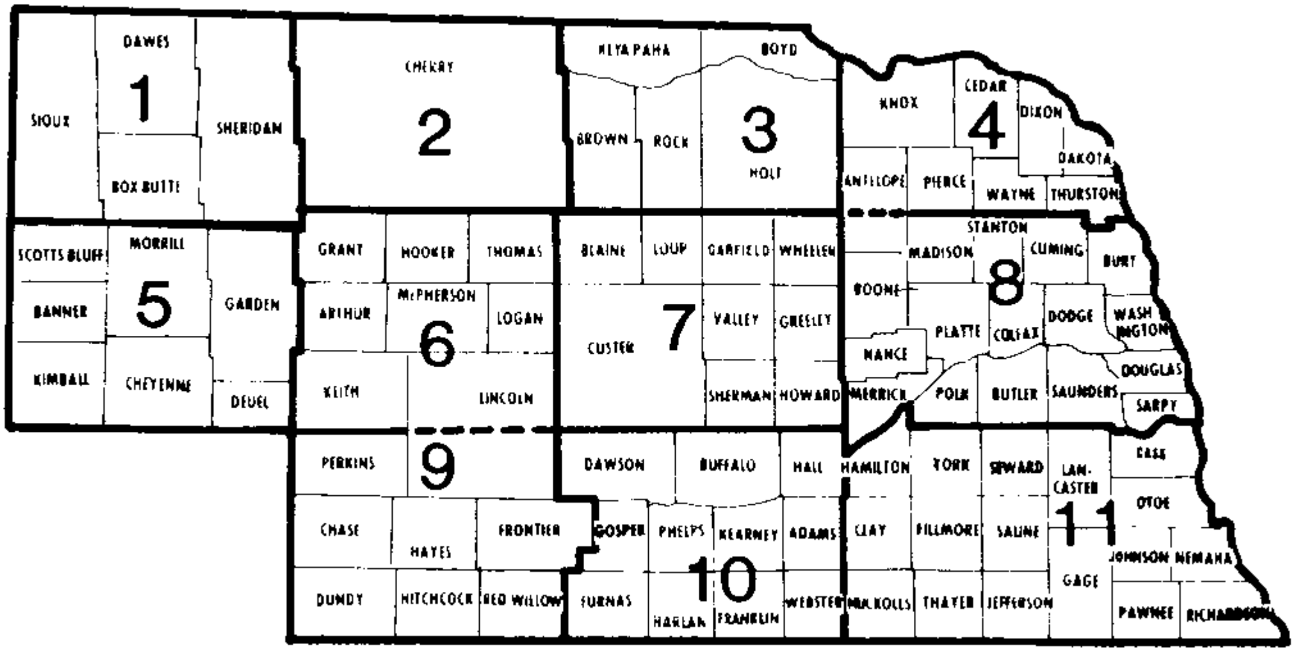
$Q_{AUXILIARY}$ (from above) ________

DDY (from data above) ÷ ________

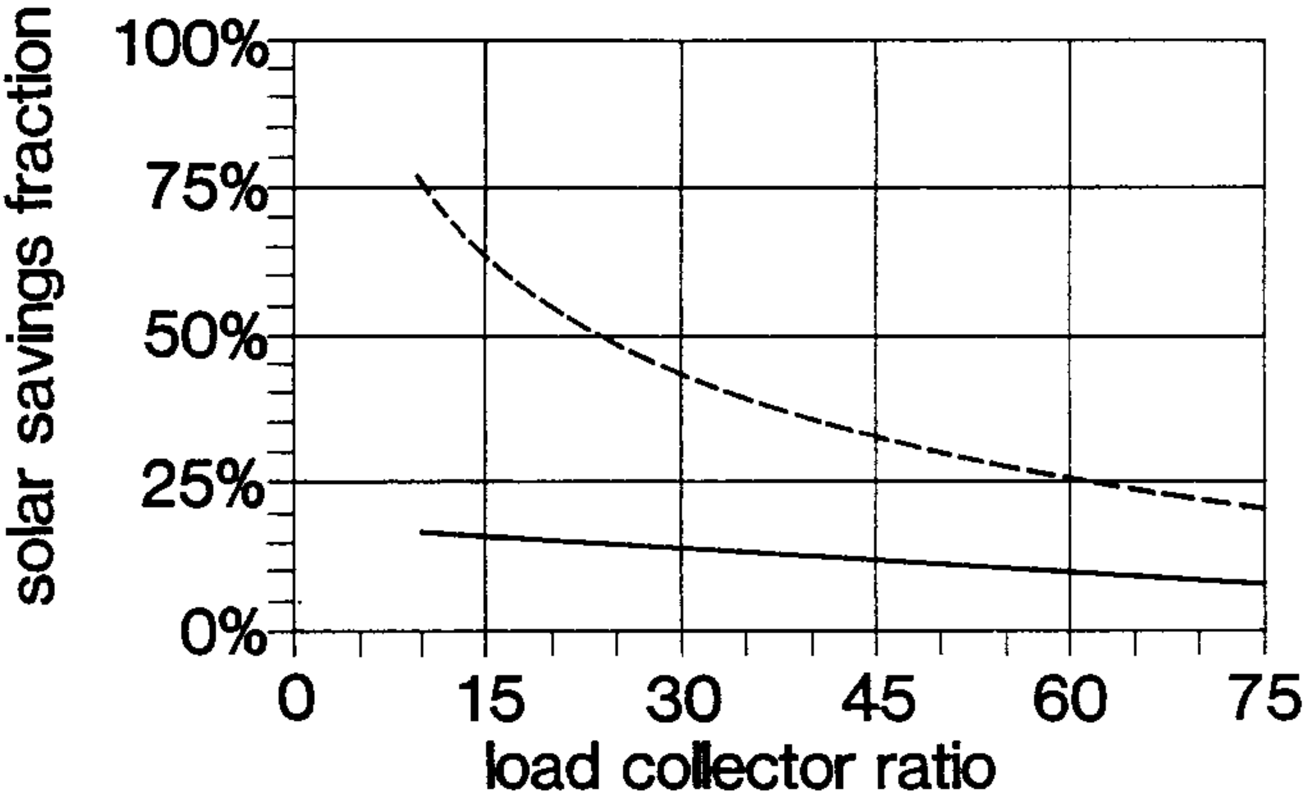
FLOOR AREA (from data above) ÷ ________

THERMAL INTEGRITY FACTOR = ☐ TIF

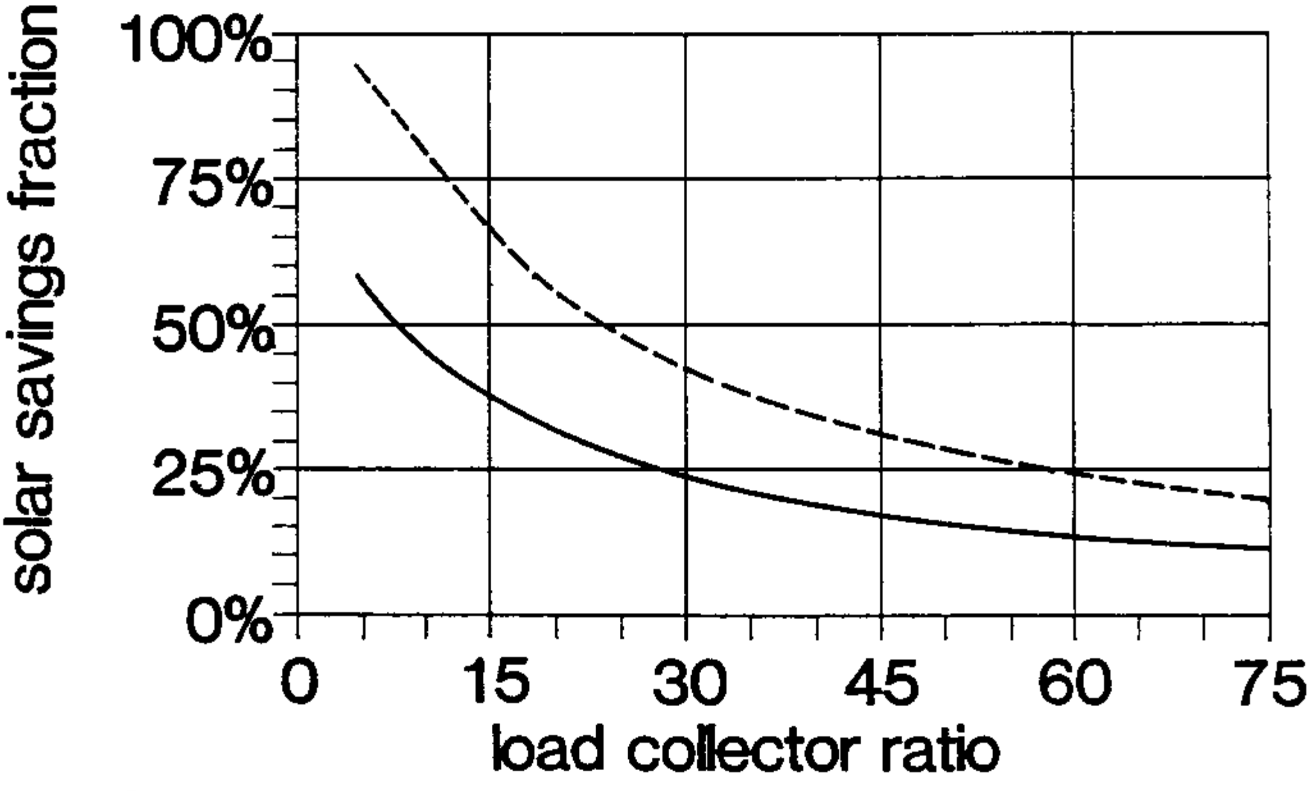
APPENDIX 2



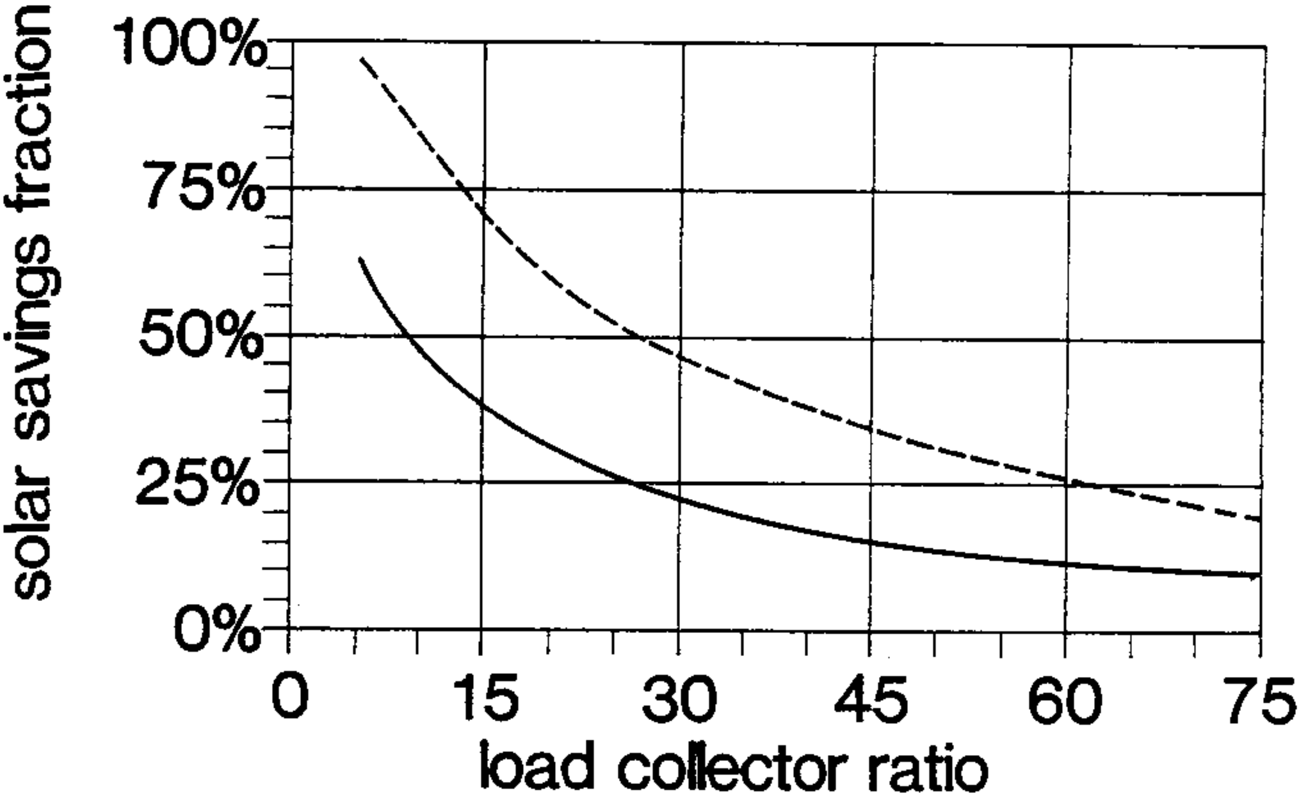
NEBRASKA AREAS



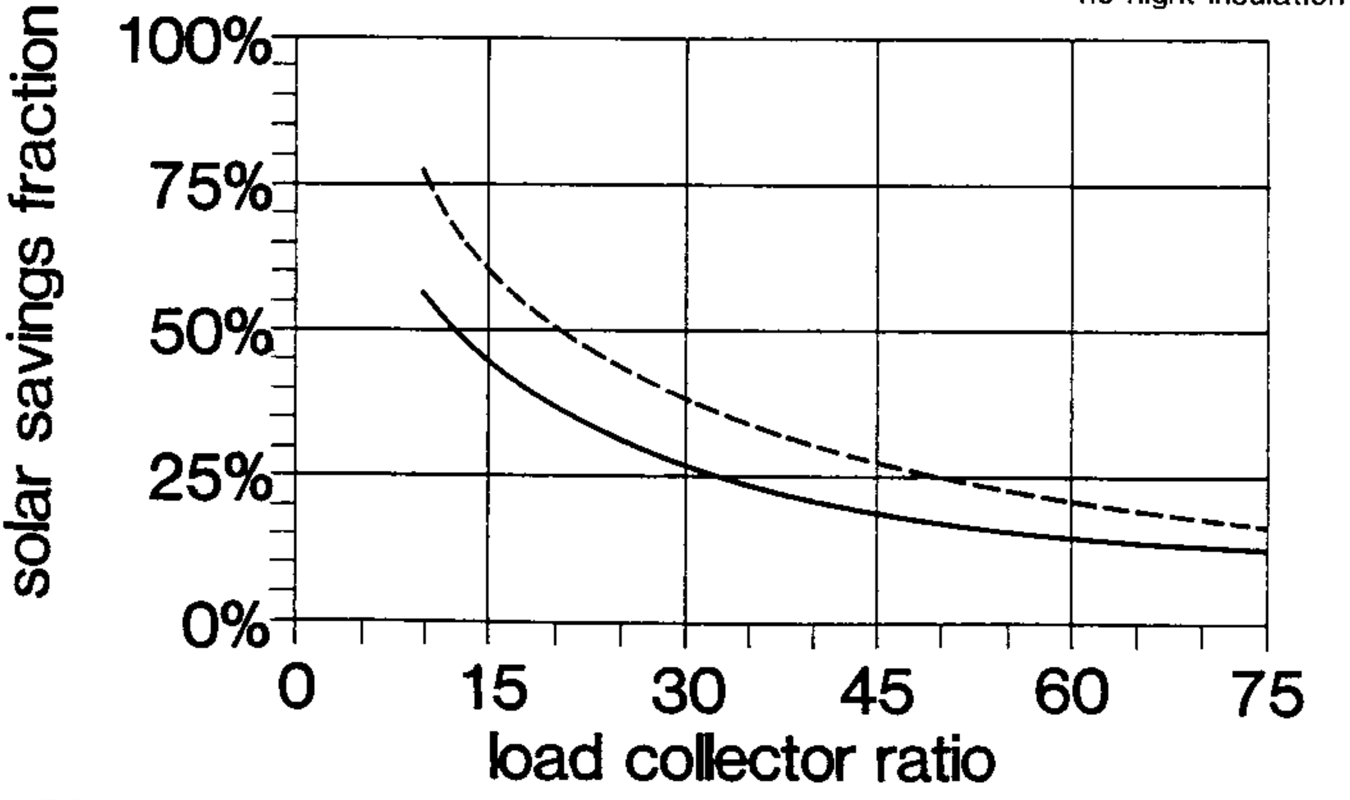
DIRECT GAIN AREA 1



TROMBE WALL AREA 1

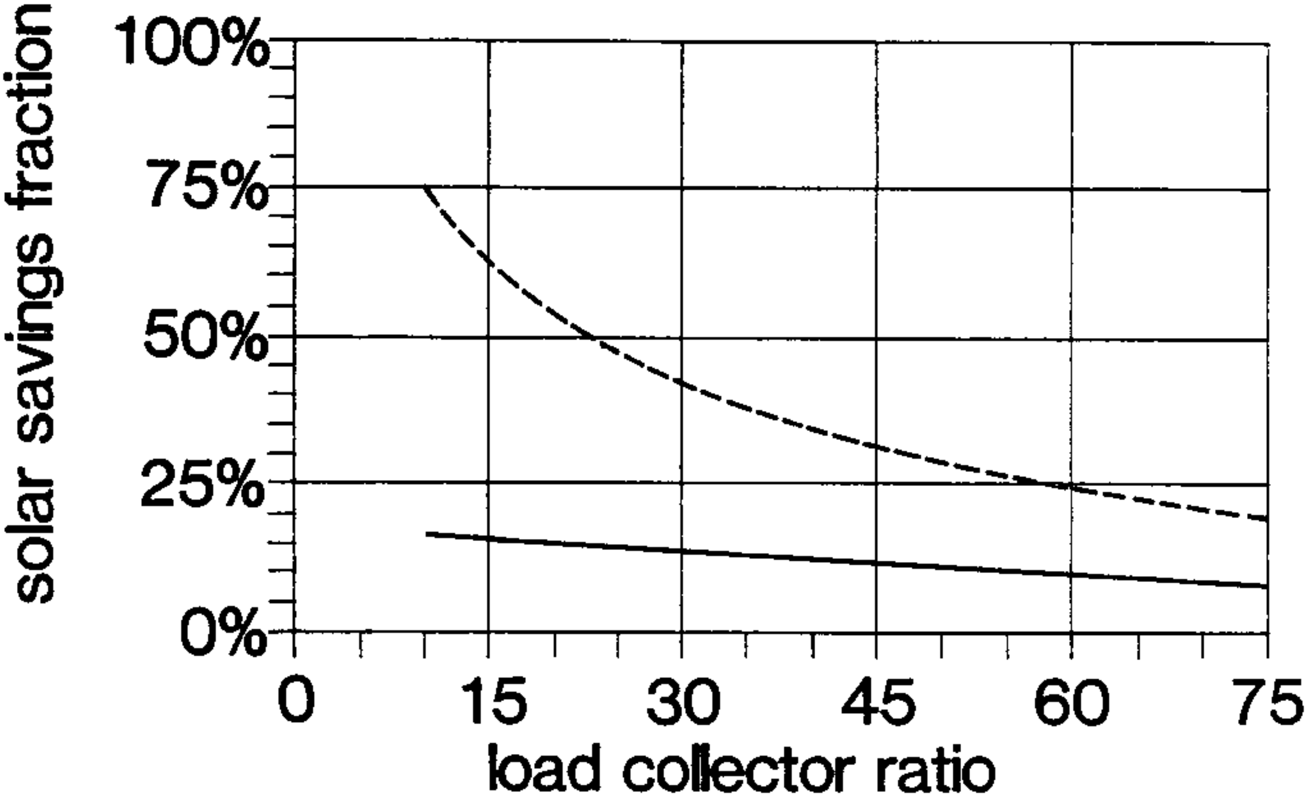


WATER WALL AREA 1



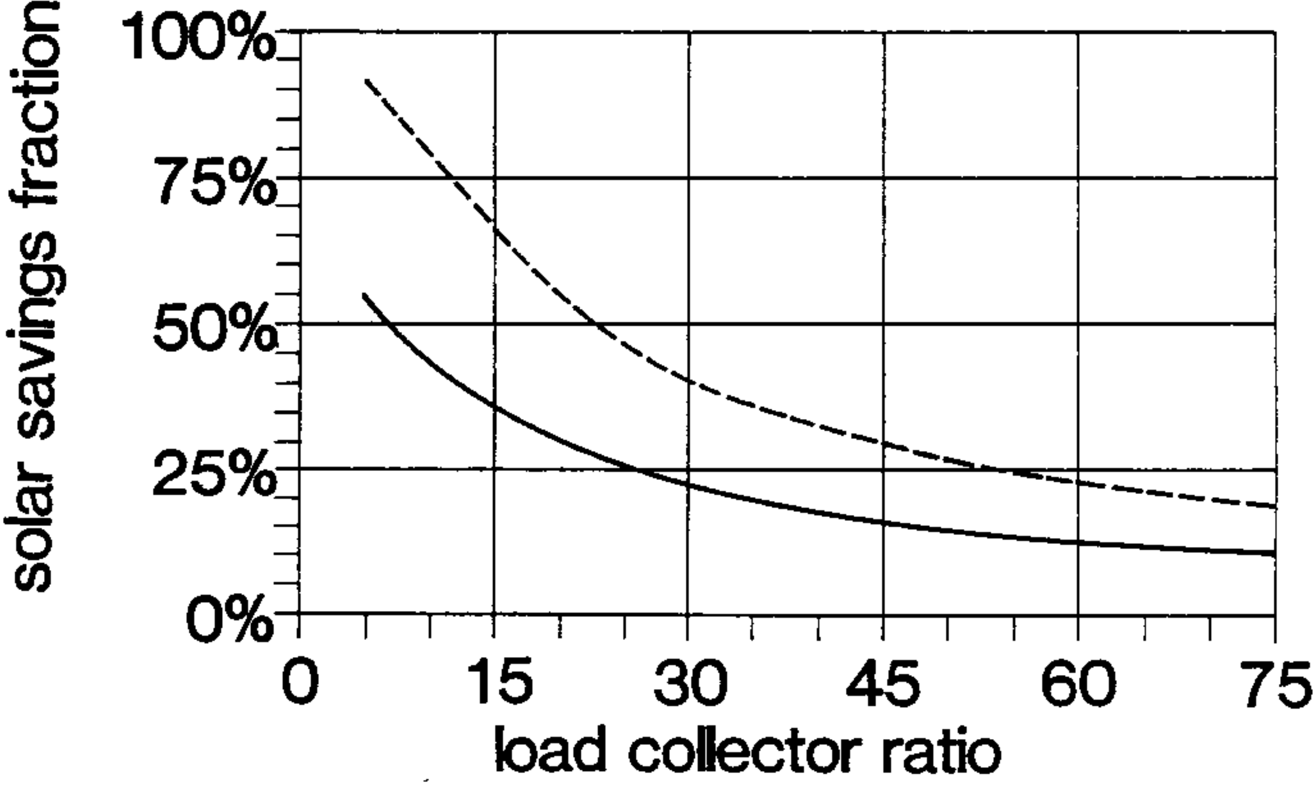
GREENHOUSE AREA 1

APPENDIX 2

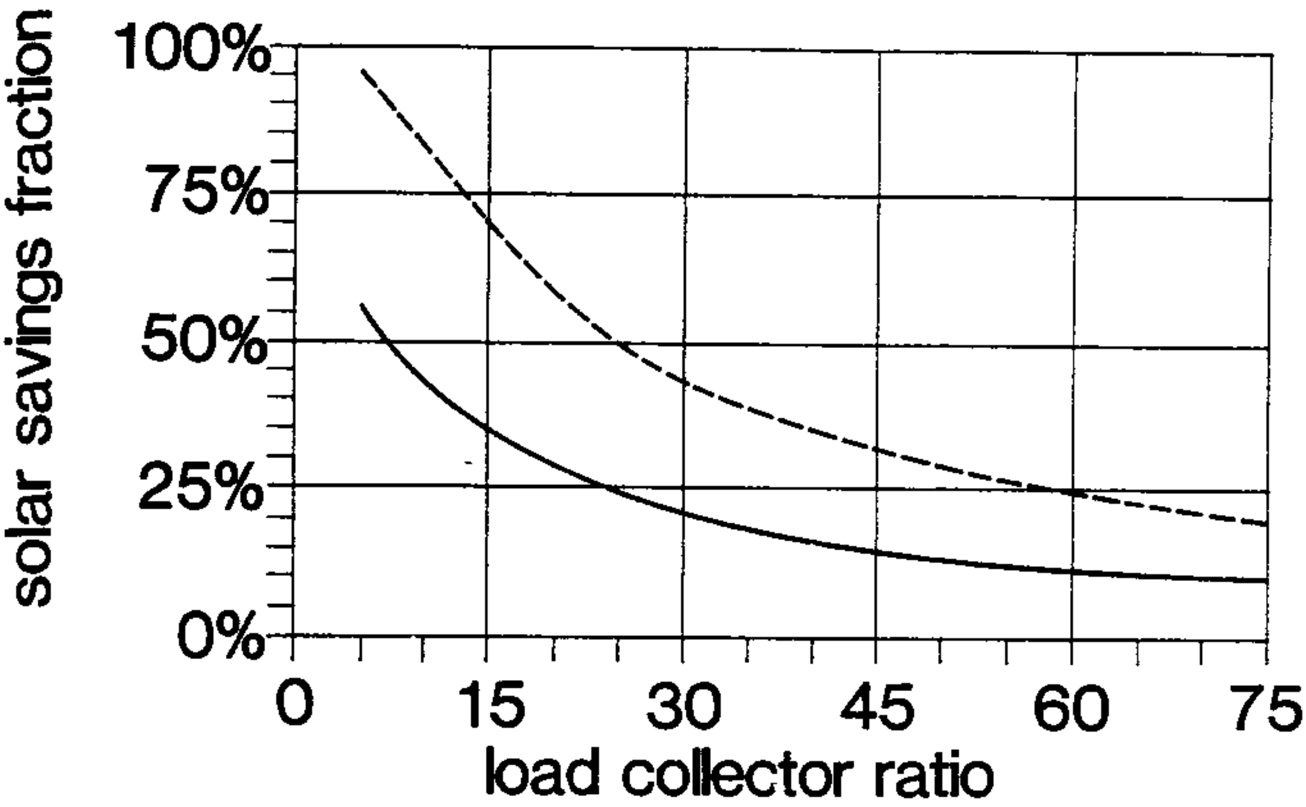


DIRECT GAIN AREA 2

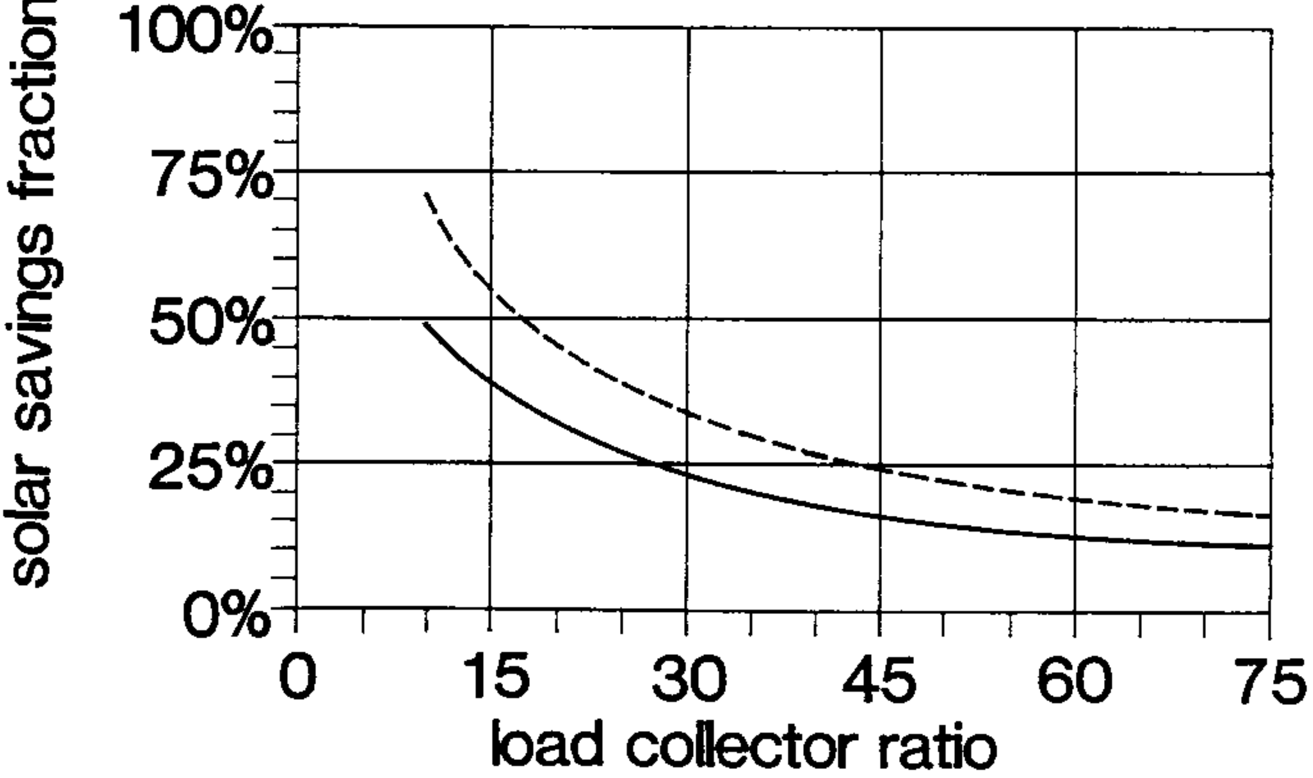
- - - - - - - night insulation
——————— no night insulation



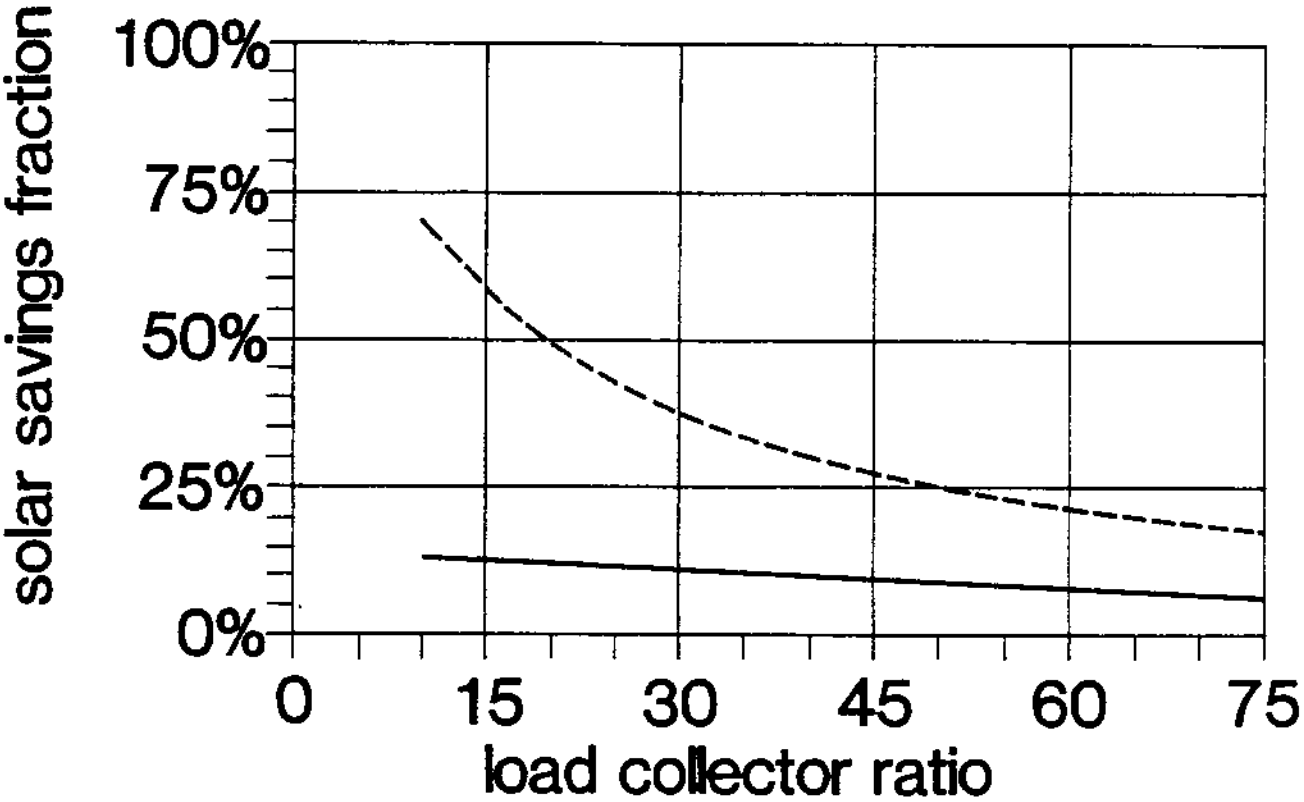
TROMBE WALL AREA 2



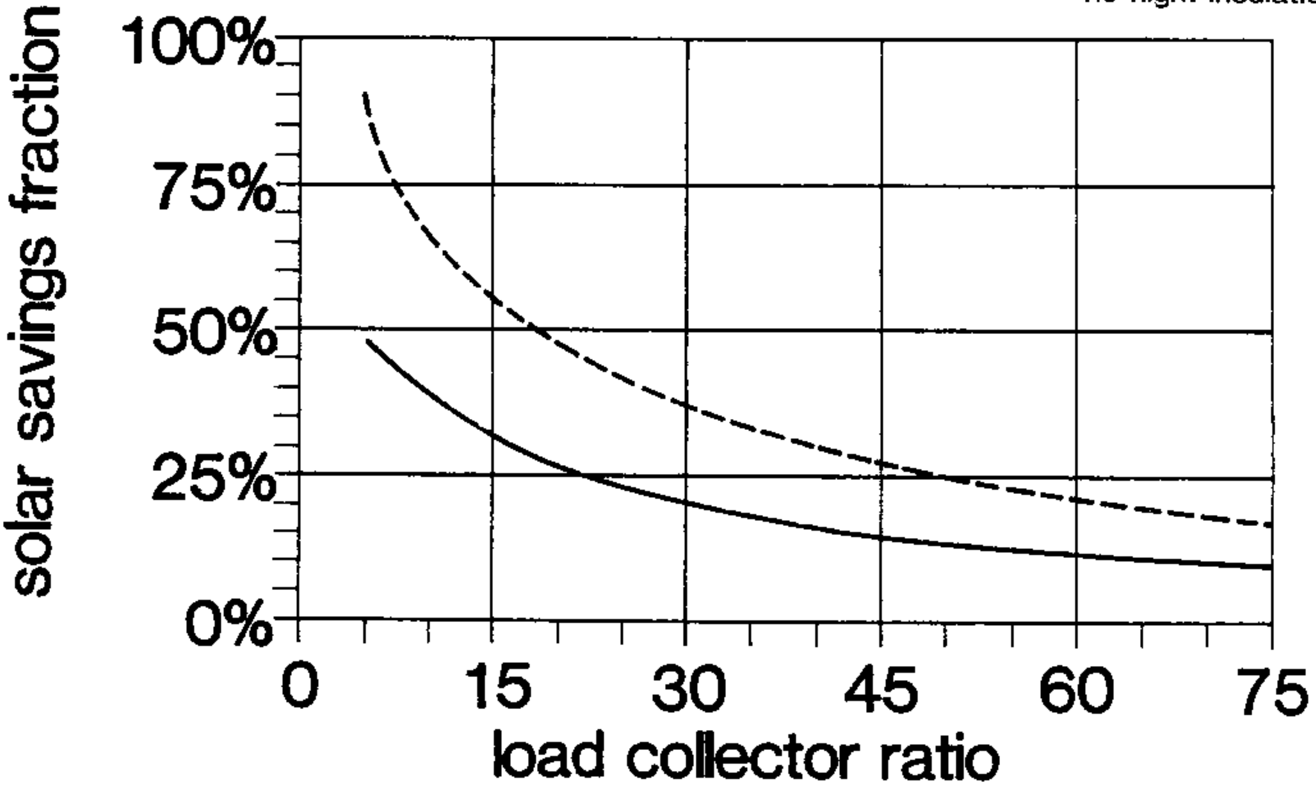
WATER WALL AREA 2



GREENHOUSE AREA 2



DIRECT GAIN AREA 3



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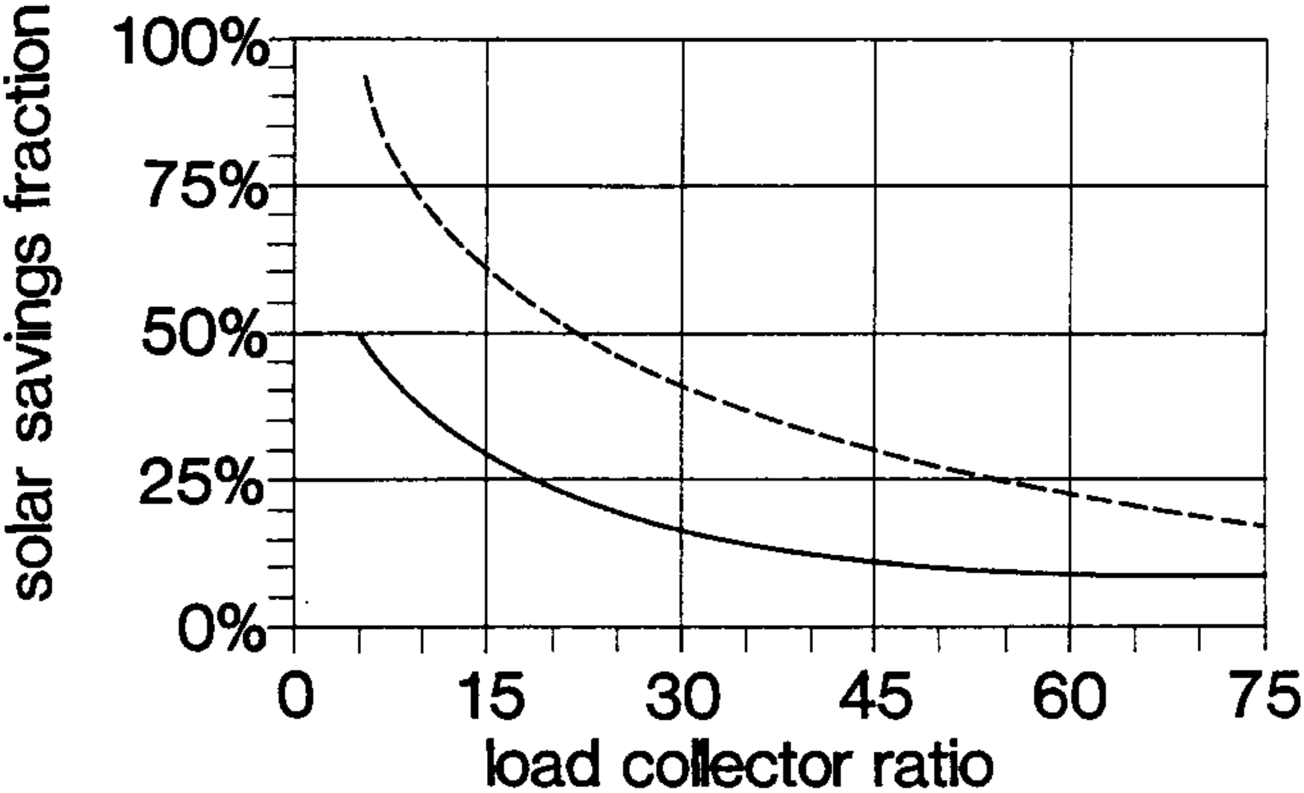
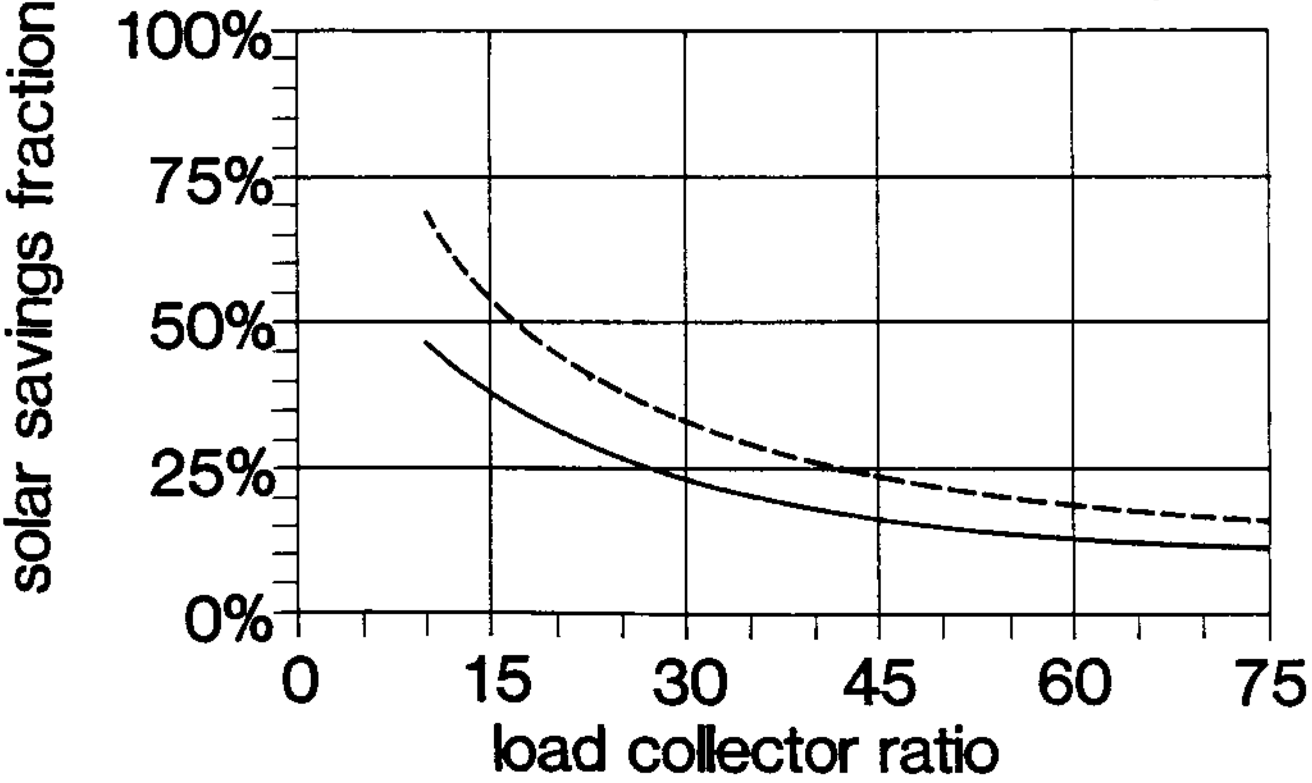
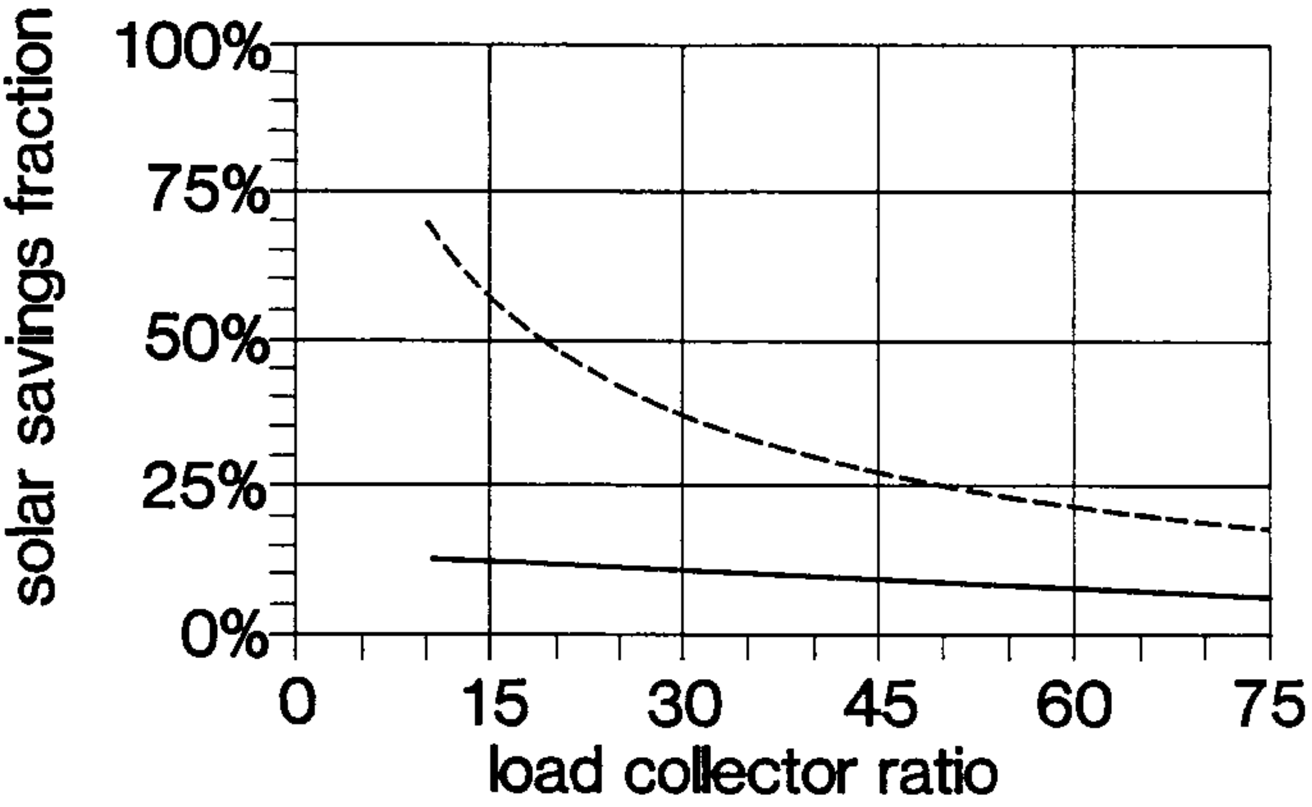


WATER WALL AREA 3

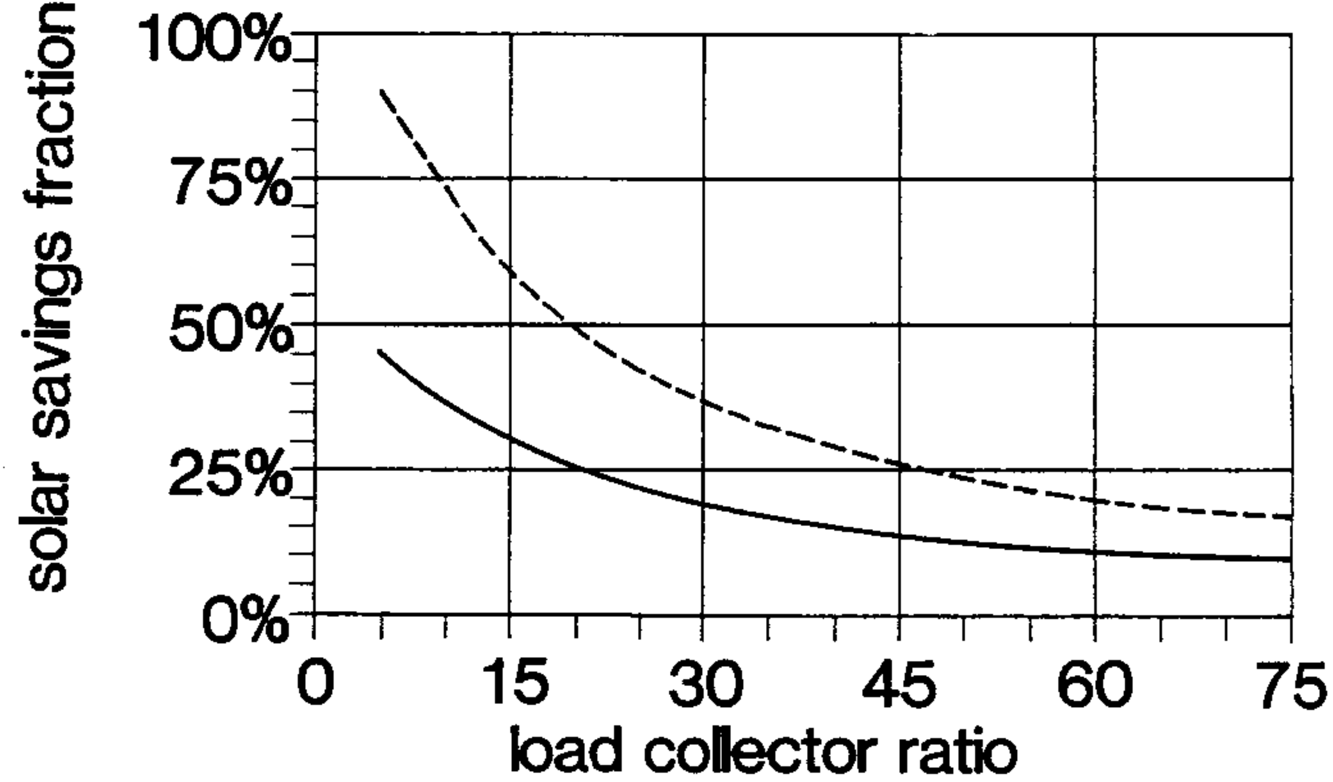


GREENHOUSE AREA 3

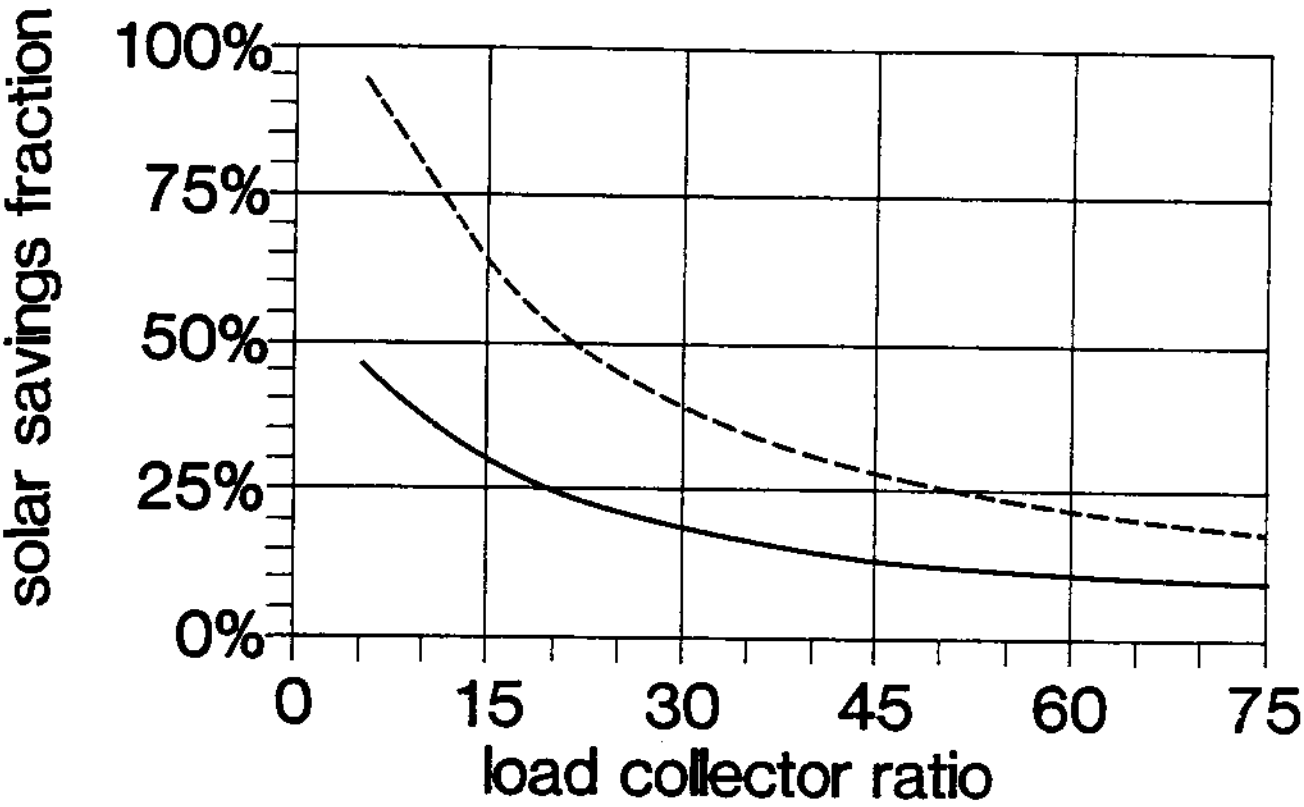


DIRECT GAIN AREA 4

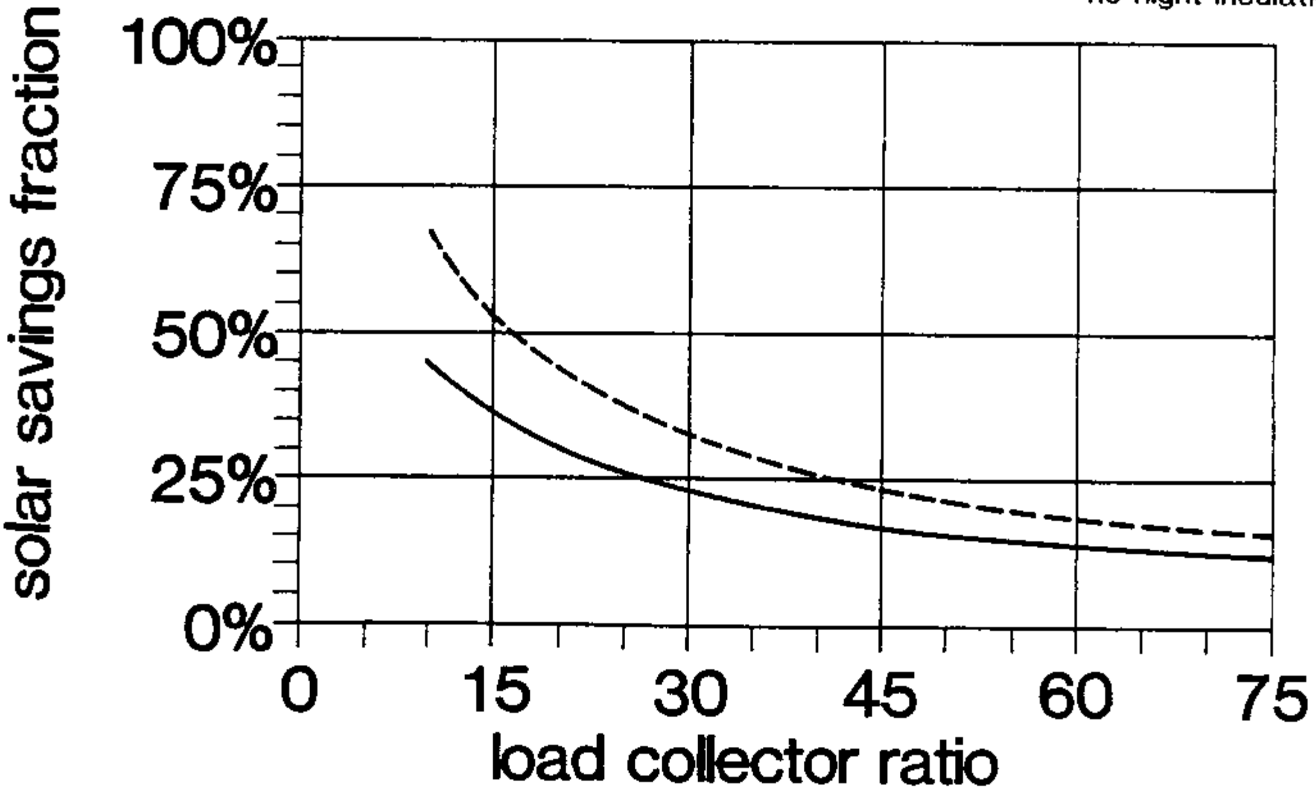
- - - - - - night insulation
——— no night insulation



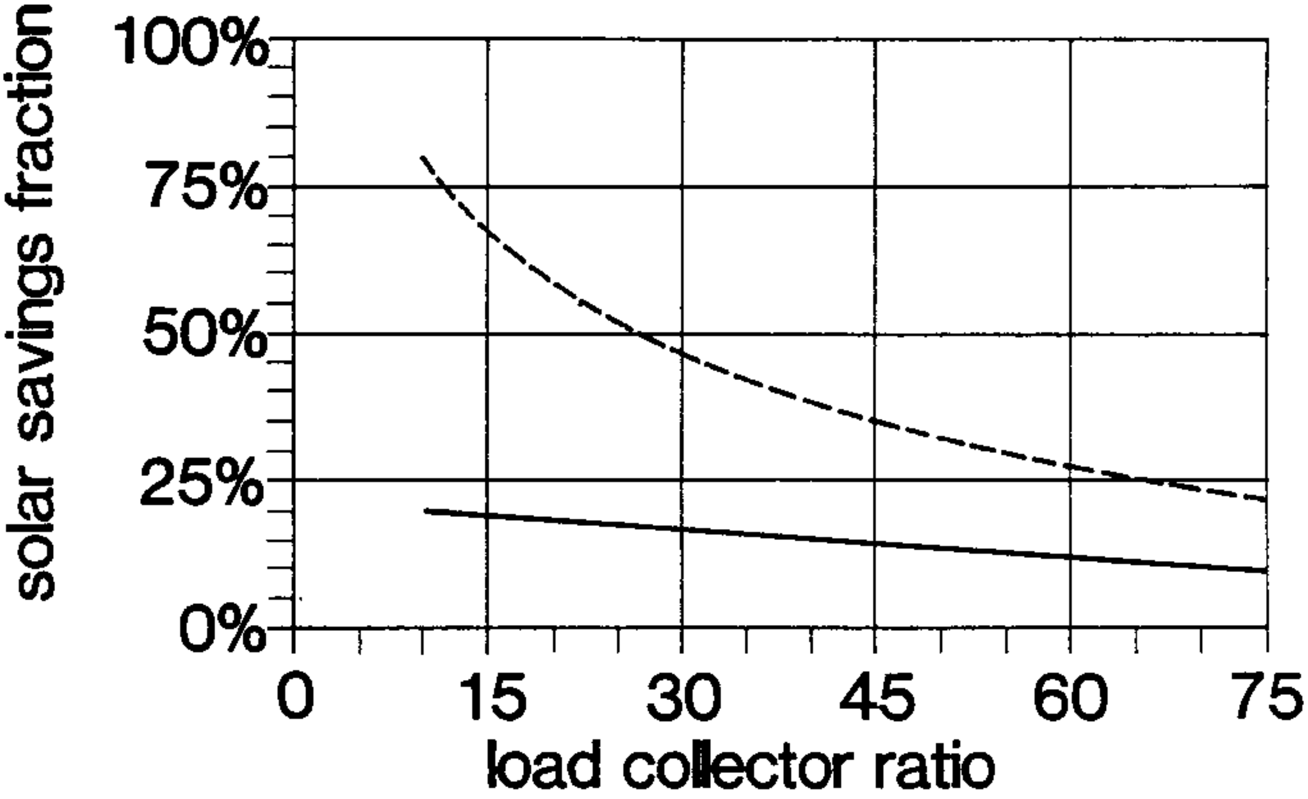
TROMBE WALL AREA 4



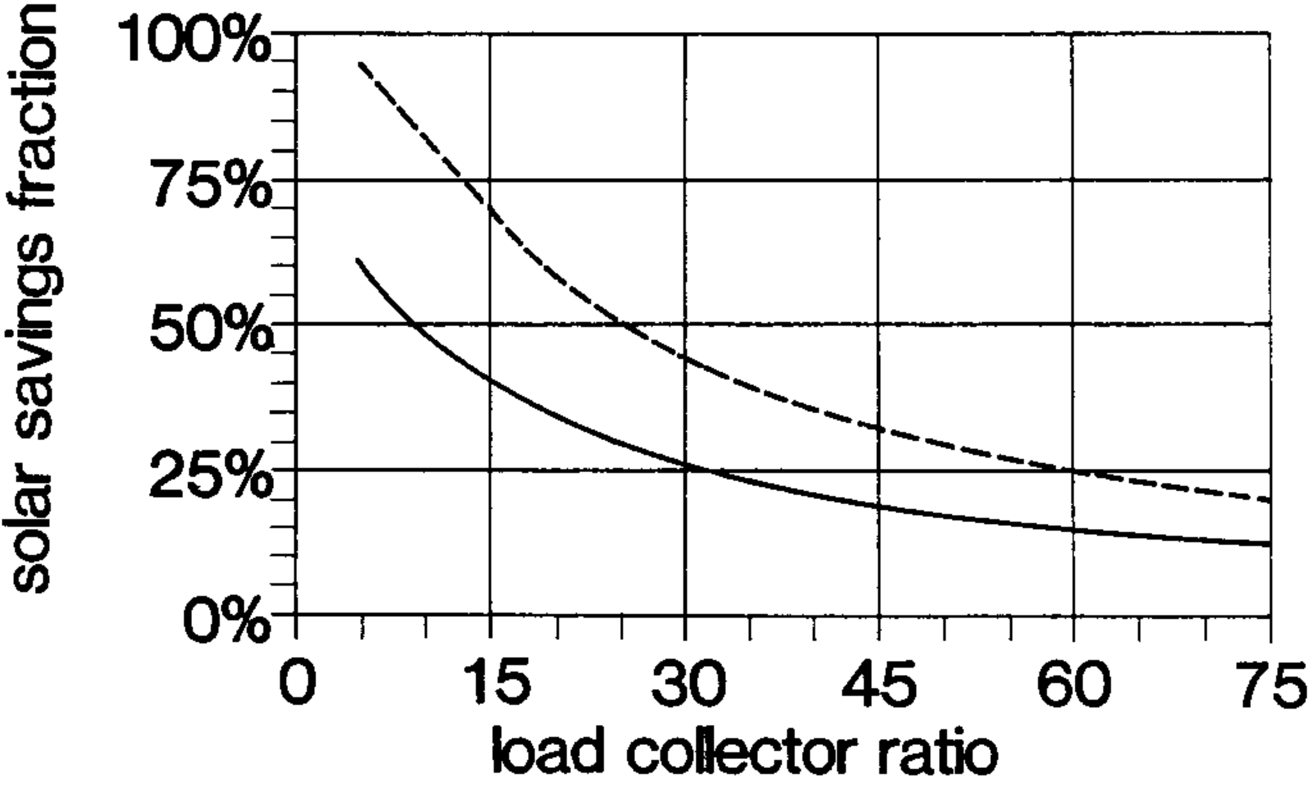
WATER WALL AREA 4



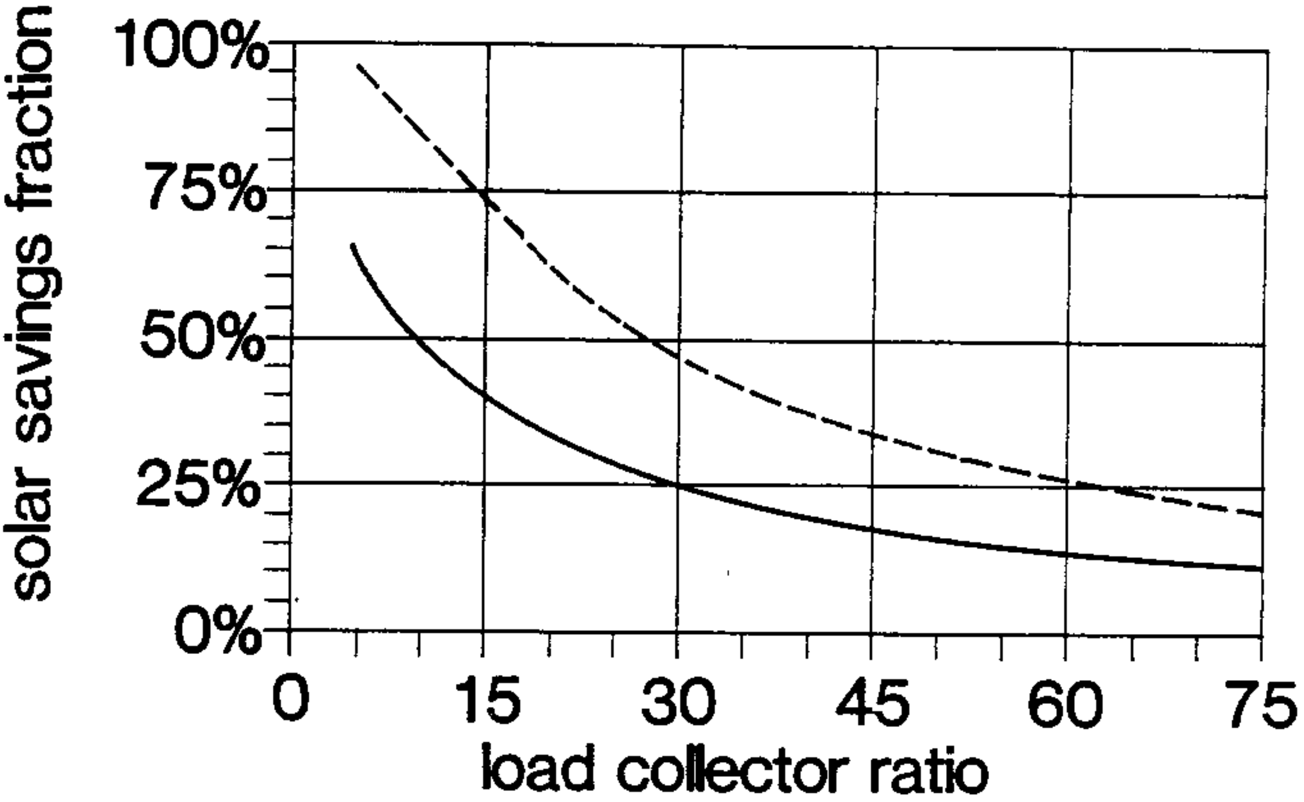
GREENHOUSE AREA 4



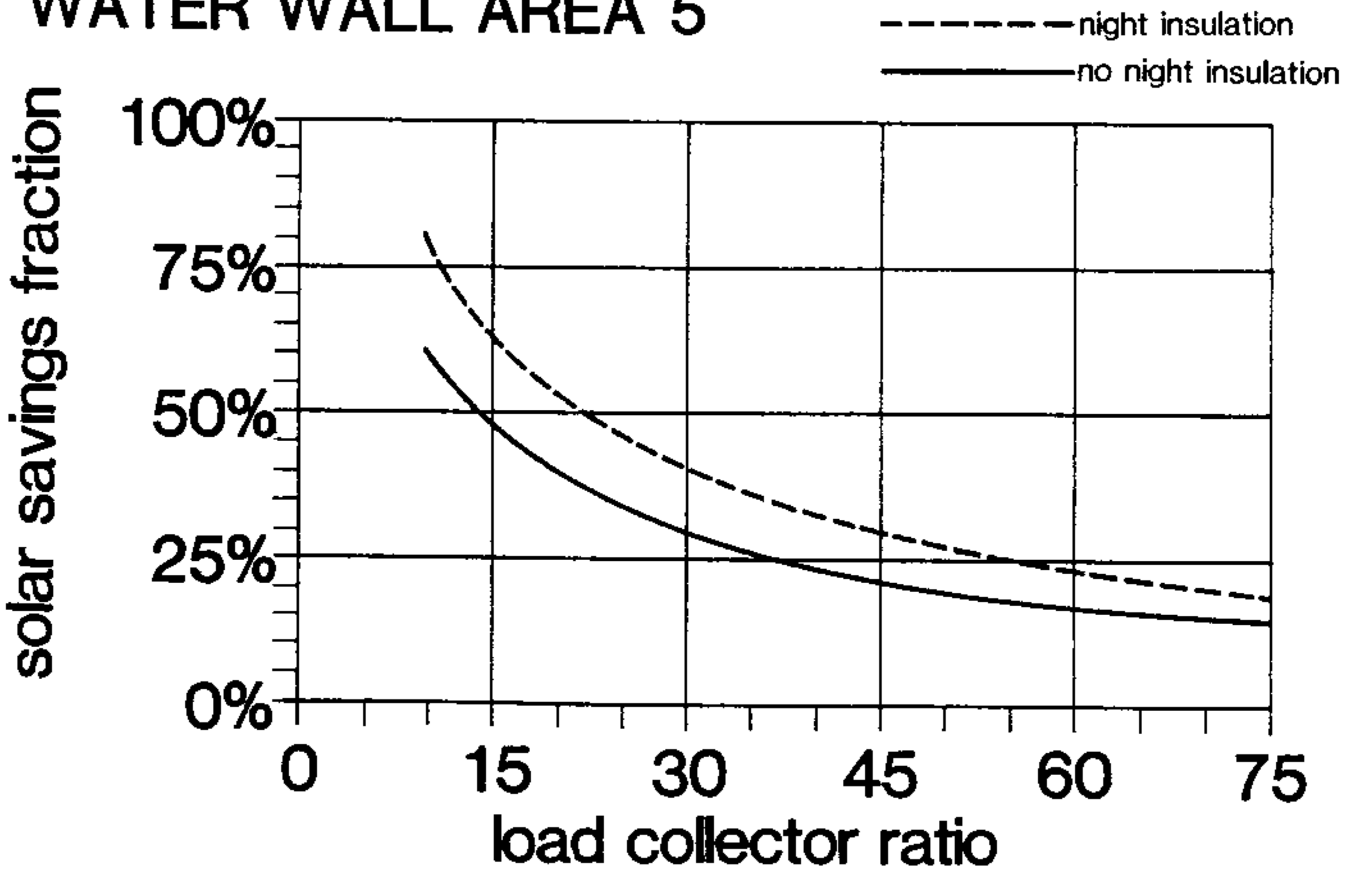
DIRECT GAIN AREA 5



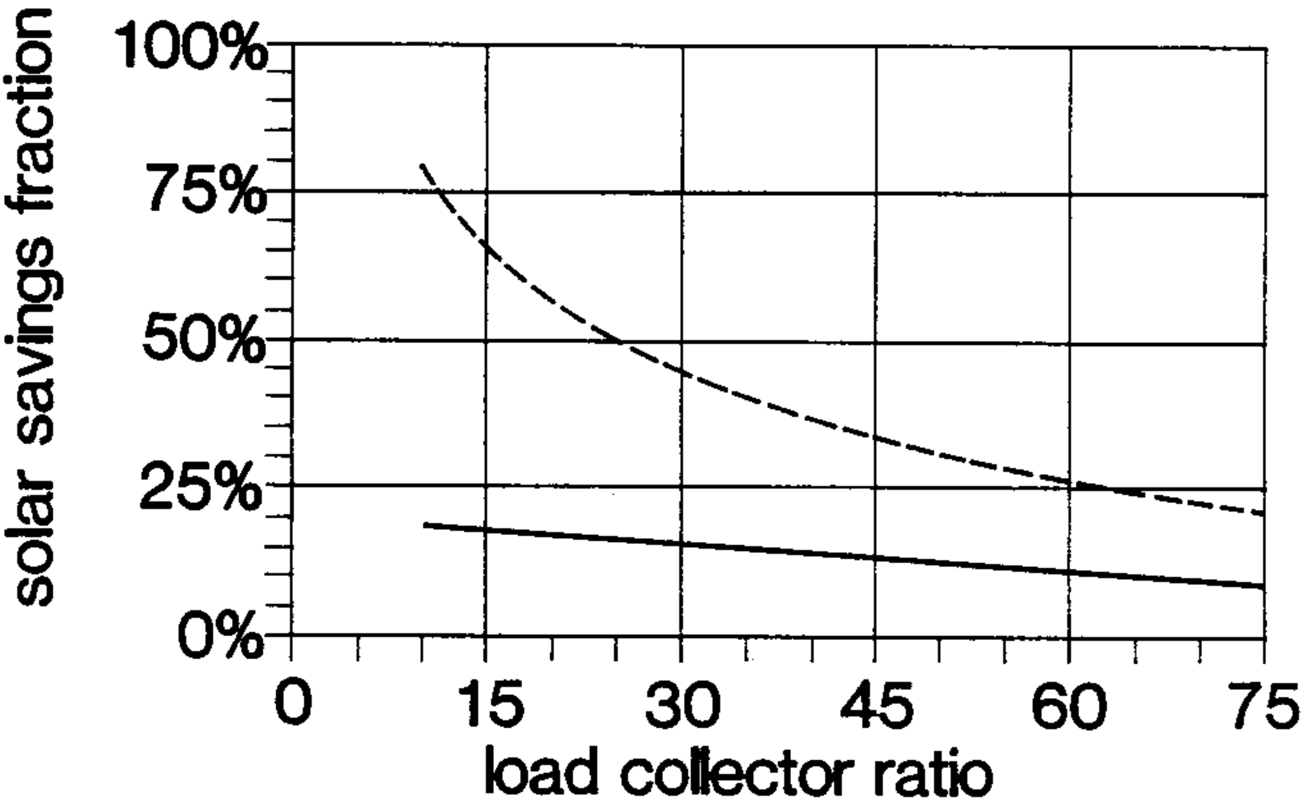
TROMBE WALL AREA 5



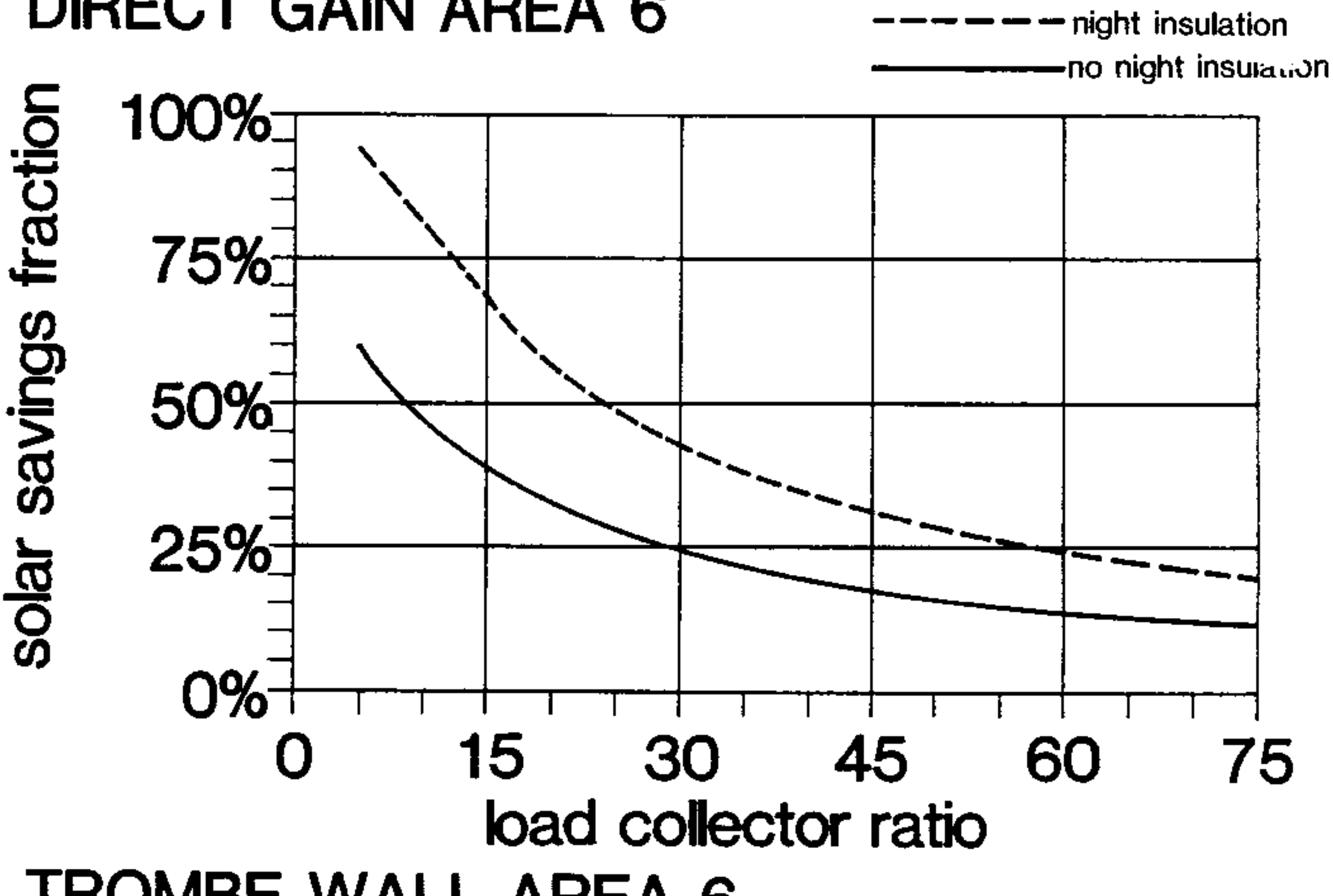
WATER WALL AREA 5



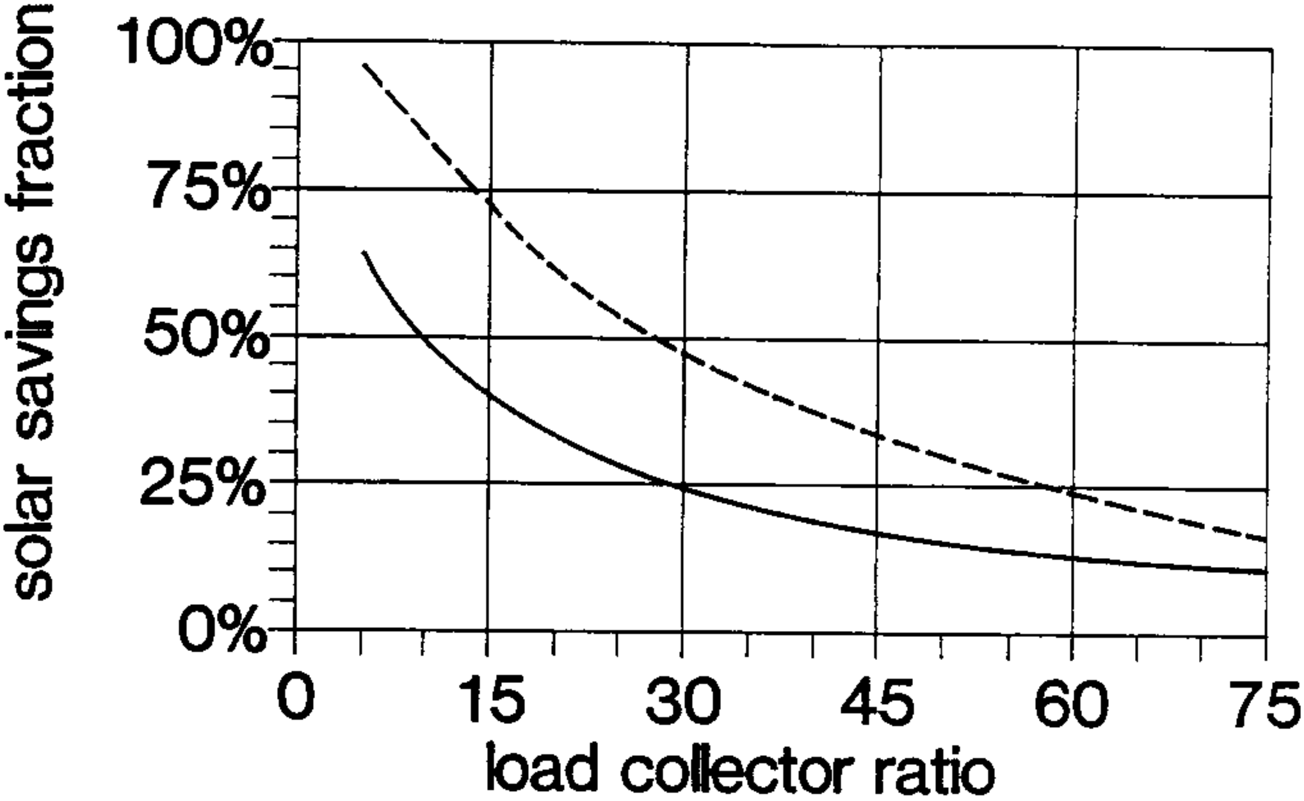
GREENHOUSE AREA 5



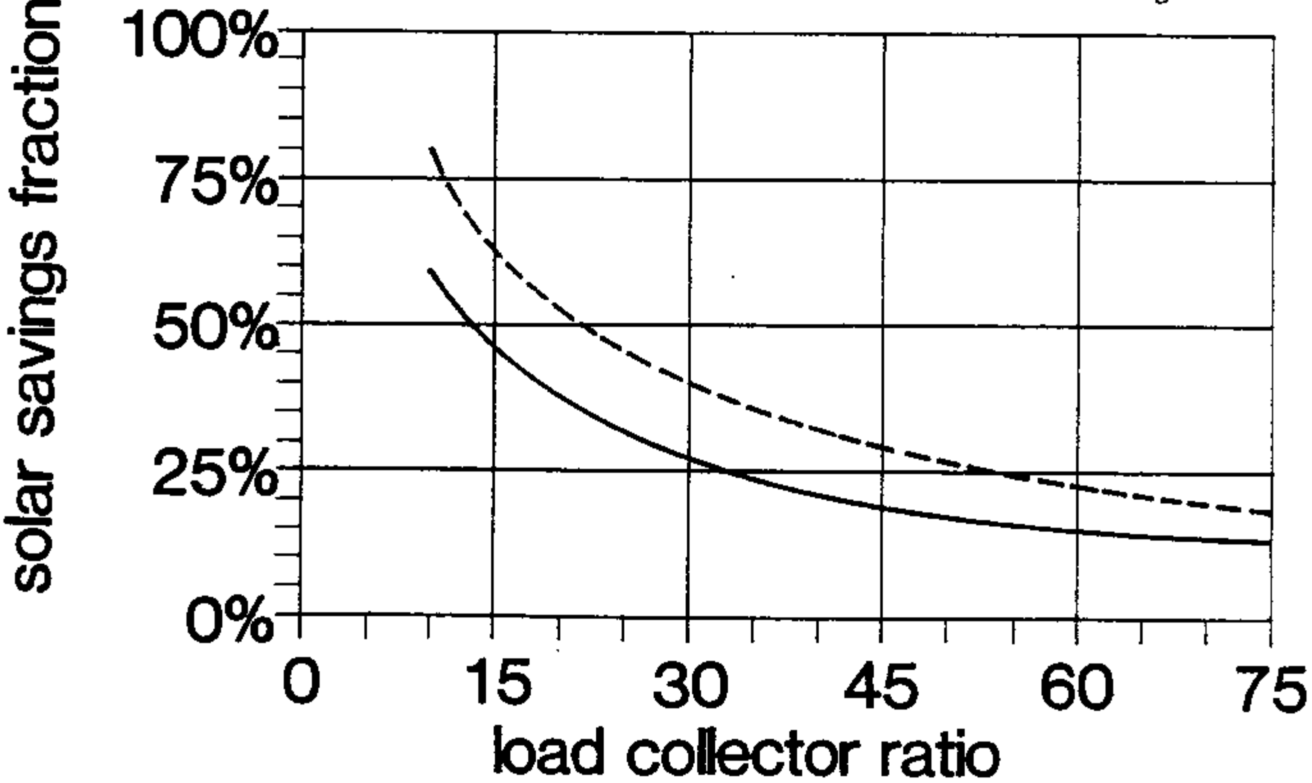
DIRECT GAIN AREA 6



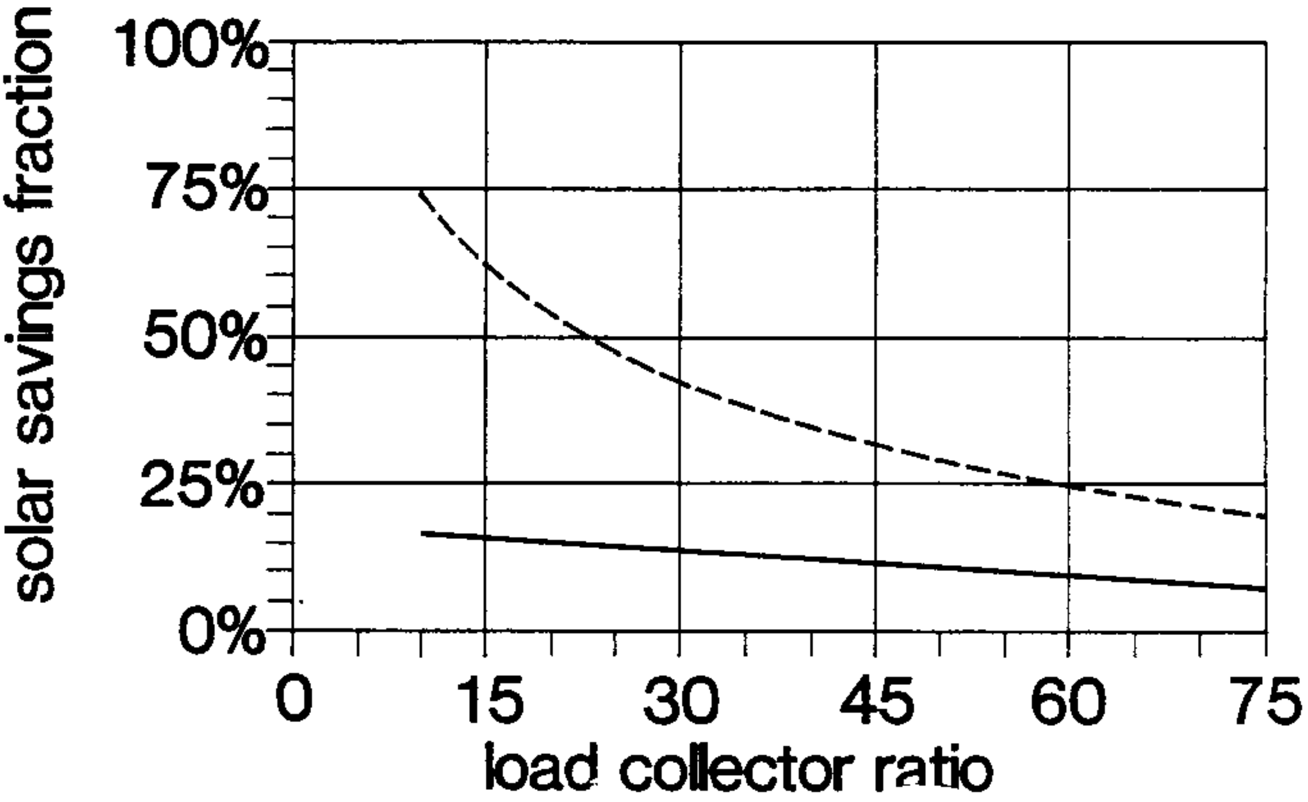
TROMBE WALL AREA 6



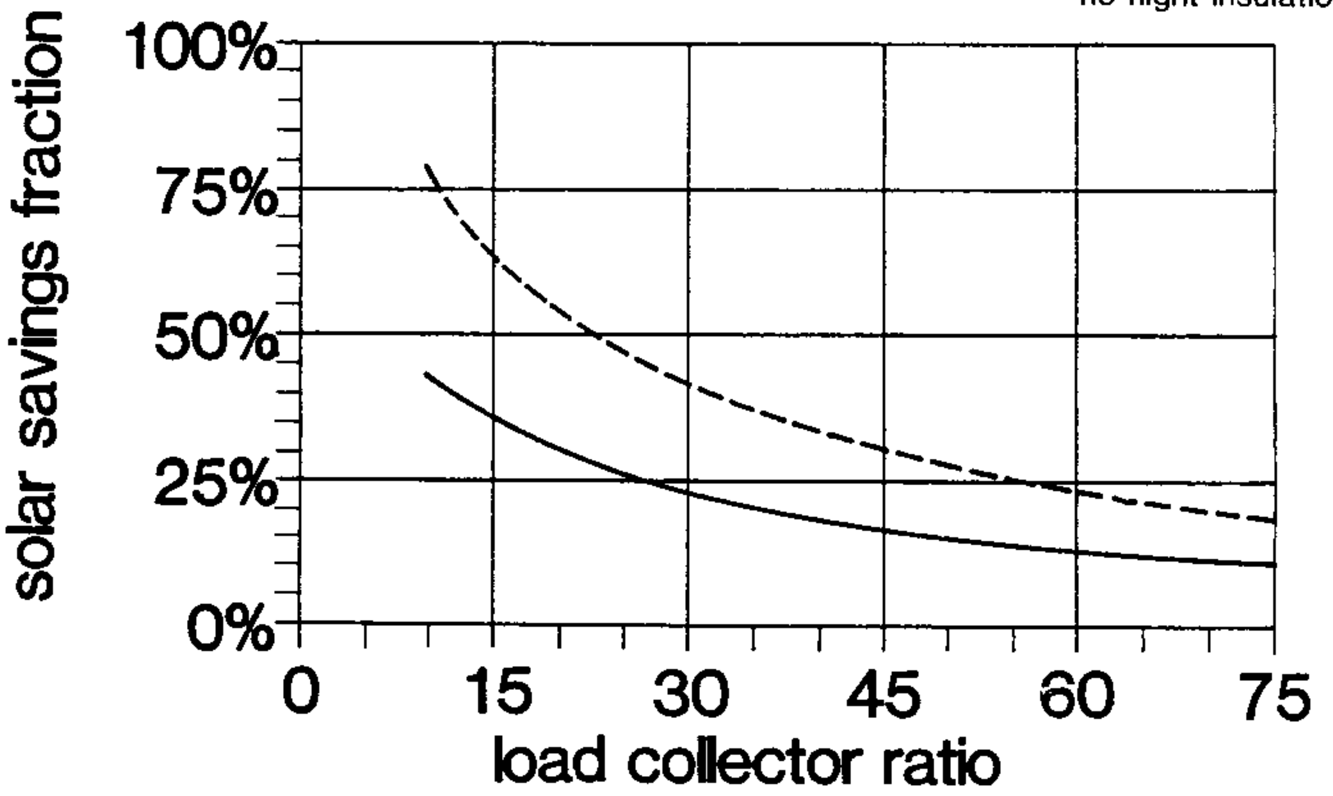
WATER WALL AREA 6



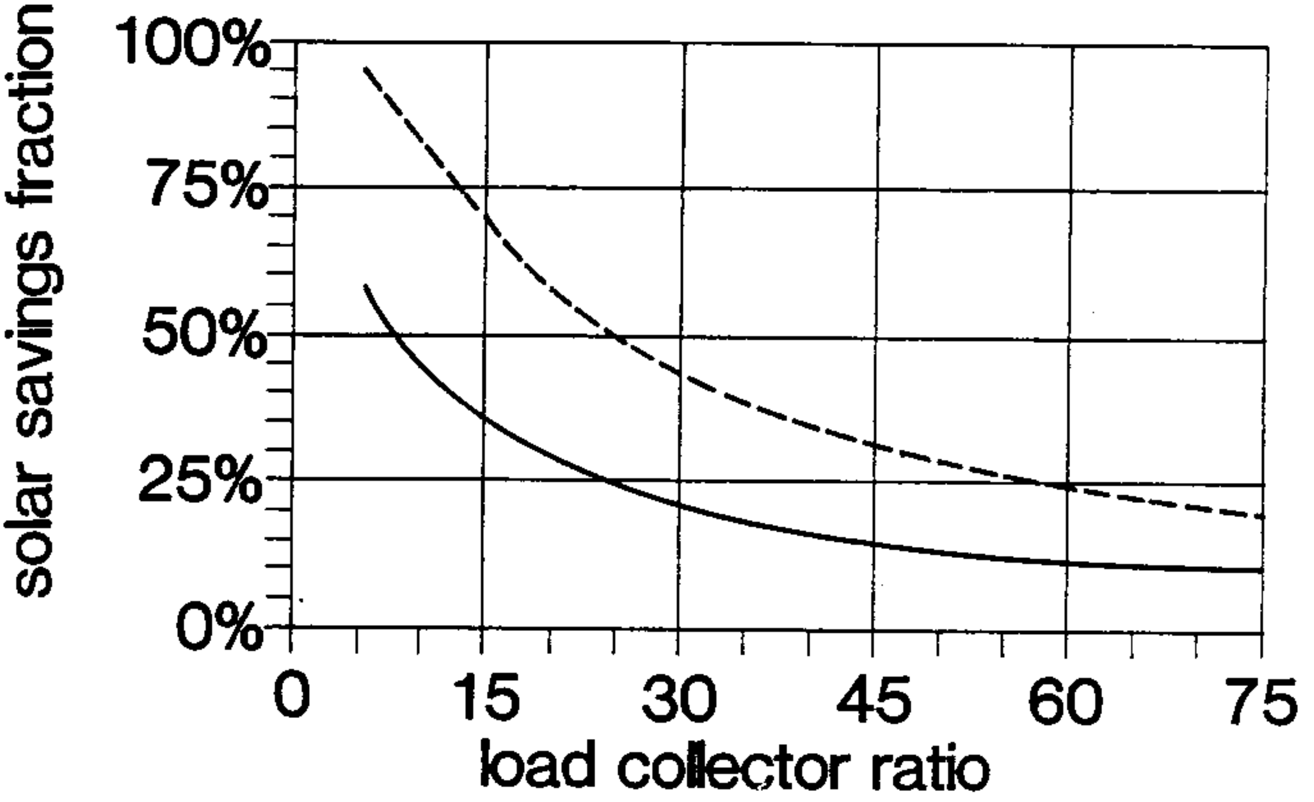
GREENHOUSE AREA 6



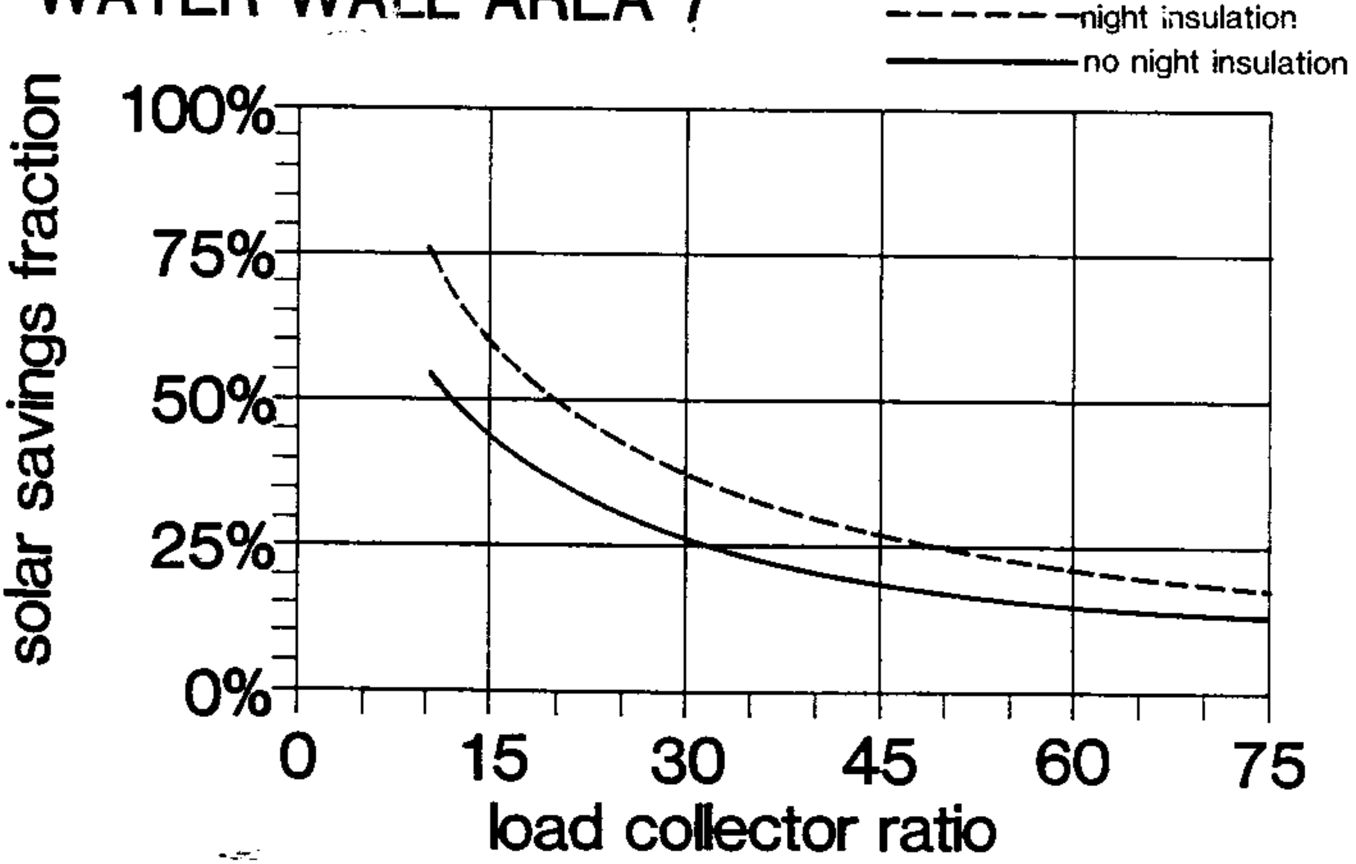
DIRECT GAIN AREA 7



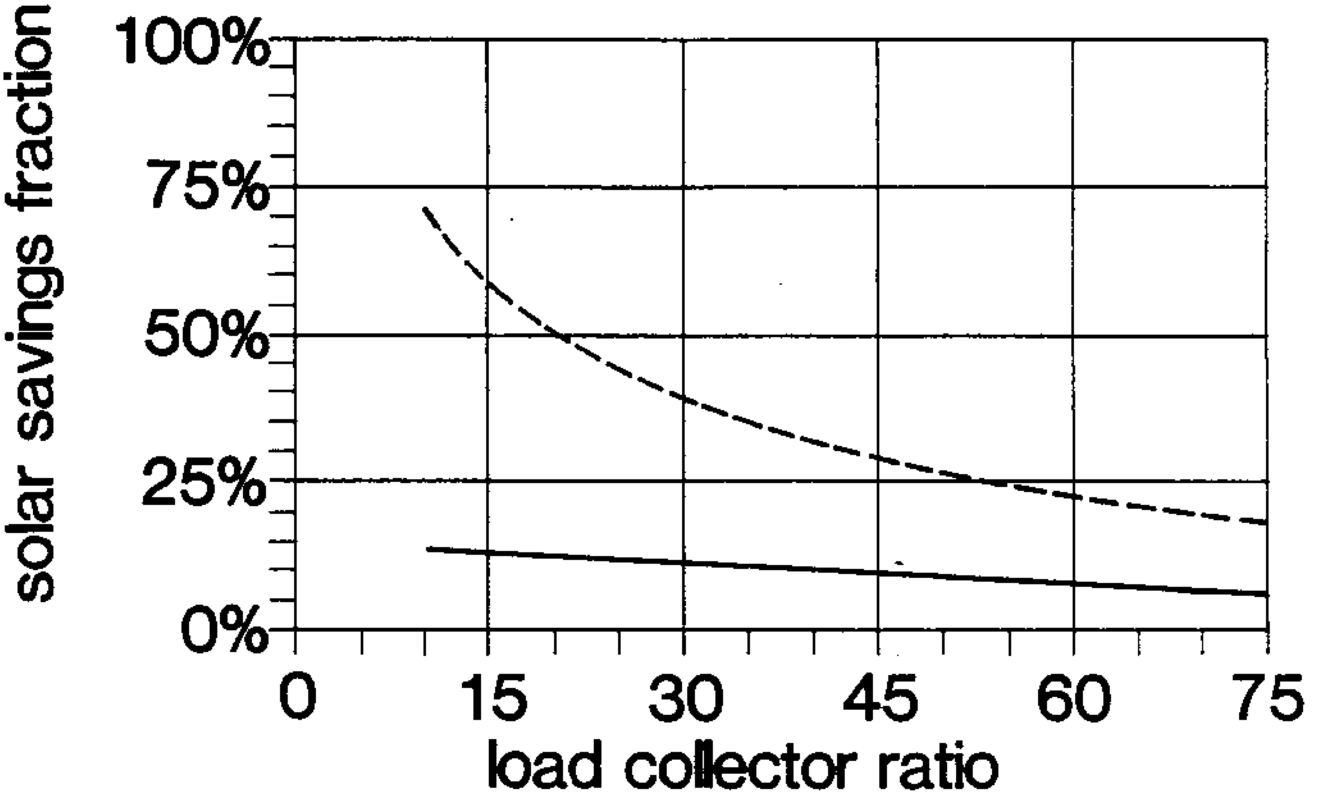
TROMBE WALL AREA 7



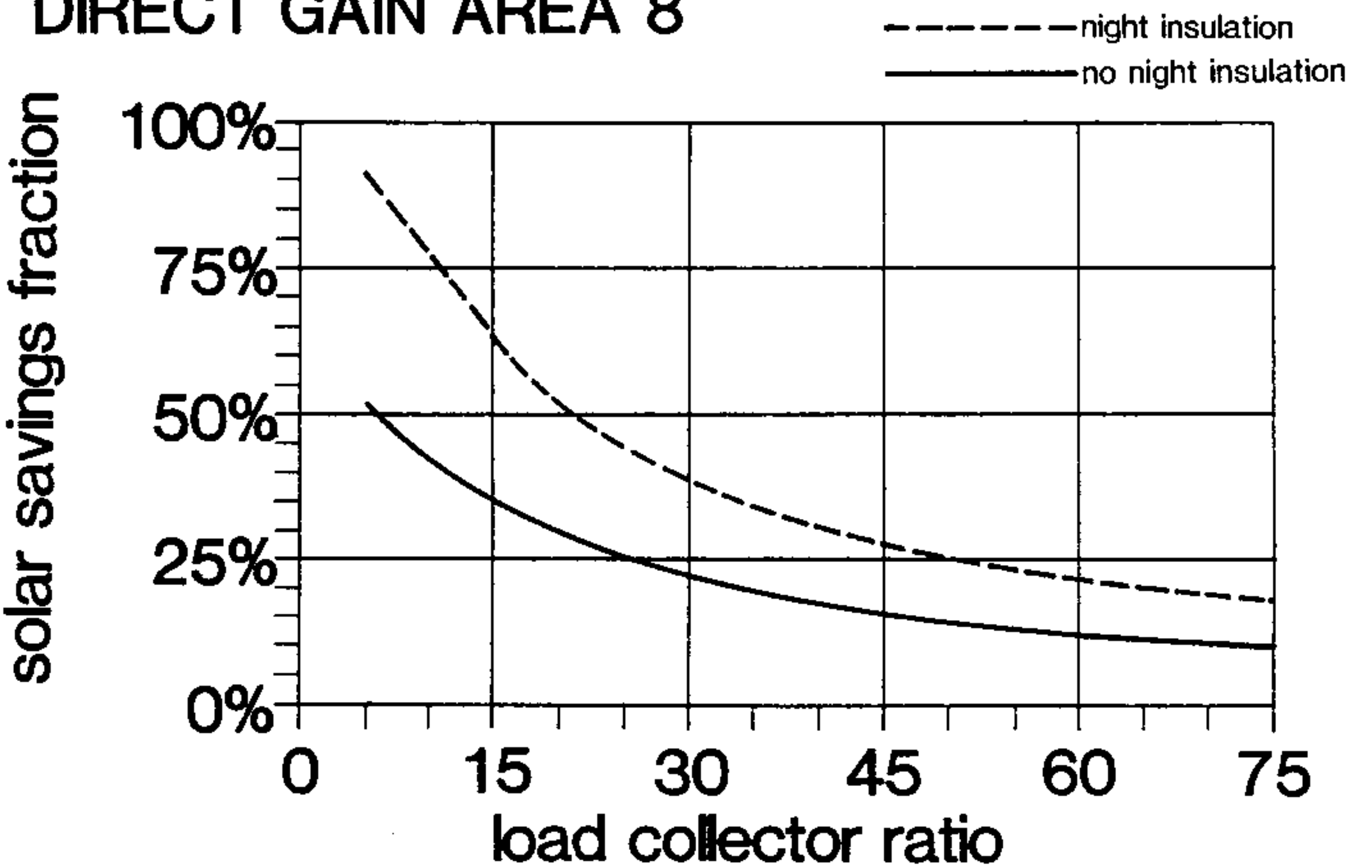
WATER WALL AREA 7



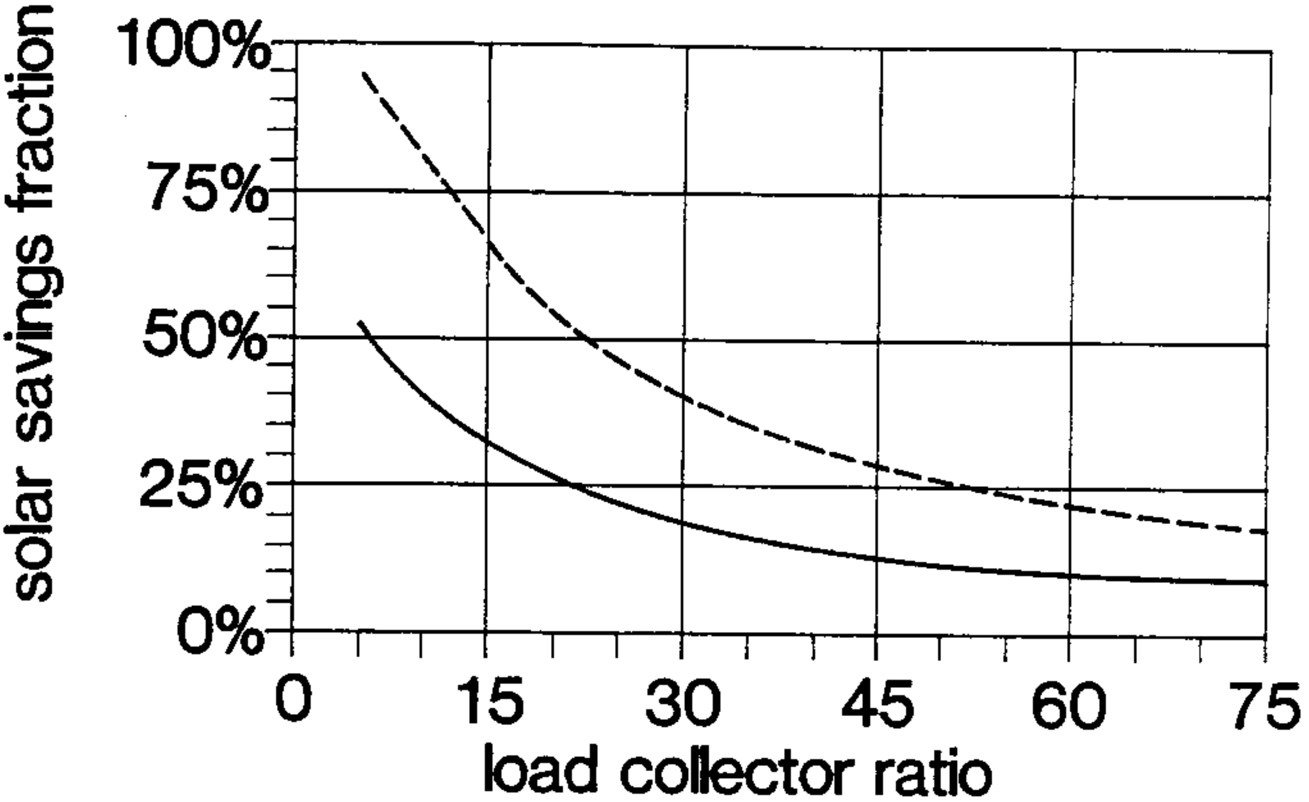
GREENHOUSE AREA 7



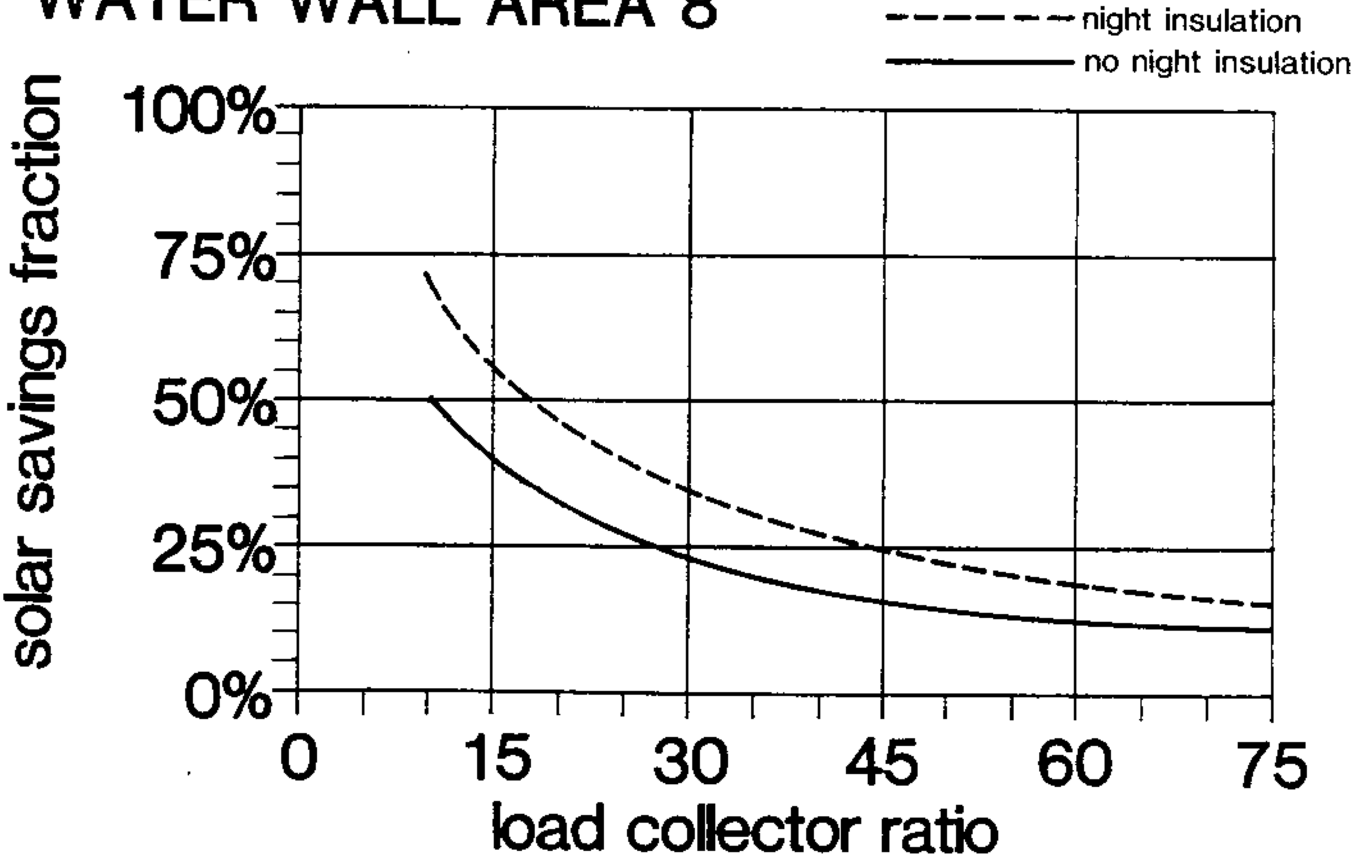
DIRECT GAIN AREA 8



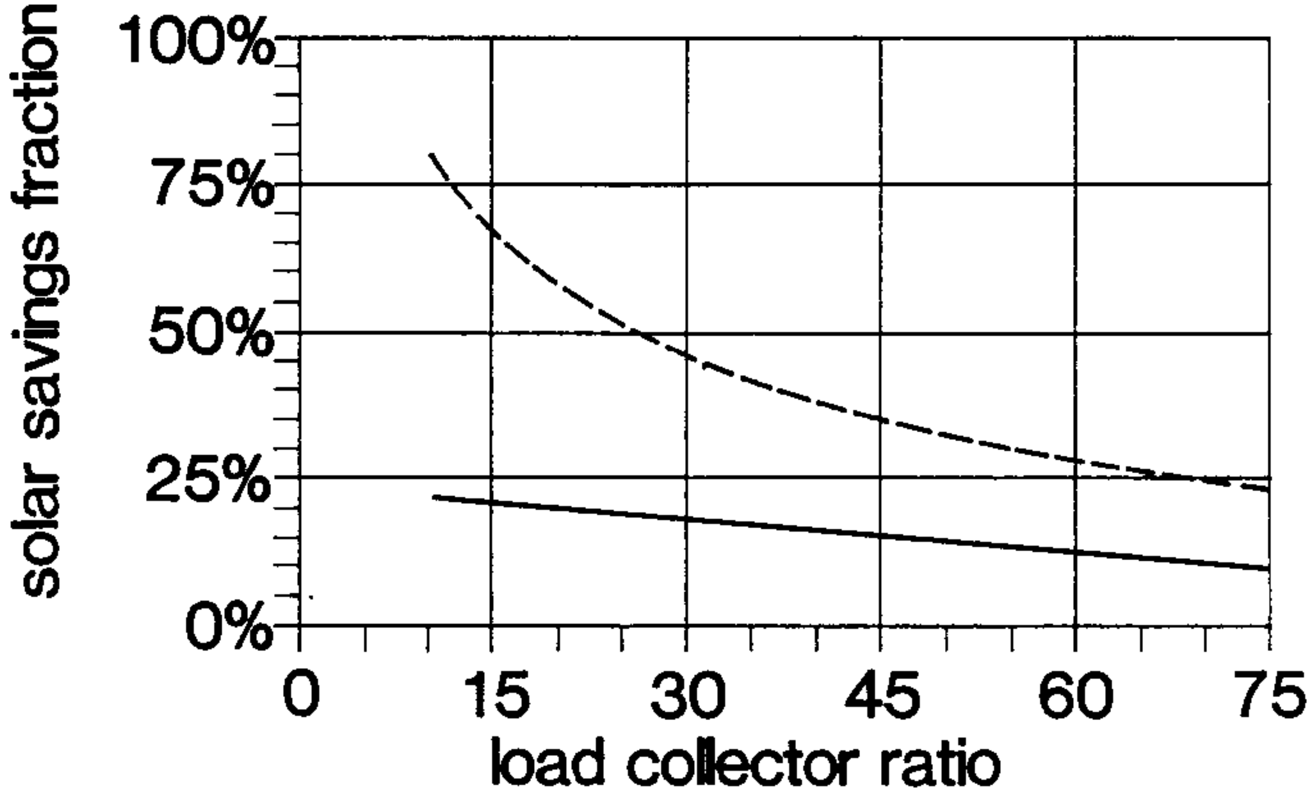
TROMBE WALL AREA 8



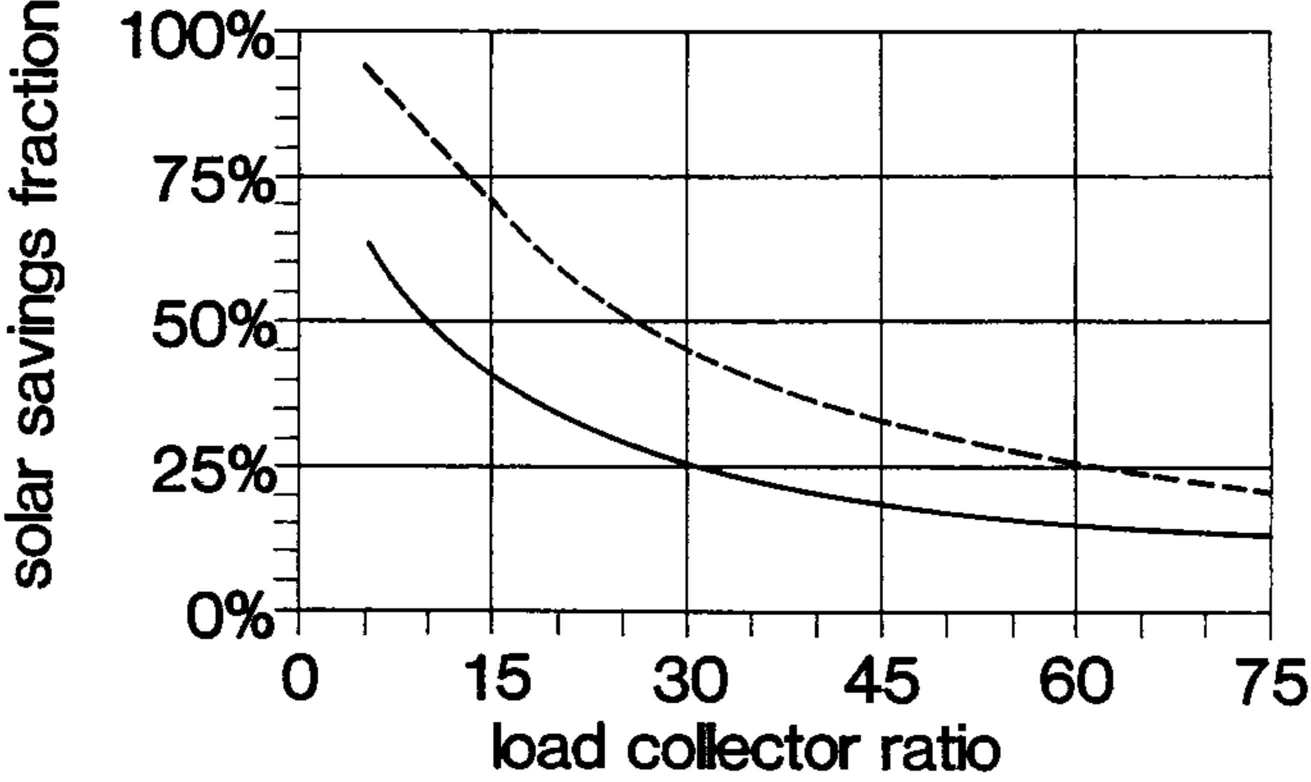
WATER WALL AREA 8



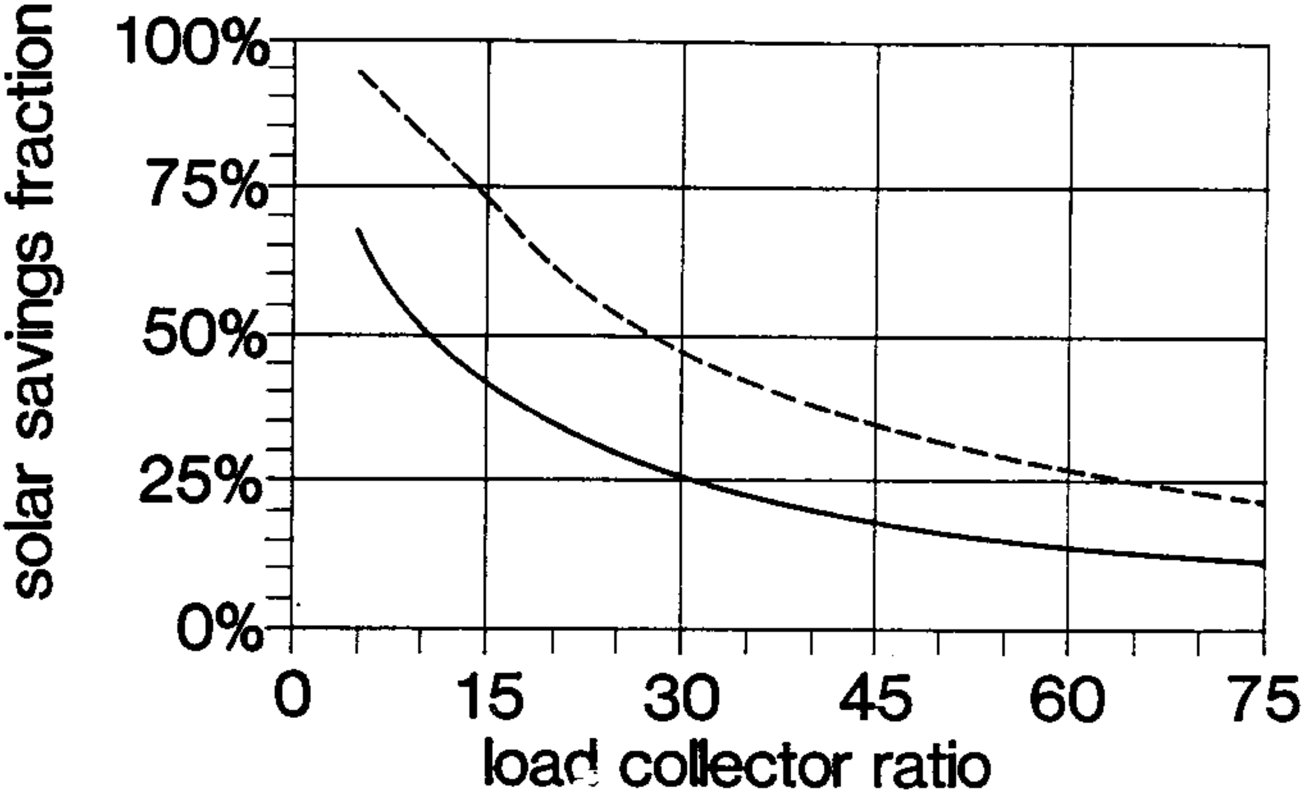
GREENHOUSE AREA 8



DIRECT GAIN AREA 9

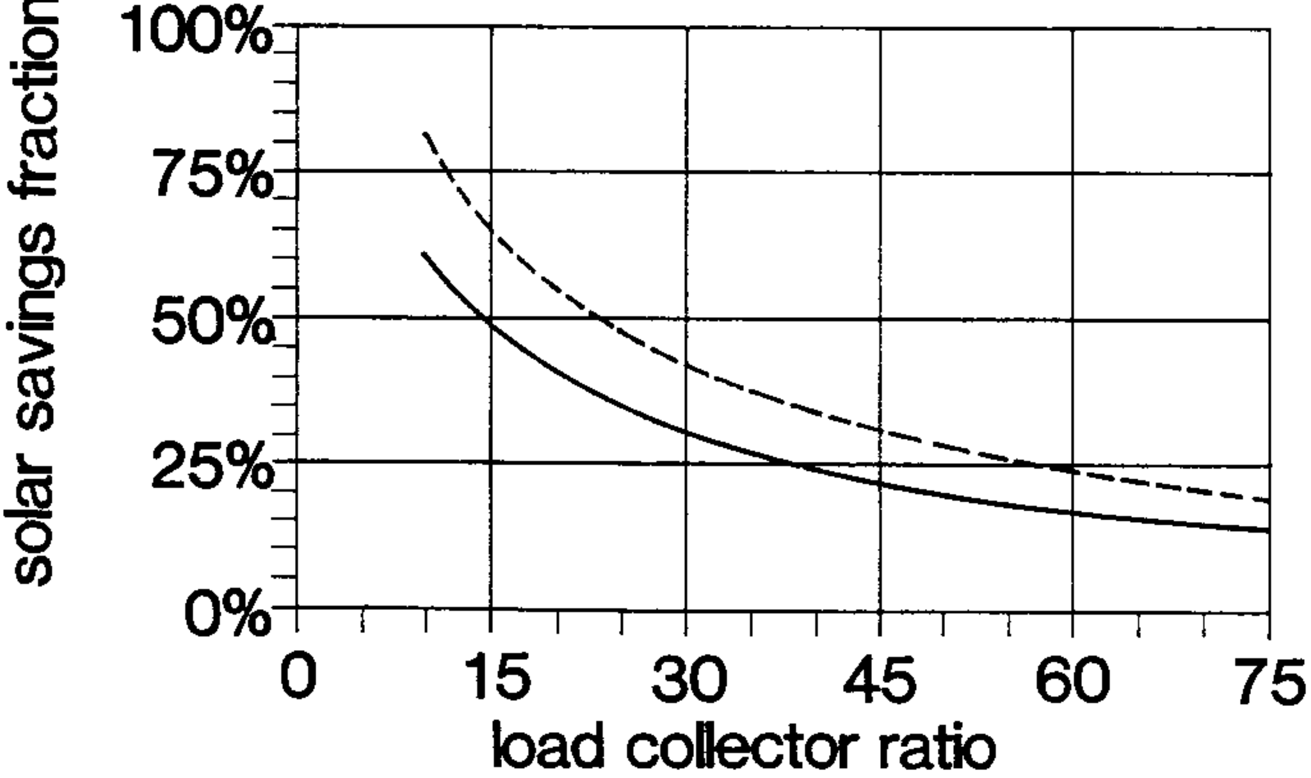


TROMBE WALL AREA 9

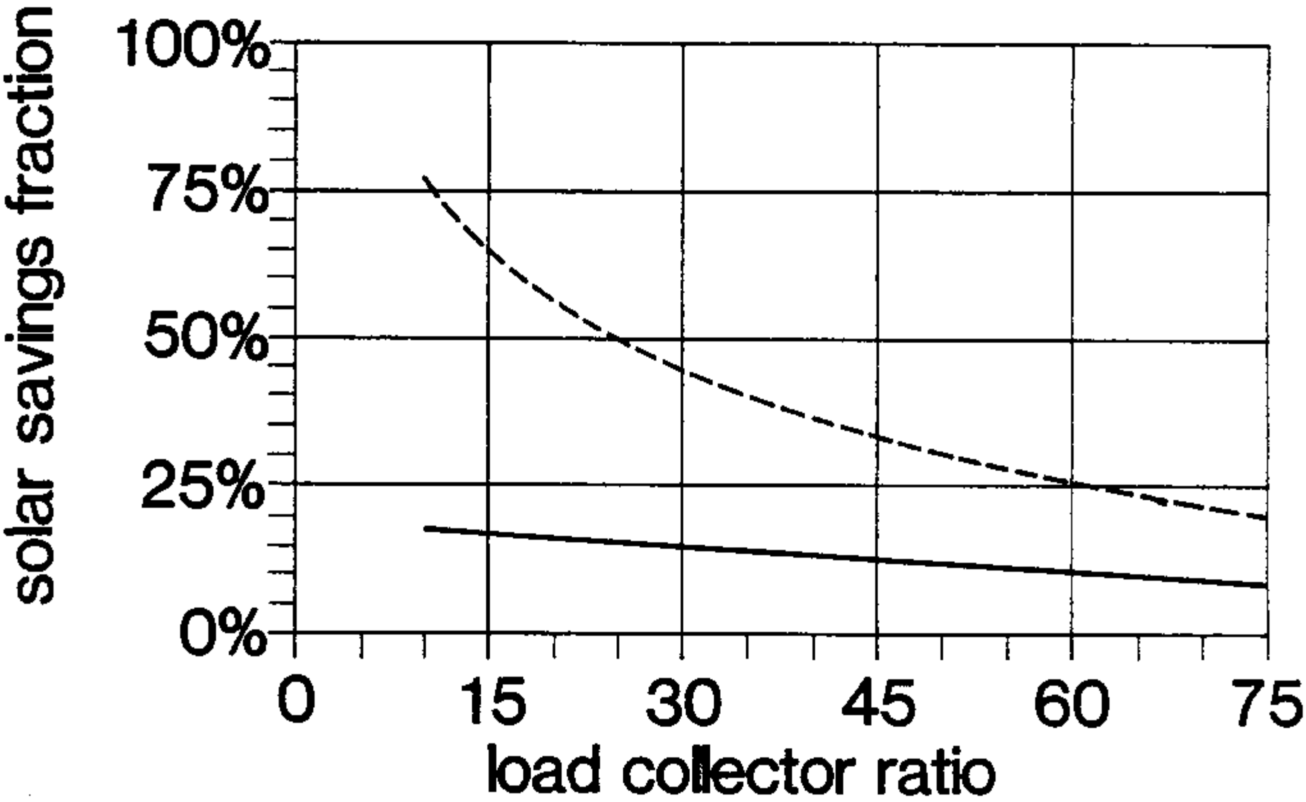


WATER WALL AREA 9

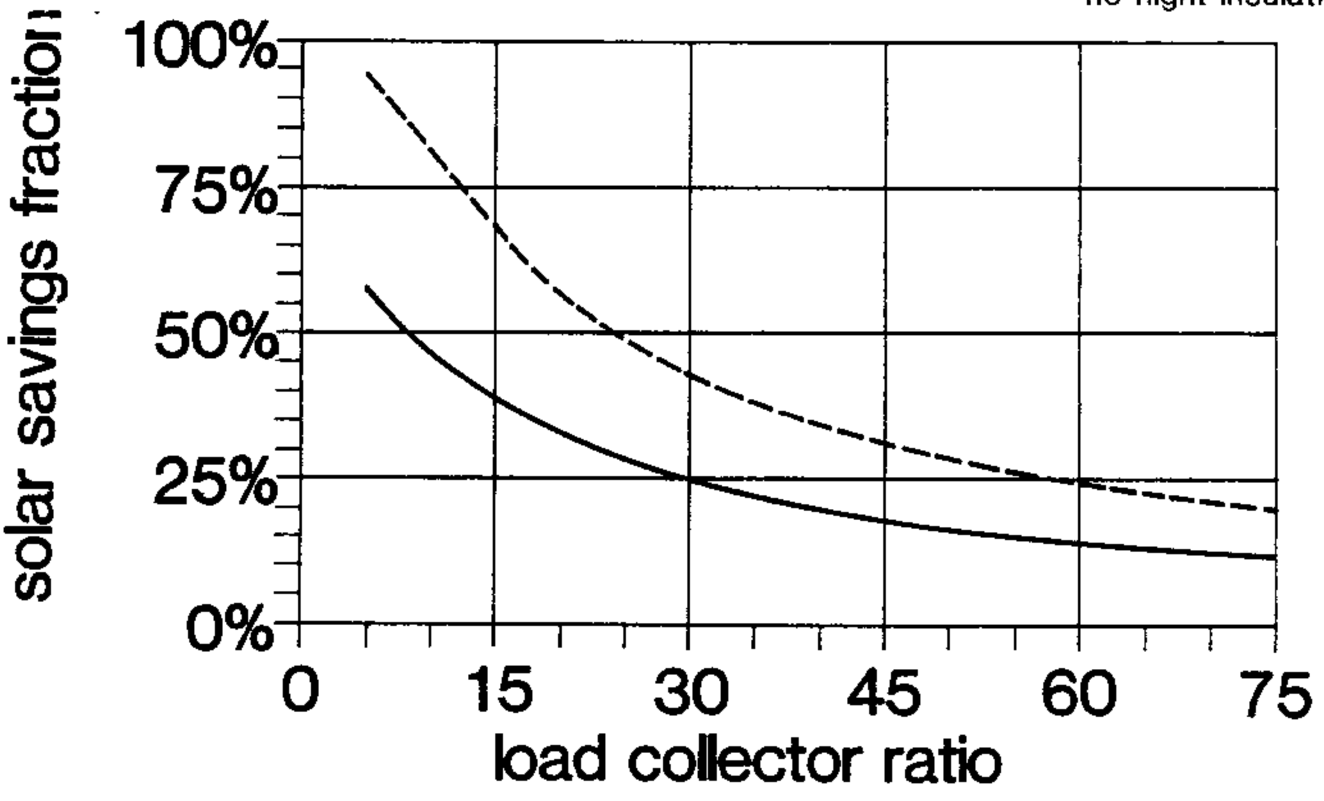
- - - - - - night insulation
——— no night insulation



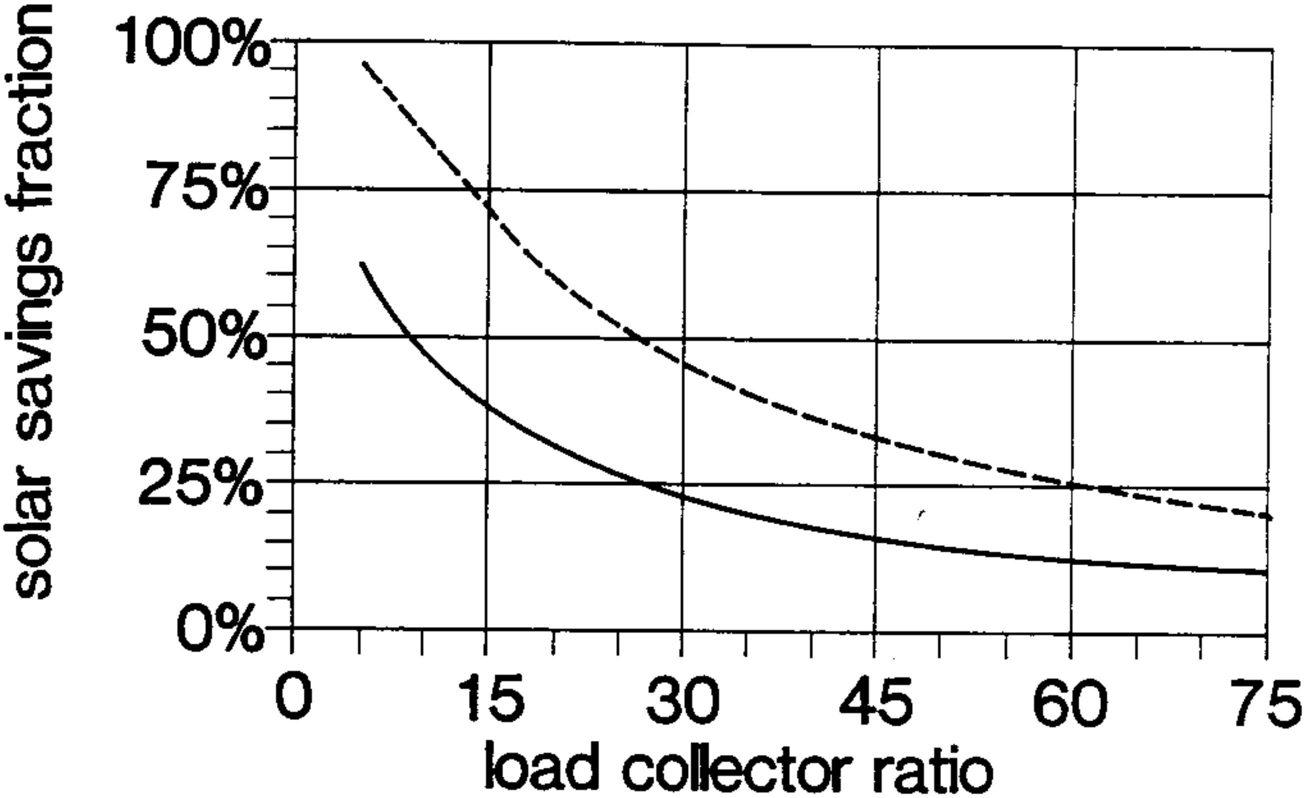
GREENHOUSE AREA 9



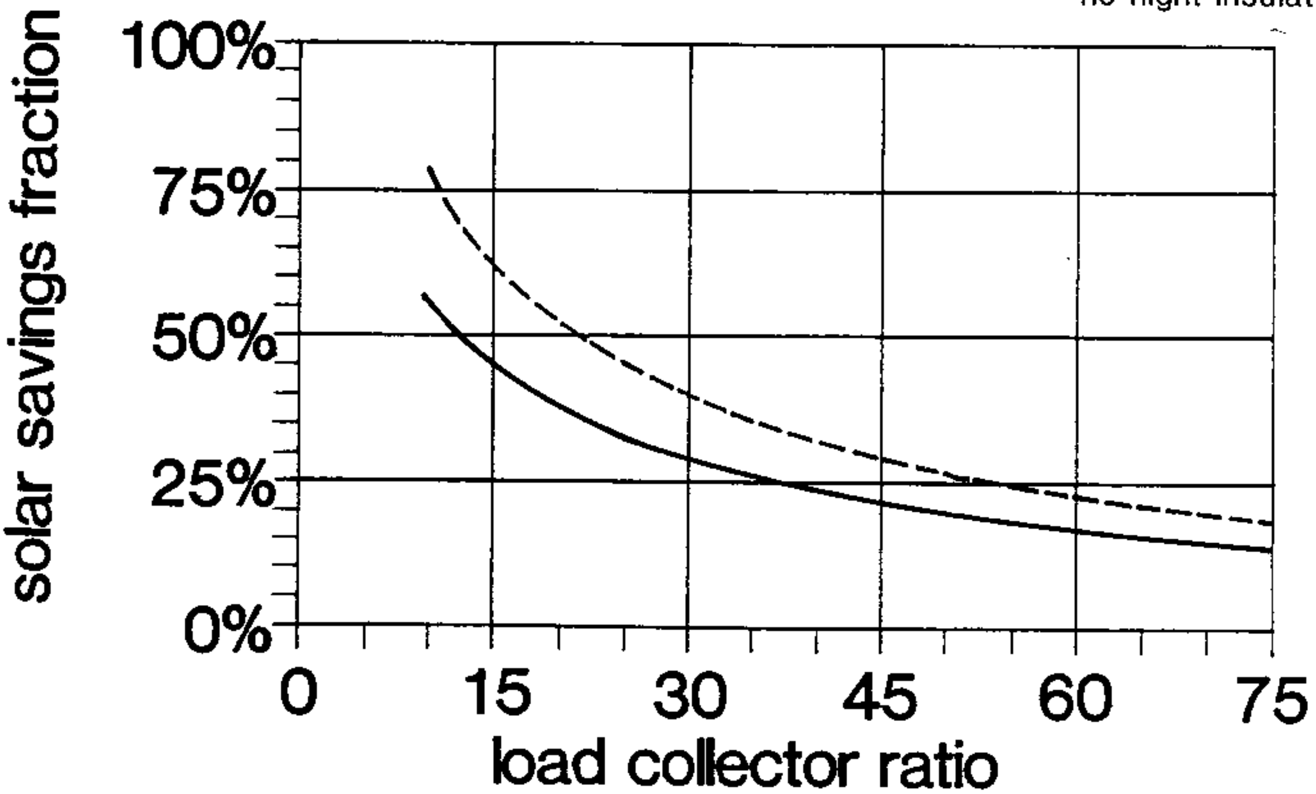
DIRECT GAIN AREA 10



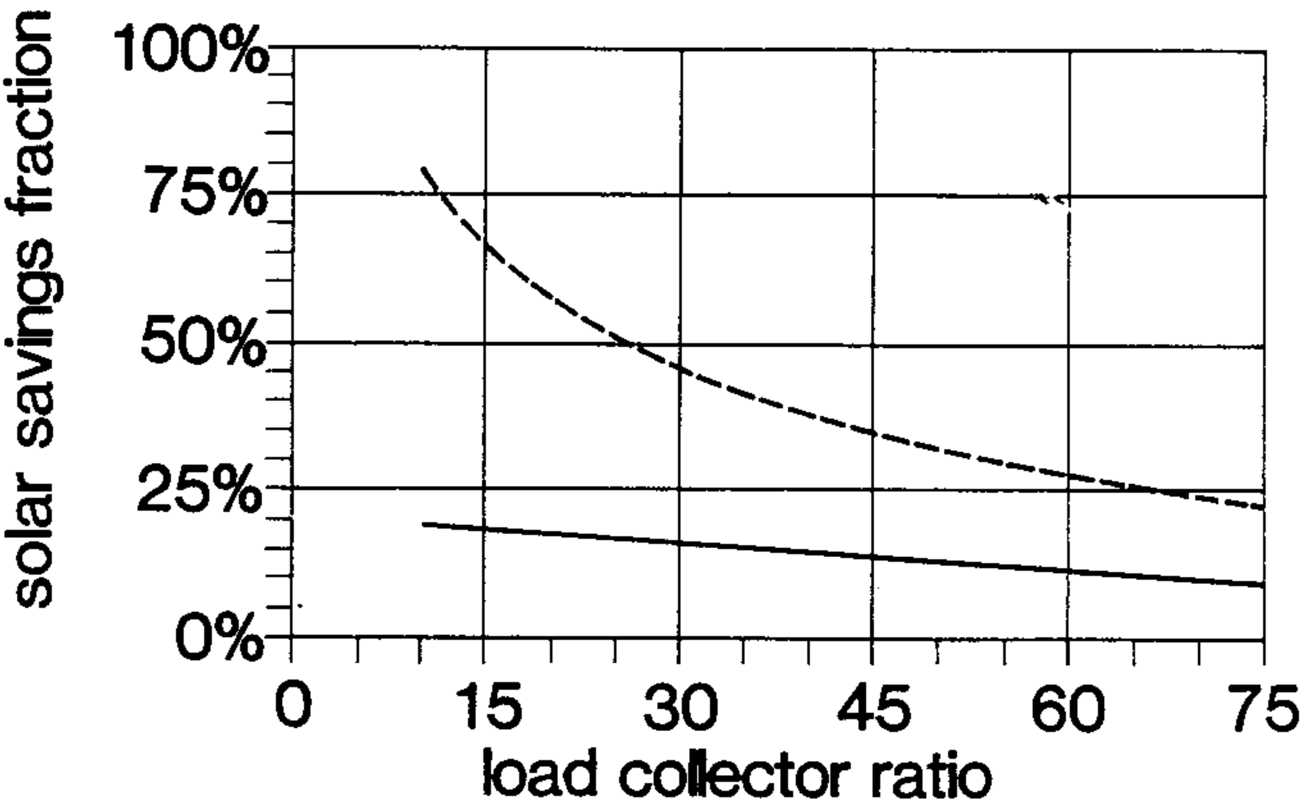
TROMBE WALL AREA 10



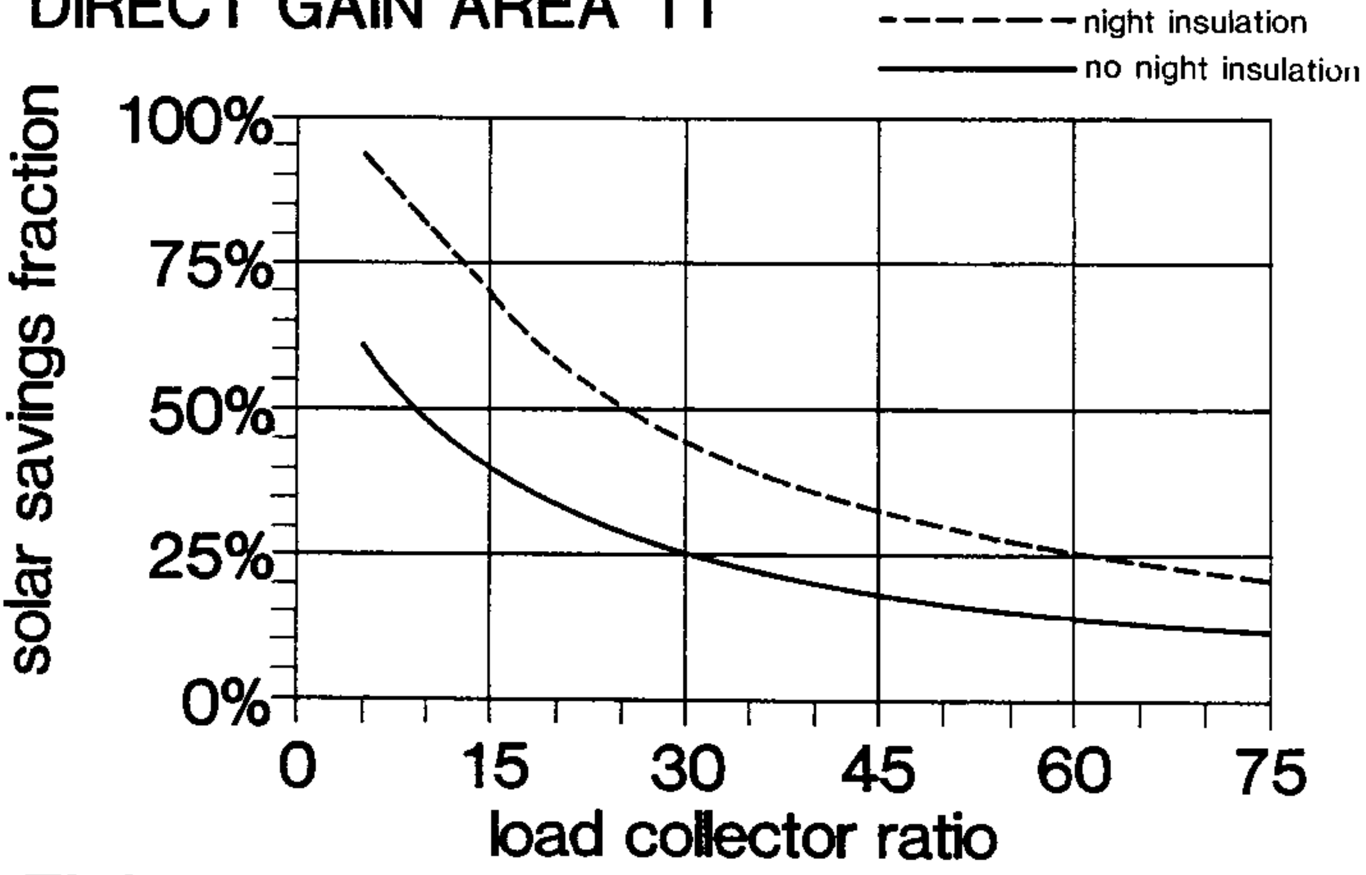
WATER WALL AREA 10



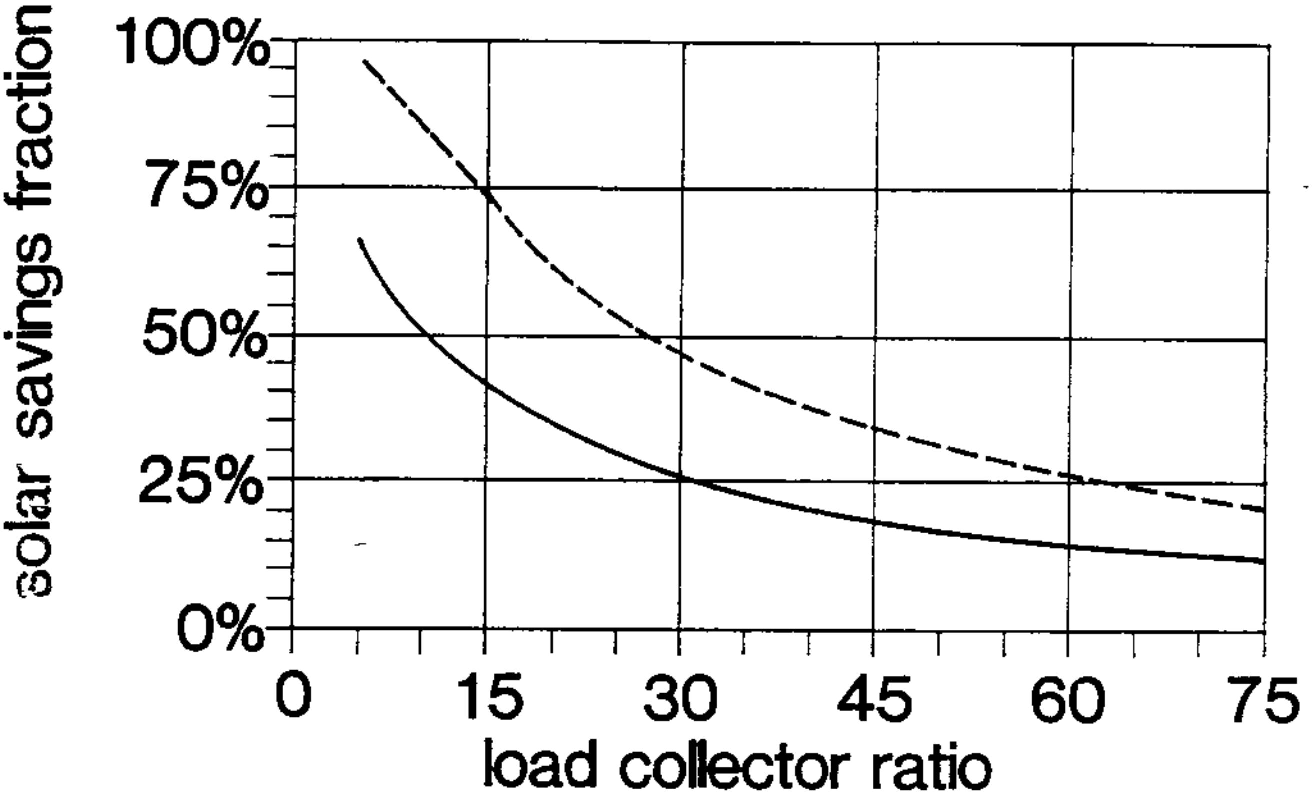
GREENHOUSE AREA 10



DIRECT GAIN AREA 11

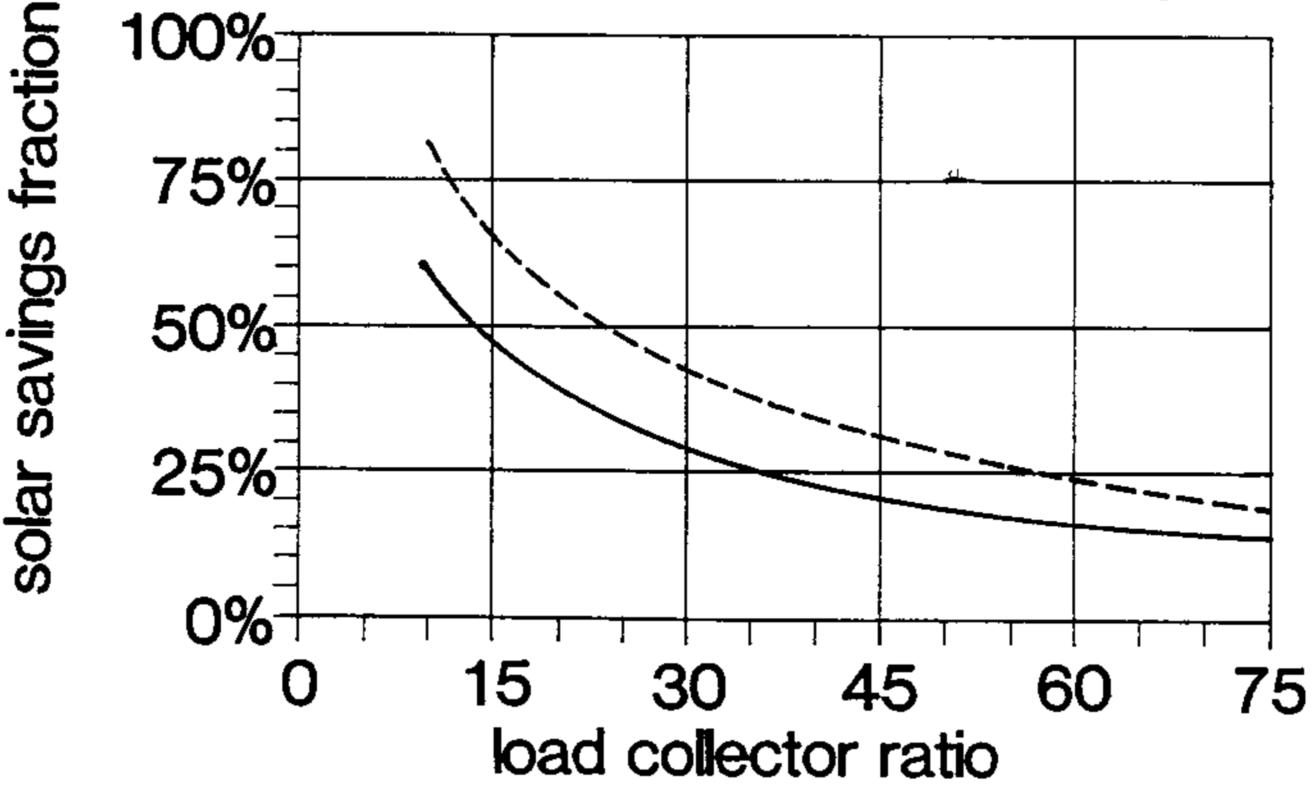


TROMBE WALL AREA 11



WATER WALL AREA 11

------night insulation
————no night insulation



GREENHOUSE AREA 11

APPENDIX 3

NEBRASKA

MONTHLY AND ANNUAL HEATING DEGREE DAY NORMALS

STATION	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	ANNUAL
Ainsworth	7	7	129	395	834	1187	1311	1067	983	520	228	58	6726
Albion	6	15	129	392	837	1215	1376	1103	970	495	210	48	6796
Alliance	11	15	183	487	882	1150	1243	1005	977	585	304	104	6946
Alma	0	0	69	315	750	1104	1206	935	815	383	147	29	5753
Arthur	11	13	154	462	876	1178	1287	1039	980	548	266	88	6902
Ashland	5	8	86	318	765	1163	1336	1047	884	401	159	25	6197
Atkinson	6	8	131	387	840	1221	1361	1103	989	510	217	52	6825
Auburn	0	6	64	278	705	1085	1234	960	797	351	139	17	5636
Beatrice	0	5	69	299	732	1110	1256	977	825	372	154	20	5819
Beaver City	0	0	60	309	744	1082	1187	916	803	375	143	28	5647
Benkelman	0	0	104	352	756	1084	1138	896	828	424	174	46	5766
Big Springs	0	5	126	421	816	1116	1209	974	902	495	234	70	6368
Blair	0	11	98	333	798	1190	1370	1092	924	432	171	27	6437
Box Butte	7	13	190	499	909	1194	1296	1053	1026	618	342	122	7269
Bridgeport	0	6	134	431	837	1125	1203	952	902	510	249	85	6434
Broken Bow	10	9	142	420	852	1184	1305	1050	961	513	235	59	6740
Burwell	10	12	150	436	885	1240	1380	1109	998	528	235	59	7042
Butte	5	8	118	395	855	1240	1386	1117	995	505	212	50	6886
Cambridge	0	0	94	343	777	1110	1206	935	831	402	159	36	5893
Centr City	0	0	90	334	777	1150	1299	1022	887	426	181	31	6197
Chadron	9	10	165	477	882	1194	1302	1042	983	570	297	100	7031
Clarkson	0	9	107	360	816	1206	1370	1098	939	459	184	34	6582
Clay Center	0	0	77	311	759	1135	1271	977	853	417	169	29	5998
Columbus	0	7	90	335	780	1172	1327	1053	899	429	175	30	6297
Crescent L	10	15	161	468	870	1159	1243	1005	964	543	283	90	6811
Crete	0	0	73	297	747	1128	1280	994	843	389	150	21	5922
Culbertson	0	0	102	376	807	1116	1215	949	862	445	188	48	6102
Curtis	0	0	91	381	813	1132	1225	960	859	439	175	40	6115
David City	0	0	85	326	783	1169	1330	1050	899	425	166	28	6261
Ewing	7	10	128	405	867	1252	1392	1117	983	496	215	47	6919
Fairbury	0	11	90	308	753	1122	1271	991	853	403	155	29	5986
Fairmont	0	5	82	310	756	1135	1293	1005	874	421	176	29	6086
Falls City	0	7	60	263	678	1057	1203	935	780	341	135	16	5475
F Robinson	11	12	183	474	879	1153	1265	1030	922	591	319	116	7025
Franklin	0	0	68	315	741	1085	1209	935	812	386	146	35	5732
Fremont	0	6	76	312	762	1159	1321	1042	871	398	150	20	6117
Geneva	0	6	81	319	768	1138	1283	1002	871	416	173	27	6084
Genoa	0	7	102	346	789	1175	1321	1047	896	432	175	30	6320
Gordon	13	17	184	499	918	1231	1336	1075	1017	591	311	114	7306
Gothenburg	0	0	98	374	801	1128	1234	974	871	441	174	44	6139

STATION	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	ANNUAL
Grand Is	6	0	107	362	804	1178	1324	1044	915	461	184	35	6420
Halsey	7	5	133	413	849	1184	1305	1047	958	506	233	54	6684
Harrison	23	29	238	546	948	1228	1330	1096	1082	684	402	161	7766
Hartington	0	11	113	364	840	1256	1420	1137	983	475	190	39	6827
Hastings	0	8	107	325	765	1122	1249	991	871	426	172	34	6070
Hayes Cntr	7	11	127	376	801	1101	1215	974	905	486	214	67	6284
Hay Springs	9	12	179	493	906	1200	1302	1050	1011	597	316	114	7189
Hebron	0	5	78	311	762	1128	1283	1000	856	400	161	26	6010
Holdrege	0	0	90	326	765	1107	1225	958	849	414	160	32	5926
Imperial	0	0	105	388	792	1082	1181	946	884	476	213	55	6122
Kearney	0	0	113	366	819	1169	1308	1042	936	475	194	45	6467
Kimball	7	11	176	484	849	1097	1178	966	946	588	317	104	6723
Kingsley D	0	7	104	365	768	1073	1203	974	899	483	225	69	6169
Lexington	0	0	107	384	804	1147	1256	997	899	469	202	44	6309
Lincoln	0	0	83	329	780	1169	1327	1039	884	419	166	22	6218
Lodgepole	0	6	124	407	804	1079	1159	938	893	501	246	76	6233
Loup City	0	6	119	392	831	1194	1324	1053	921	466	192	43	6541
Madison	0	7	104	369	819	1212	1373	1098	939	454	181	30	6586
Madrid	0	0	100	384	807	1110	1203	960	890	476	202	47	6179
McCook	0	0	86	330	744	1057	1163	913	815	392	170	44	5714
Merriman	9	11	145	443	873	1194	1308	1058	1001	560	269	84	6955
Minden	0	0	93	322	768	1116	1237	972	859	426	172	37	6002
Mitchell	5	14	186	477	364	1156	1249	1002	970	579	300	105	6907
Mullen	8	7	135	413	822	1138	1246	1014	952	516	220	75	6546
Norfolk	6	11	123	397	861	1265	1429	1151	998	500	203	37	6981
North Loup	0	8	117	385	819	1190	1327	1053	930	473	200	43	6545
N Platte	7	8	141	439	864	1184	1290	1033	952	522	238	65	6743
Oakdale	8	13	135	411	855	1243	1401	1126	983	489	211	45	6920
Ogallala	0	7	131	425	834	1135	1240	986	911	494	218	65	6446
Omaha Epp	0	6	71	301	750	1147	1314	1036	865	391	148	20	6049
Omaha North	7	10	99	342	813	1218	1389	1106	942	456	186	33	6601
O Neill	6	9	136	407	858	1246	1386	1126	1004	513	220	49	6960
Osceola	0	6	92	336	783	1175	1339	1053	899	436	170	28	6317
Oshkosh	0	11	129	438	846	1138	1234	980	915	506	234	70	6501
Osmond	0	9	118	390	855	1262	1426	1145	989	482	193	37	6903
Pawnee City	0	0	48	252	681	1060	1203	930	769	332	135	16	5426
Purdum	7	6	121	409	840	1178	1290	1047	961	513	225	60	6657
Ravenna	0	0	94	358	807	1183	1283	1014	893	439	174	36	6261
Red Cloud	0	0	75	326	762	1122	1240	955	825	384	143	27	5859
Saint Paul	6	7	105	364	804	1175	1308	1039	902	442	173	34	6359

APPENDIX 3

STATION	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	ANNUAL
Scottsbluff	0	8	160	459	864	1169	1243	994	952	564	280	91	6774
Seward	0	5	83	322	762	1141	1293	1014	862	398	160	23	6063
Sidney	0	7	153	454	846	1113	1197	963	924	546	275	86	6564
Stanton	6	15	117	376	825	1225	1383	1103	946	456	189	36	6677
Stapleton	10	8	131	416	840	1166	1274	1030	955	522	233	65	6650
Syracuse	0	7	73	302	750	1135	1296	1011	843	380	145	19	5961
Tecumseh	0	7	77	309	738	1119	1271	983	825	386	153	22	5890
Tekamah	0	6	83	320	783	1181	1355	1078	908	417	175	24	6330
Valentine	8	10	154	470	912	1259	1383	1134	1048	576	273	73	7300
Wakefield	5	14	116	395	846	1262	1426	1134	970	472	186	34	6860
Walthill	0	10	120	384	849	1249	1432	1142	964	467	185	41	6843
Wpng Water	5	6	82	307	753	1147	1305	1019	856	393	158	25	6056
West Point	0	13	105	353	816	1218	1395	1112	942	444	172	32	6602
York	0	0	87	320	762	1138	1290	1011	874	416	160	24	6082

APPENDIX 4

INSULATING VALUES OF CONSTRUCTION MATERIALS

1.Conductivities (k), Conductances (C) and Resistance (R) of Building and Insulating Materials

(The constants are expressed in Btu/hr-sq ft-°F. Conductivities are per inch thickness, and Conductances are for thickness or construction stated, but not per inch thickness. All values are for a mean temperature of 75 °F, except as noted by an (*) which have been reported at 45 °F.)

				Resistance[1] (R)		
Description	Density (lb/ft^3)	Conductivity (k)	Conductance (C)	Per Inch thickness (1/k)	For thickness listed	Specific Heat, Btu/lb (°F)
BUILDING BOARD						
Boards, Panels,Subflooring, Sheathing, Woodboard Panel Products						
Asbestos-cement board.........	120	4.0	--	0.25	--	0.24
Asbestos-cement board..0.125".	120	---	33.00	----	0.03	
Asbestos-cement board...0.25"	120	---	16.50	----	0.06	
Gypsum or plaster board.0.375".	50	---	3.10	----	0.32	0.26
Gypsum or plaster board...0.5".	50	---	2.22	----	0.45	
Gypsum or plaster board.0.625".	50	---	1.78	----	0.56	
Plywood (Douglas fir)..........	34	0.8	--	1.25	--	0.29
Plywood (Douglas fir)....0.25".	34	---	3.20	----	0.31	
Plywood (Douglas fir)...0.375".	34	---	2.13	----	0.47	
Plywood (Douglas fir).....0.5".	34	---	1.60	----	0.62	
Plywood (Douglas fir)...0.625".	34	---	1.29	----	0.77	
Plywood or wood panels...0.75".	34	---	1.07	----	0.93	0.29
Vegetable fiber board						
Sheathing, regular density.............0.5".	18	---	0.76	----	1.32	0.31
..................0.78125".	18	---	0.49	----	2.06	
Sheathing, intermediate density.....0.5".	22	---	0.82	----	1.22	0.31
Nail-base sheathing....0.5".	25	---	0.88	----	1.14	0.31
Shingle backer.......0.375".	18	---	1.06	----	0.94	0.31
Shingle backer......0.3125".	18	---	1.28	----	0.78	
Sound deadening board..0.5".	15	---	0.74	----	1.35	0.30
Tile and lay-in panels, plain or acoustic........	18	0.4	----	2.50	----	0.14
.....................0.5".	18	---	0.80	----	1.25	
.....................0.75".	18	---	0.53	----	1.89	
Laminated paperboard........	30	0.5	----	2.00	----	0.33
Homogeneous board from repulped paper...........	30	0.5	----	2.00	----	0.28

APPENDIX 4

				Resistance[1] (R)		
Description	Density (lb/ft^3)	Conductivity (k)	Conductance (C)	Per Inch thickness (1/k)	For thickness listed	Specific Heat, Btu/lb (°F)
Hardboard						
Medium density..............	50	0.73	----	1.37	----	0.31
High density, service temp. service underlay.........	55	0.82	----	1.22	----	0.32
High density, std. tempered.	63	1.00	----	1.00	----	0.32
Particleboard						
Low density.................	37	0.54	----	1.85	----	0.31
Medium density..............	50	0.94	----	1.06	----	0.31
High density................	62.5	1.18	----	0.85	----	0.31
Underlayment.........0.625".	40	---	1.22	----	0.82	0.29
Wood subfloor............0.75".		---	1.06	----	0.94	0.33
BUILDING MEMBRANE						
Vapor--permeable felt.........	---	---	16.7	----	0.06	
Vapor-- seal, 2 layers of mopped 15-lb felt...........	---	---	8.35	----	0.12	
Vapor--seal, plastic film......	---	---	----	----	Negl.	
FINISH FLOORING MATERIALS						
Carpet and fibrous pad.........	---	---	0.48	----	2.08	0.34
Carpet and rubber pad..........	---	---	0.81	----	1.23	0.33
Cork tile..............0.125".	---	---	3.60	----	0.28	0.48
Terrazzo..................1".	---	---	12.5	----	0.08	0.19
Tile-- asphalt, linoleum, vinyl, rubber...............	---	---	20.0	----	0.05	0.30
vinyl abestos...............						0.24
ceramic.....................						0.19
Wood, hardwood finish....0.75".			1.47		0.68	
INSULATING MATERIALS						
BLANKET and BATT						
Mineral fiber, fibrous from processed from rock, slag, or glass						
approx.^{2} 2-2.75".............	0.3-2.0	---	0.143	----	7	0.17-0.23
approx.^{2} 3-3.5"..............	0.3-2.0	---	0.091	----	11	
approx.^{2} 3.5-6.5"............	0.3-2.0	---	0.053	----	19	
approx.^{2} 6-7"................	0.3-2.0		0.045		22	
approx.^{3} 8.5"................	0.3-2.0		0.033		30	

Description	Density[3] (lb/ft^3)	Conductivity (k)	Conductance (C)	Resistance[1] (R) Per Inch thickness (1/k)	For thickness listed	Specific Heat, Btu/lb (°F)
BOARD and SLABS						
Cellular glass	8.5	0.38	---	2.63	----	0.24
Glass fiber, organic bonded	4-9	0.25	---	4.00	----	0.23
Expanded rubber (rigid)	4.5	0.22	---	4.55	----	0.40
Expanded polystyrene extruded						
Cut cell surface	1.8	0.25	---	4.00	----	0.23
Expanded polystyrene extruded						
Smooth skin surface	2.2	0.20	---	5.00	----	0.29
Expanded polystrene extruded						
Smooth skin surface	3.5	0.19	---	5.26	----	
Expanded polyurethane[4]						
(R-11 exp.)	1.5	0.16	---	6.25	----	0.38
(thickness 1" or greater)	2.5					
Mineral fiber with resin						
binder	15	0.29	---	3.45	----	0.17
Mineral fiberboard, wet felted						
Core or roof insulation	16-17	0.34	---	2.94	----	
Acoustical tile	18	0.35	---	2.86	----	0.19
Acoustical tile	21	0.37	---	2.70	----	
Mineral fiberboard, wet molded						
Acoustical tile[5]	23	0.42	---	2.38	----	0.14
Wood or cane fiberboard						
Acoustical tile[5] 0.5"	----	---	0.80	----	1.25	0.31
Acoustical tile[5] 0.75"	----	---	0.53	----	1.89	
Interior finish(plank, tile)	15	0.35	---	2.86	----	0.32
Wood shredded(cemented in						
performed slabs)	22	0.60	---	1.67	----	0.31
LOOSE FILL						
Cellulosic insulation(milled						
paper or wood pulp)	2.3-3.2	0.27-0.32	---	3.13-3.7	----	0.33
Sawdust or shavings	8-15	0.45	---	2.22	----	0.33
Wood fiber softwoods	2.0-3.5	0.30	---	3.33	----	0.33
Perlite, expanded	5-8	0.37	---	2.70	----	0.26
Mineral fiber(rock,						
slag or glass)						
approx.[2] 3.75-5"	0.6-2	---	---		11	0.17
approx.[2] 6.5-8.75"	0.6-2	---	---		19	
approx.[2] 7.5-10"	0.6-2	---	---		22	
approx.[2] 10.25-13.75	0.6-2	---	---		30	
Vermiculite, exfoliated	7-8.2	0.47	---	2.13	----	3.20
	4-6	0.44		2.27	----	

APPENDIX 4

Description	Density (lb/ft^3)	Conductivity (k)	Conductance (C)	Resistance[1] (R)		Specific Heat, Btu/lb (°F)
				Per Inch thickness (1/k)	For thickness listed	
ROOF INSULATION[6]						
Performed, for use above deck Different roof insulations are available in different thicknesses to provide the design C values listed.[6] Consult individual manufactures for actual thickness of their material			0.72 to 0.12			1.39 to 8.33
MASONRY MATERIALS						
CONCRETES						
Cement mortar..................	116	5.0	---	0.20	----	
Gypsum-fiber concrete 87.5% gypsum, 12.5% wood chips......................	51	1.66	---	0.60	----	0.21
Lightweight aggregates including expanded shale, clay or slate; cinders; pumice; vermiculite; also cellular concretes	120	5.2	---	0.19	----	
	100	3.6	---	0.28	----	
	80	2.5	---	0.40	----	
	60	1.7	---	0.59	----	
	40	1.15	---	0.86	----	
	30	0.90	---	1.11	----	
	20	0.70		1.43		
Perlite, expanded.............	40	0.93		1.08		
	30	0.71		1.41		
	20	0.50		2.00		0.32
Sand and gravel or stone aggregate(oven dried)......	140	9.00	---	0.11		0.22
Sand and gravel or stone aggregate(not dried).......	140	12.0	---	0.08		
Stucco.........................	116	5.00	---	0.20		

Description	Density (lb/ft^3)	Conductivity (k)	Conductance (C)	Resistance[1] (R) Per Inch thickness (1/k)	Resistance[1] (R) For thickness listed	Specific Heat, Btu/lb ($^{\circ}$F)
MASONRY UNITS						
Brick, common[7]	120	5.0	---	0.20	----	0.19
Brick, face[7]	130	9.0	---	0.11	----	
Clay tile, hollow:						
1 cell deep 3".	---	---	1.25	----	0.80	0.21
1 cell deep 4".	---	---	0.90	----	1.11	
2 cells deep 6".	---	---	0.66	----	1.52	
2 cells deep 8".	---	---	0.54	----	1.85	
2 cells deep 10".	---	---	0.45	----	2.22	
3 cells deep 12".	---	---	0.40	----	2.50	
Concrete blocks, three oval core:						
Sand and gravel aggregate 4".	---	---	1.40	----	0.71	0.22
8".	---	---	0.90	----	1.11	
12".	---	---	0.78	----	1.28	
Cinder aggregate 3".	---	---	1.16	----	0.86	0.21
4".	---	---	0.90	----	1.11	
8".	---	---	0.58	----	1.72	
12".	---	---	0.53	----	1.89	
Lightweight aggregate 3".	---	---	0.79	----	1.27	0.21
(expanded shale, 4".	---	---	0.67	----	1.50	
clay, slate or 8".	---	---	0.50	----	2.00	
slag; pumice) 12".	---	---	0.44	----	2.27	
Concrete blocks, rectangular core[8]						
Sand and gravel aggregate 2 core, 8" 36 lb.[9]	---	---	0.96	----	1.04	0.22
Same with filled cores[8]	---	---	0.52	----	1.93	0.22
Lightweight aggregate(expanded shale, clay, slate or slag, pumice):						
3 core, 6" 19 lb.[9]	---	---	0.61	----	1.65	0.21
Same with filled cores[10]	---	---	0.33	----	2.99	
2 core, 8" 24 lb.[9]	---	---	0.46	----	2.18	
Same with filled cores[10]	---	---	0.20	----	5.03	
3 core, 12" 38 lb.[9]	---	---	0.40	----	2.48	
Same with filled cores[10]	---	---	0.17	----	5.82	
Stone, lime or sand	---	12.5	----	0.08	----	0.19
Gypsum partition tile:						
3 x 12 x 30" solid	---	---	0.79	----	1.26	0.19
3 x 12 x 30" 4-cell	---	---	0.74	----	1.35	
4 x 12 x 30" 3-cell	---	---	0.60	----	1.67	

APPENDIX 4

				Resistance[1] (R)		
Description	Density (lb/ft^3)	Conductivity (k)	Conductance (C)	Per Inch thickness (1/k)	For thickness listed	Specific Heat, Btu/lb (°F)
PLASTERING MATERIALS						
Cement plaster, sand aggregate.	116	5.0	----	0.20	---	0.20
Sand aggregate.....0.375".	---	---	13.3	----	0.88	0.20
Sand aggregate......0.75".	---	---	6.66	----	0.15	0.20
Gypsum plaster:						
Lightweight						
aggregate........0.5".	45	---	3.12	----	0.32	
......0.625".	45	---	2.67	----	0.39	
Lightweight agg. on metal						
lath............0.75".	---	---	2.13	----	0.47	
Perlite aggregate.........	45	1.5	----	0.67	----	0.32
Sand aggregate............	105	5.6	----	0.18	----	0.20
Sand aggregate.......0.5".	105	---	11.1	----	0.09	
Sand aggregate.....0.625".	105	---	9.10	----	0.11	
Sand aggregate on metal						
lath............0.75".	---	---	7.70	----	0.13	
Vermiculite aggregate.....	45	1.7	----	0.59	----	
ROOFING						
Asbestos-cement shingles.......	120	---	4.76	----	0.21	0.24
Asphalt roll roofing...........	70	---	6.50	----	0.15	0.36
Asphalt shingles...............	70	---	2.27	----	0.44	0.30
Build-up roofing........0.375".	70	---	3.00	----	0.33	0.35
Slate....................0.5".	---	---	20.0	----	0.05	0.30
Wood shingles, plain and						
plastic film faced........	---	---	1.06	----	0.94	0.31
SIDING MATERIALS(ON FLAT SURFACE)						
Shingles						
Asbestos-cement...........	120	---	4.75	----	0.21	
Wood, 16", 7.5 exposure...	---	---	1.15	----	0.87	0.31
Wood, double, 16", 12"						
exposure...........	---	---	0.84	----	1.19	0.28
Wood, plus insul. backer						
board,0.1325"......	---	---	0.71	----	1.40	0.31

Description	Density (lb/ft^3)	Conductivity (k)	Conductance (C)	Resistance[1] (R)		Specific Heat, Btu/lb (^{o}F)
				Per Inch thickness (1/k)	For thickness listed	
Siding						
Asbestos-cement, 0.25, lapped	---	---	4.76	----	0.21	0.24
Asphalt roll roofing	---	---	6.50	----	0.15	0.35
Asphalt insulating siding (0.5" bed)	---	---	0.69	----	1.46	0.35
Wood, drop, 1 x 8"	---	---	1.27	----	0.79	0.28
Wood, bevel 0.5 x 8", lapped	---	---	1.23	----	0.81	0.28
Wood, bevel 0.75 x 10", lapped	---	---	0.95	----	1.05	0.28
Wood, plywood, 0.375", lapped	---	---	1.59	----	0.59	0.29
Wood, medium density siding, 0.4375"	40	1.49	----	0.67		0.28
Aluminum or steel[11], over sheathing						
Hollow-backed	---	---	1.61	----	0.61	0.29
Insulating-board backed nominal 0.375"	---	---	0.55	----	1.82	0.32
Insulating-board backed nominal 0.375", foil backed			0.34		2.96	
Architectural glass	---	---	10.0	----	0.10	0.20
WOODS						
Maple, oak, and similar hardwoods	45	1.10	----	0.91	----	0.30
Fir, pine, and similar softwoods	32	0.80	----	1.25	----	0.33
0.75"	32	----	1.06	----	0.94	0.33
1.5"		----	0.53	----	1.89	
2.5"		----	0.32	----	3.12	
3.5"		----	0.23	----	4.35	

APPENDIX 4

NOTES:

1. Resistance values are the reciprocals of C before rounding off to two decimal places.
2. Conductivity varies with fiber diameter.Insulation is produced by different densities; therefore, there is a wide variation in thickness for the same R-value among manufacturers. No effort should be made to relate any specific R-value to any specific thickness.
3. Does not include paper backing and facing, if any.
4. Values are for aged board stock.
5. Insulating values of acoustical tile vary, depending on density of the board and on type, size, and depth of perforations.
6. The U.S. Department of Commerce, Simplified Practice Recommendation for Thermal Conductance Factors for Preformed Above-Deck Roof Insulation, No. R257-55, recognizes the specifications of roof insulation on the basis of the C-values shown. Roof insulation is made in thicknesses to meet these values.
7. Face brick and common brick do not always have these specific densities. When density is different from that shown, there will be a change in thermal conductivity.
8. Data on rectangular core concrete blocks differ from the above data on oval core blocks, due to core configuration, different mean temperatures, and possibly differences in unit weights. Weight data on the oval core blocks tested are not available.
9. Weights of units approximately 7.625" high and 15.75" long. These weights are given as a means of describing the blocks tested, but conductance values are for 1 square foot of area.
10. Vermiculite, perlite, or mineral wool insulation. Where insulation is used, vapor barries or other precautions must be considered to keep insulation dry.
11. Values for metal siding applied over flat surfaces vary widely, depending on amount of ventilation of air space beneath the siding; whether air is reflective or nonreflective; and on the thickness, type, and were obtained from several guarded hotbox tests(ASTM C236) or calibrated hotbox(BSS 77) on hollowbacked types and types made using backing-boards of wood fiber,foamed plastic, and glass fiber. Departures of + or -50% or more from the values given may occur.

2. THERMAL CONDUCTIVITY (K) OF INDUSTRIAL INSULATION FOR MEAN TEMPERATURES INDICATED

(Expressed in Btu/hr-sq ft-°F-in.)

Form, Material Composition	Accepted Max Temp for Use, °F^1	Typical Density (lb/ft^3)	Typical Conductivity (k) at Mean Temp °F							
			-25	0	25	50	75	100	200	300
BLANKETS & FELTS										
Mineral Fiber										
Mineral fiber, glass Blanket, flexible, fine-fiber organic bonded	350	0.65	0.25	0.26	0.28	0.30	0.33	0.36	0.53	
		0.75	0.24	0.25	0.27	0.29	0.32	0.34	0.48	
		1.0	0.23	0.24	0.25	0.27	0.29	0.32	0.43	
		1.5	0.21	0.22	0.23	0.25	0.27	0.28	0.37	
		2.0	0.2	0.21	0.22	0.23	0.25	0.26	0.33	
		3.0	0.19	0.2	0.21	0.22	0.23	0.24	0.31	
Blanket, flexible, textile-fiber organic bonded	350	0.65	0.27	0.28	0.29	0.3	0.31	0.32	0.5	0.68
		0.75	0.26	0.27	0.28	0.29	0.31	0.32	0.48	0.66
		1.0	0.24	0.25	0.26	0.27	0.29	0.31	0.48	0.6
		1.5	0.22	0.23	0.24	0.25	0.27	0.29	0.39	0.51
		3.0	0.2	0.21	0.22	0.23	0.24	0.25	0.32	0.41
Felt, semirigid organic bonded Laminated & felted Without binder	400	3-8			0.24	0.25	0.26	0.27	0.35	0.44
	850	3	0.19	0.2	0.21	0.22	0.23	0.24	0.35	0.55
Note: Other values include: -100F:0.16; -75F:0.17; -50F:0.18										
	1200	7.5								0.35
Note: Other values include: 500F:0.45; 700F:0.6										

Mean Temperatures:			25	50	75	100	200	300	500
(Rock, slag or glass) Blanket metal reinforced	1200	6-12				0.26	0.32	0.39	0.54
	1000	2.5-6				0.24	0.31	0.40	0.61
Vegetable & Animal Fiber									
Hair felt or hair felt plus jute	180	10	0.26	0.28	0.29	0.30			

APPENDIX 4

Form, Material Composition	Accepted Max Temp for Use, °F¹	Typical Density (lb/ft³)	Typical Conductivity (k) at Mean Temp °F							
BLOCKS, BOARDS, PIPE INSULATION										
Mean Temperatures:			50	75	100	200	300	500	700	900
Asbestos										
Laminated asbestos paper	700	30			0.40	0.45	0.5	0.6		
Corrugated & laminated asbestos paper										
4-ply	300	11-13		0.54	0.57	0.68				
6-ply	300	15-17		0.49	0.51	0.59				
8-ply	300	18-20		0.47	0.49	0.57				
Molded Amosite & Binder	1500	15-18			0.32	0.37	0.42	0.52	0.62	0.72
85% Magnesia	600	11-12			0.35	0.38	0.42			
Calcium Silicate	1200	11-13			0.38	0.41	0.44	0.52	0.62	0.72
	1800	12-15						0.63	0.74	0.95
Diatomaceous Silica	1600	21-22						0.64	0.68	0.72
	1900	23-25						0.70	0.75	0.80
Cellular Glass	800	9	0.38	0.40	0.42	0.48	0.55			

Note: other values include, -50F:0.32; -25F:0.33; 0F:0.35; 25F:0.36

Mean Temperatures:			0	25	50	75	100	200	300	500
Mineral Fiber										
Glass, Organic bonded, block and boards	400	3-10	0.20	0.22	0.24	0.25	0.26	0.33	0.4	

Note:other values include,-100F:0.16; -75F:0.17; -50F:0.18; -25F:0.19

Nonpunking binder	1000	3-10					0.26	0.31	0.38	0.52
Pipe insulation, slag or glass	350	3-4	0.2	0.21	0.22	0.23	0.24	0.29		
	500	3-10	0.2	0.22	0.24	0.25	0.26	0.33	0.4	
Inorganic bonded-block	1000	10-15					0.33	0.38	0.45	0.55
	1800	15-24					0.32	0.37	0.42	0.52

Note: other values include, 700F:0.62; 900F:0.74

Pipe insulation slag or glass	1000	10-15					0.33	0.38	0.45	0.55
Resin binder		15	0.25	0.26	0.28	0.29				

Note: other values include, -50F:0.23; -25F:0.24

Form, Material Composition	Accepted Max Temp for Use, °F[1]	Typical Density (lb/ft^3)	Typical Conductivity (k) at Mean Temp °F							
Mean Temperatures			-100	-75	-50	-25	0	25	50	75
Rigid Polystyrene										
Extruded, Refrigerant 12 exp	170	3.5	0.16	0.16	0.15	0.16	0.16	0.17	0.18	0.19
Note: other value includes, 100F:0.20										
Extruded, Refrigerant 12 exp	170	2.2	0.16	0.16	0.17	0.16	0.17	0.18	0.19	0.2
Extruded	170	1.8	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.25
Note: other value includes, 100F:0.27										
Molded beads	170	1	0.18	0.20	0.21	0.23	0.24	0.25	0.26	0.28
Polyurethane[2]										
Refrigerant 11 exp	210	1.5-2.5	0.16	0.17	0.18	0.18	0.18	0.17	0.16	0.16
Note: other value includes, 100F:0.17										
Rubber, Rigid Foamed	150	4.5						0.20	0.21	0.22
Note: other value includes, 100F:0.23										
Vegetable & Animal Fiber										
Wool felt(pipe insulation)	180							0.28	0.30	0.31
Note: other value includes, 100F:0.33										

APPENDIX 4

Form, Material Composition	Accepted Max Temp for Use, °F[1]	Typical Density (lb/ft³)	Typical Conductivity (k) at Mean Temp °F							
INSULATING CEMENTS										
Mean Temperatures			100	200	300	500	700	900		
Mineral Fiber (Rock, slag, or glass) With colloidal clay binder	1800	24-30	0.49	0.55	0.61	0.73	0.85			
With hydraulic setting binder	1200	30-40	0.75	0.80	0.85	0.95				
LOOSE FILL										
Mean Temperatures			-75	-50	-25	0	25	50	75	100
Cellulose insulation (milled pulverized paper or wood pulp)		2.5-3						0.26	0.27	0.29
Mineral fiber, slag, rock or glass		2-5		0.19	0.21	0.23	0.25	0.26	0.28	0.31
Perlite(expanded)		5-8	0.27	0.29	0.30	0.32	0.34	0.35	0.37	0.39
Note: other value includes, -100F:0.25										
Vermiculite (expanded)		7-8.2		0.39	0.40	0.42	0.44	0.45	0.47	0.49
		4-6		0.34	0.35	0.38	0.40	0.42	0.44	0.46

Notes:

1. These temperatures are generally accepted as maximum. When operating temperature approaches these limits follow the manufacture's recommendations.
2. Values are for aged board stock. Note: Some polyurethane foams are formed by means which produce a stable product(with respect to k), but most are blown with refrigerant and will change with time.

3. U VALUES OF SOLID WOOD DOORS

Btu per (hr x sq ft x °F)

	Winter			Summer
	No Storm Door	Storm Door[2]		No Storm Door
Thickness[1]		Wood	Metal	
1"	0.64	0.30	0.39	0.61
1.25"	0.55	0.28	0.34	0.53
1.5"	0.49	0.27	0.33	0.47
2"	0.43	0.24	0.24	0.42

Notes:

1. Nominal thickness.
2. Values for wood storm doors are for approximately 50% glass; for metal storm door values apply for any percent of glass.

4. U VALUES OF WINDOWS, SKYLIGHTS AND LIGHT-TRANSMITTING PARTITIONS

(These values are for heat transfer from air to air in Btu/hr-sq ft-°F)

PART A--Vertical Panels(Exterior Windows, Sliding Patio Doors, and Partitions)-
Flat Glass, Glass Block, and Plastic Sheet

	Exterior[1]		
Description	Winter	Summer	Interior
FLAT GLASS[2]			
Single glass	1.10	1.04	0.73
Insulating glass--double[3]			
0.1875" air space[4]	0.62	0.65	0.51
0.25" air space[4]	0.58	0.61	0.49
0.5" air space[5]	0.49	0.56	0.46
0.5" air space, low emittance coating[6]			
e= 0.20	0.32	0.38	0.32
e= 0.40	0.38	0.45	0.38
e= 0.60	0.43	0.51	0.42
Insulating glass--triple[3]			
0.25" air space[4]	0.39	0.44	0.38
0.5" air space[7]	0.31	0.39	0.30
Storm windows			
1" to 4" air space[4]	0.50	0.50	0.44
PLASTIC SHEET			
Single glazed			
0.125" thick	1.06	0.98	----
0.25" thick	0.96	0.89	----
0.5" thick	0.81	0.76	----

APPENDIX 4

	Exterior[1]		
Description	Winter	Summer	Interior
PLASTIC SHEET (continued)			
Insulating unit--double[3]			
0.25" air space[4]	0.55	0.56	----
0.5" air space[3]	0.43	0.45	----
GLASS BLOCK[8]			
6 x 6 x 4" thick	0.60	0.57	0.46
8 x 8 x 4" thick	0.56	0.54	0.44
-- with cavity divider	0.48	0.46	0.38
12 x 12 x 4" thick	0.52	0.50	0.41
-- with cavity divider	0.44	0.42	0.36
12 x 12 x 2" thick	0.60	0.57	0.46

PART B--Horizontal Panels(Skylights)--Flat Glass, Glass Block, and Plastic Domes

	Exterior[1]		
Description	Winter[9]	Summer[10]	Interior[6]
FLAT GLASS[5]			
Single glass	1.23	0.83	0.96
Insulating glass--double[3]			
0.1875" air space[4]	0.70	0.57	0.62
0.25" air space[4]	0.65	0.54	0.59
0.5" air space[3]	0.59	0.49	0.56
0.5" air space, low emittance coating[6]			
e= 0.20	0.48	0.36	0.39
e= 0.40	0.52	0.42	0.45
e= 0.60	0.56	0.46	0.50
GLASS BLOCK[8]			
11 x 11 x 3" thick with cavity divider	0.53	0.35	0.44
12 x 12 x 4" thick with cavity divider	0.51	0.34	0.42
PLASTIC DOMES[11]			
Single-walled	1.15	0.80	----
Double-walled	0.70	0.46	----

PART C--Adjustment Factors for Various Window and sliding Patio Door Types
(Multiply U Values in Parts A and B by These Factors)

Description	Single Glass	Double or Triple Glass	Storm Windows
WINDOWS			
All glass[12]	1.00	1.00	1.00
Wood sash--80% glass	0.90	0.95	0.90
Wood sash--60% glass	0.80	0.85	0.80
Metal sash--80% glass	1.00	1.20[13]	1.20[13]
SLIDING PATIO DOORS			
Wood frame	0.95	1.00	----
Metal frame	1.00	1.10[13]	----

Notes:

1. See Part C for adjustment for varies window and sliding patio doors types.
2. Emittance of uncooled glass surface = 0.84.
3. Double and triple refer to the number of lights of glass.
4. 0.125" glass
5. 0.25" glass
6. Coating on either glass surface facing air space; all other glass surfaces uncoated.
7. Window design: 0.25" glass--0.125" glass--0.25" glass.
8. Dimensions are nominal.
9. For heat flow up.
10. For heat flow down.
11. Based on area or opening, not total surface area.
12. Refers to windows with negligible opaque area.
13. Values will be less than thes when metal sash and frame incorporate thermal breaks. In some thermal break designs, U values wll be equal to or less than those for the glass. Windows manufactures should be consulted for specific data.

APPENDIX 4

5. RESISTANCE (R) VALUES OF AIR SURFACES

		Type of Surfaces		
Position of Surface	Direction of Heat Flow	Nonreflective Materials Resistance(R)	Reflective Aluminum Coated Paper Resistance(R)	Highly Reflective Foil Resistance(R)
STILL AIR				
Horizontal	Upward	0.61	1.10	1.32
45 degree slope	Upward	0.62	1.14	1.37
Vertical	Horizontal	0.68	1.35	1.70
45 degree slope	Down	0.76	1.67	2.22
Horizontal	Down	0.92	2.70	4.55
MOVING AIR				
(any position)				
15 mph wind	Any	0.17(winter)	----	----
7 1/2 mph wind	Any	0.25(summer)	----	----

6. RESISTANCE (R) VALUES OF AIR SPACE

				Types of surfaces on Opposite Sides		
Position of air Space and Thickness(in.)		Direction of Heat Flow	Season	Both Surfaces Nonreflective Materials Resistance(R)	Aluminum Coated Paper/Non-Reflective Material Resistance(R)	Foil/Non-Reflective Material Resistance(R)
Horizontal	3/4	Up	W	0.87	1.71	2.23
	3/4		S	0.76	1.63	2.26
	4		W	0.94	1.99	2.73
	4		S	0.80	1.87	2.75
45 degree slope	3/4	Up	W	0.94	2.02	2.78
	3/4		S	0.81	1.90	2.81
	4		W	0.96	2.13	3.00
	4		S	0.82	1.98	3.00
Vertical	3/4	Horizontal	W	1.01	2.36	3.48
	3/4		S	0.84	2.10	3.28
	4		W	1.01	2.34	3.45
	4		S	0.91	2.16	3.44
45 degree slope	3/4	Down	W	1.02	2.40	3.57
	3/4		S	0.84	2.09	3.24
	4		W	1.08	2.75	4.41
	4		S	0.90	2.50	4.36
Horizontal	3/4	Down	W	1.02	2.39	3.55
	1 1/2		W	1.14	3.21	5.74
	4		W	1.23	4.02	8.94
	3/4		S	0.84	2.08	3.25
	1 1/2		S	0.93	2.76	5.24
	4		S	0.99	3.38	8.03

APPENDIX 4

EMISSIVITY OF VARIOUS MATERIALS

Material Description	Emissivity Ratio	Surface Condition
Aluminum	0.03	Polished
Aluminum(alloy 1100)	0.09	Commericial sheet heavily oxidized
Aluminum-coated paper	0.20	Polished
Aluminum foil	0.05	Bright
Aluminum sheet	0.12	
Asbestos, board	0.96	
Asbestos, insulation	0.93	"Paper"
Black surface, absolute	1.0	
Brass:		
red(85% Cu, 15% Zn)	0.030	Highly polished
yellow(65% Cu, 35% Zn)	0.033	Highly polished
Brick building	0.93	
Building materials: wood, paper, masonry. nonmetallic paints	0.90	
Cadmium	0.02	
Carbon(gas retort)	0.81	
Chalk	0.34	
Concrete	0.88	
Concrete	0.97	Rough
Copper(electrolytic)	0.072	Commercial, shiny
Earth	0.41	Dry, packed
Fireclay brick	0.75	At 1832 degree F
German silver(nickel silver)	0.135	Polished
Glass:		
crown(soda-lime)	0.94	Smooth
regular	0.84	Smooth
Gold	0.02	Highly polished
Graphite "Karbate" (impervious)	0.75	
Gypsum	0.903	On a smooth plate
Ice (32 ^{o}F)	0.95	
Iron:		
cast	0.435	Freshly turned
wrought	0.94	Dull, oxidized
Lead	0.28	Grey, oxidized
Limestone	0.36-0.90	At 145-380^{o}F
Lime wash	0.91	
Magnesium	0.55	Oxidized
Marble	0.931	Light grey,polished
Nickel	0.045	Electroplated, polished

EMISSIVITY OF VARIOUS MATERIALS

Material Description	Emissivity Ratio	Surface Condition
Paints:		
aluminum	0.50	
aluminum lacquer	0.39	On rough plate
black lacquer	0.80	
black shellac	0.91	"Matte" finish
flat black lacquer	0.96	
oils	0.92-0.96	All colors
white enamel	0.91	On rough plate
white lacquer	0.80	
Paper	0.92	Pasted on tinned plate
Plaster	0.91	Rough, white
Platinum	0.054	Polished
Porcelain	0.92	Glazed
Rubber:		
vulcanized(soft)	0.86	Rough
vulcanized(hard)	0.95	Glossy
Silver	0.02	Polished and at 440°F
Steel, galvanized	0.25	Bright
Steel(mild)	0.12	Cleaned
Tin	0.06	Bright and at 122°F
Tungsten	0.032	Filament at 80°F
Wood, white oak	0.90	Planed
Zinc:		
cast	0.05	Polished
galvanizing	0.23	Fairly bright

APPENDIX 5

CONVERSION TABLES

1. Conversion Factors

Multiply	By	To Obtain
acres	43,560	square feet
acres	0.004047	square kilometers
acres	4,047	square meters
acres	0.0015625	square miles
acres	4,840	square yards
acre-feet	43,560	cubic feet
acre-feet	1,233.5	cubic meters
acre-feet	1,613.3	cubic yards
angstroms	1x10^{-8}	centimeters
angstroms	3.937x10^{-9}	inches
angstroms	0.0001	microns
barrels (petroleum, U.S.) (bbl.)	5.6146	cubic feet
barrels	35	gallons (imperial)
barrels	42	gallons (U.S.)
barrels	158.98	liters
barrels	5,800,000	Btu (energy)
board feet	0.0833	cubic feet
brick number of common	5.4	pounds
British thermal unit (Btu)	251.99	calories, gram
Btu	777.649	foot-pounds
Btu	0.00039275	horsepower-hours
Btu	1,054.35	joules
Btu	0.000292875	kilowatt-hours
Btu	1,054.35	watt-seconds
Btu	0.55556	centigrade heat units
Btu/hr	4.2	cal/min
Btu/hr	777.65	ft-lb/hr
Btu/hr	0.0003927	horsepower
Btu/hr	0.000292875	kilowatts
Btu/hr	0.292875	watts (or joule/sec)
Btu/hr	7.25x10^{-4}	cal/gr
Btu/sq ft	0.271246	cal/sq cm (or langleys)
Btu/sq ft	0.292875	watt-hr/sq ft
Btu/sq ft/hr	3.15x10^{-3}	kilowatts/sq meter
Btu/sq ft/hr	4.51x10^{-3}	cal/sq cm/min (or langleys/min)
Btu/sq ft/hr	3.15x10^{-4}	watts/sq cm
Btu/hr/sq ft/deg F	5.783x10^{4}	watts/cm^{2}/deg C
Btu/hr/sq ft (deg F/in)	1	chu/hr/sq ft (deg C/in)
calories (cal)	0.003968	Btu
calories	3.08596	foot-pounds
calories	1.55857x10^{-6}	horsepower-hours
calories	4.184	joules (or watt-sec)
calories	1.1622x10-6	kilowatt-hours

Multiply	By	To Obtain
calories, food unit (Cal)	1,000	calories
cal/min	0.003968	Btu/min
cal/min	0.06973	watts
cal/sq cm	3.68669	Btu/sq ft
cal/sq cm	1.0797	watt-hr/sq ft
cal/sq cm/min	796,320	Btu/sq ft/hr
candle power (spherical)	12.566	lumens
cantigrade heat units(chu)	1.8	Btu
centimeters (cm)	0.032808	feet
centimeters	0.03937	inches
centimeters	0.01	meters
centimeters	10.000	microns
cords	8	cord-feet
cords	128 (or 4x4x8)	cubic feet
cubic centimeters	3.5314667	cubic feet
cubic centimeters	0.06102	cubic inches
cubic centimeters	1×10^{-6}	cubic meters
cubic centimeters	0.001	liters
cubic centimeters	0.0338	ounces (U.S. fluid)
cubic feet (ft^3)	0.02831685	cubic meters
cubic feet	7.4805	gallons (U.S.,liq)
cubic feet	28.31685	liters
cubic feet	29.922	quarts (U.S.,liq)
cubic feet	0.037037	cubic yards
cubic feet of common brick	120	pounds
cubic feet of water (60 deg F)	62.366	pounds of water
cubic feet/second	448.83	gallons
cubic inches (in^3)	16.387	cubic centimeters
cubic inches	0.0005787	cubic feet
cubic inches	0.004329	gallons (U.S.,liq)
cubic inches	0.5541	ounces (U.S.,fluid)
cubic meters	1×10^{6}	cubic centimeters
cubic meters	35.314667	cubic feet
cubic meters	264.172	gallons (U.S.,liq)
cubic meters	1,000	liters
cubic yard	27	cubic feet
cubic yard	0.76455	cubic meters
cubic yard	201.97	gallons (U.S.,liq)
cubic yards of sand	2,700	pounds
feet (ft)	30.48	centimeters
feet	12	inches
feet	0.00018939	miles (statute)
foot-candles	1	lumens/sq ft
foot-pounds (ft-lb)	0.001285	Btu
foot-pounds	0.324048	calories
foot-pounds	5.0505×10^{-7}	horsepower-hours
foot-pounds	3.76616×10^{-7}	kilowatt-hours

APPENDIX 5

Multiply	By	To Obtain
furlong	220	yards
gallons (U.S.,dry)	1.163647	gallons (U.S.,liq)
gallons (U.S.,liq)	3,785.4	cubic centimeters
gallons	0.13368	cubic feet
gallons	231	cubic inches
gallons	0.0037854	cubic meters
gallons	3.7854	liters
gallons	8	pints (U.S.,liq)
gallons	4	quarts (U.S.,liq)
gallons of water	8.3453	pounds of water at 60 deg F
grams (gr)	0.035274	ounces (avdp.)
grams	0.002205	pounds (avdp.)
grams-centimeters	9.3011×10^{-8}	Btu
horsepower	42.4356	Btu/min
horsepower	2.546	Btu/hr
horsepower	33,000	ft lb/min
horsepower	1.014	metric horsepower
horsepower-hours	2,546.14	Btu
horsepower-hours	0.7457	kilowatt-hours
horsepower, metric (chevalvapours)	0.9863	horsepower
inches	2.54	centimeters
inches	0.83333	feet
joules	0.0009485	Btu
joules	0.73756	foot-pounds
joules	0.0002778	watt-hours
joules	1	watt-seconds
kilo calories/gram	1,378.54	Btu/lb
kilograms	2.2046	pounds (avdp)
kilometers	1,000	meters
kilometers	0.62137	miles (statute)
kilometer/hour	54.68	ft/min
kilowatts	56.90	Btu/min
kilowatts	3,414.43	Btu/hr
kilowatts	737.56	ft-lb/sec
kilowatts	1.34102	horsepower
kilowatt hours	3,414.43	Btu
kilowatt hours	2.66×10^{6}	foot-pounds
kilowatt hours	1.34102	horsepower-hours
langleys	1	cal/sq cm
langleys	3.69	Btu/sq ft
langleys/minutes	0.00698	watts/sq cm
liters	1,000	cubic centimeters
liters	0.0353	cubic feet
liters	0.2642	gallons (U.S.,liq)
liters	1.0567	quarts (U.S.,liq)
lumens	0.079577	candle power (spherical)

Multiply	By	To Obtain
lumens(at 5,550 angstroms)	0.0014706	watts
meters	3.2808	feet
meters	39.37	inches
meters	1.0936	yards
micron	10,000	angstroms
micron	0.0001	centimeters
miles (statute)	5,280	feet
miles	1.6093	kilometers
miles	1.760	yards
milliliter	1	cubic centimeter
millimeter	0.1	centimeters
months (mean calendar)	730.1	hours
ounces (avdp)	0.0625	pounds (avdp)
ounces (U.S.,liq)	29.57	cubic centimeters
ounces	1.8047	cubic inches
ounces	0.0625 (or 1/16)	pint (U.S.,liq)
pints (U.S.,liq)	473.18	cubic centimeters
pints	28.875	cubic inches
pints	0.5	quarts (U.S.,liq)
pounds (avdp)	0.45359	kilograms
pounds	16	ounces (avdp)
pounds of water	0.01602	cubic feet of water
pounds of water	0.1198	gallons (U.S.,liq)
pounds of water evaporated at 212 deg F	970.3	Btu
quarts (U.S.,liq)	0.25	gallons (U.S.,liq)
quarts	0.9463	liters
quarts	32	ounces (U.S.,liq)
quarts	2	pints (U.S.,liq)
radians	57.30	degrees
square centimeters	0.0010764	square feet
square centimeters	0.1550	square inches
square feet	2.2957×10^{-5}	acres
square feet	0.09290	square meters
square inches	6.4516	square centimeters
square inches	0.006944	square feet
square kilometers	247.1	acres
square kilometers	1.0764×10^{7}	square feet
square kilometers	0.3861	square miles
square meters	10.7639	square feet
square meters	1.196	square yards
square miles	640	acres
square miles	2.788×10^{7}	square feet
square miles	2.590	square kilometers
square yards	9 (or3x3)	square feet
square yards	0.83613	square meters
therms	1×10^{5}	Btu
tons (long)	1,016	kilograms

APPENDIX 5

Multiply	By	To Obtain
tons	2,240	pounds (avdp)
tons (metric)	1,000	kilograms
tons	2,204.6	pounds (avdp)
tons (short)	907.2	kilograms
tons	2,000	pounds (avdp)
tons	0.907185	metric tons
tons of refrigeration	12.000	Btu/hr
watts	3.4144	Btu/hr
watts	0.05691	Btu/min
watts	14.34	cal/min
watts	0.001341	horsepower
watts	1	joule/sec
watts/sq cm	3,172	Btu/sq ft/hr
watt-hours	3.4144	Btu
watt-hours	860.4	calories
watt-hours	0.001341	horsepower-hours
yards	3	feet
yards	0.9144	meters

2. Fahrenheit-Centigrade Conversion Table

The numbers in the center column refer to the temperature in either Fahrenheit or Centigrade degrees. If it is desired to convert from Fahrenheit to Centigrade degrees, consider the center column as a table of Fahrenheit temperatures and read the corresponding Centigrade temperature in the column at the left. If it is desired to convert from Centigrade to Fahrenheit degrees, consider the center column as a table of Centigrade values, and read the corresponding Fahrenheit temperature on the right.

For conversions not covered in the table, the following formulas are used:

$$F = 1.8C + 32 \qquad C = (F-32)/1.8$$

Deg C		Deg F	Deg C		Deg F
-46	-50	-58	-17.2	1	33.8
-40	-40	-40	-16.7	2	35.6
-34	-30	-22	-16.1	3	37.4
-29	-20	-4	-15.6	4	39.2
-23	-10	14	-15.0	5	41.0
-17.8	0	32-	-14.4	6	42.8

Deg C		Deg F	Deg C		Deg F
-13.9	7	44.6	12.2	54	129.2
-13.3	8	46.4	12.8	55	131.0
-12.8	9	48.2	13.3	56	132.8
-12.2	10	50.0	13.9	57	134.6
-11.7	11	51.8	14.4	58	136.4
-11.1	12	53.6	15.0	59	138.2
-10.6	13	55.4	15.6	60	140.0
-10.0	14	57.2	16.1	61	141.8
-9.4	15	59.0	16.7	62	143.6
-8.9	16	60.8	17.2	63	145.4
-8.3	17	62.6	17.8	64	147.2
-7.8	18	64.4	18.3	65	149.0
-7.2	19	66.2	18.9	66	150.8
-6.7	20	68.0	19.4	67	152.6
-6.1	21	69.8	20.0	68	154.4
-5.6	22	71.6	20.6	69	156.2
-5.0	23	73.4	21.1	70	158.0
-4.4	24	75.2	21.7	71	159.8
-3.9	25	77.0	22.2	72	161.6
-3.3	26	78.8	22.8	73	163.4
-2.8	27	80.6	23.3	74	165.2
-2.2	28	82.4	23.9	75	167.0
-1.7	29	84.2	24.4	76	168.8
-1.1	30	86.0	25.0	77	170.6
-0.6	31	87.8	25.6	78	172.4
0-	32	89.6	26.1	79	174.2
0.6	33	91.4	26.7	80	176.0
1.1	34	93.2	27.2	81	177.8
1.7	35	95.0	27.8	82	179.6
2.2	36	96.8	28.3	83	181.4
2.7	37	98.6	28.9	84	183.2
3.3	38	100.4	29.4	85	185.0
3.9	39	102.2	30.0	86	186.8
4.4	40	104.0	30.6	87	188.6
5.0	41	105.8	31.1	88	190.4
5.6	42	107.6	31.7	89	192.2
6.1	43	109.4	32.2	90	194.0
6.7	44	111.2	32.8	91	195.8
7.2	45	113.0	33.3	92	197.6
7.8	46	114.8	33.9	93	199.4
8.3	47	116.6	34.4	94	201.2
8.9	48	118.4	35.0	95	203.0
9.4	49	120.2	35.6	96	204.8
10.0	50	122.0	36.1	97	206.6
10.6	51	123.8	36.7	98	208.4
11.1	52	125.6	37.2	99	210.2
11.7	53	127.4	37.8	100	212.0

APPENDIX 5

HEAT EQUIVALENTS OF FUELS AND OTHER ENERGY SOURCES

Material	Heating Value[1]	Source[2]	Heat Obtainable[3]
Solids	(Btu/lb)		(Btu/lb)
Anthracite coal	12,700-13,600	(1)	6,800-10,150
Bituminous coal	11,000-14,350	(1)	4,400-10,045
Subbituminous coal	9,000	(1)	
"Good Illinois" coal	8,500	(2)	
Lignite coal	6,900	(1)	
Coke	11,000-12,000	(3)	
Newspaper	8,500	(2)	
Brown paper	7,670	(2)	
Corrugated board	7,400	(2)	
Food cartons	7,700	(2)	
Pulp trays	8,300	(2)	
Waxed milk cartons	11,680	(2)	
Plastic film	13,780	(2)	
Polystyrene	15,730	(2)	
Polyethylene	14,890	(2)	
Typical urban refuse	5,000	(5)	
Wood-general	8,000-10,000		
-green		(4)	3,000-4,600
-dry		(4)	5,300-6,000
LIQUIDS	Btu/gal		Btu/gal
Distillate fuel oils			
-Grade 1	132,900-137,000	(1)	94,000
-Grade 2	137,000-141,800	(1)	97,300
-Grade 4	143,100-148,100	(1)	102,200
Residual fuel oils			
-Grade 5L	146,800-150,000	(1)	
-Grade 5H	149,500-152,000	(1)	
-Grade 6	151,300-155,900	(1)	
Kerosene	133,000		
Gasoline	111,000		
GASES	(Btu/ft^3)		(Btu/ft^3)
Natural gas	1,000-1,050	(1)	780
Commercial propane	2,500	(1)	1,870
Commercial butane	3,200	(1)	2,400
Propane-air or butane-air	500-1,800	(1)	350- 1,250
Acetylene	1,500	(3)	

GASES	(Btu/ft^3)	(Btu/ft^3)
Bio-gas	550	
Methane	950-1,050	
Manufactured gas (from coal)	450	
OTHER SOURCES	POTENTIAL MAXIMUM	HEAT OBTAINABLE
Electricity		
-resistance heating	3,412 Btu kwh	3,413 Btu/kwh
Water/gravity		
-per foot of heat	60 kwh/acre/ft	36 kwh/acre/ft
Wind[4] (per sq ft collector)	1.4 kwh/1,000 ft^3	.8 kwh/1,000 ft^3
-5mph avg		.5 kwh/month
-10 mph avg		4.0 kwh/month
-15 mph avg		8.0 kwh/month
Sun[4] (per sq ft collector)	432 Btu/hr (solar constant, outer atmosphere)	150 Btu/hr

NOTES:

1. Heat of combustion or calorific values. The heat produced by complete combustion of the specific fuel. This value also includes the latent heat generated by the condensation of the water vapor content of the fuel.
2. Sources for the values found in column 2 are:
   (1) ASHRAE . Handbook of Fundamentals, 1972.
   (2) MIT . Technology Review, February, 1972.
   (3) Ram Bux Singh. Biogas Plant. Gobar Gas Research Station, India, 1971.
   (4) Peter Allen. Firewood for Heat . Department of Resources and Economic Development, New Hampshire. Bulletin # 17.
   (5) Power Generation Alternatives. City of Seattle, 1972.
3. Heat obtainable, or useful heat, is equal to the heat of combustion minus heat losses due to incomplete combustion, waste flue gases, water vapor in fuels, equipment limitations, etc. These loses vary between 20% of the heat of combustion for a well-engineered gas or oil unit and 50% for a hand-fired, uncontrolled coal-burning unit.
4. Energy received from the sun and wind varies widely with time and place. These figures are illustrative only.

SOURCE:

Bruce Anderson, Solar Energy: Fundamentals in Building Design (Harrisville, N.H.: Total Environmental Action Press, 1977).

APPENDIX 5

35° NORTH LATITUDE

SLOPE	N			NE			E			SE		
	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5
5%	4.0	1.8	4.0	3.5	1.7	4.2	3.1	1.6	4.0	3.0	1.5	3.5
10%	4.6	2.0	4.6	3.5	1.8	5.3	2.8	1.6	4.6	2.6	1.5	3.5
15%	5.5	2.2	5.5	3.5	2.0	7.2	1.6	5.5	2.3	2.3	1.4	3.5
20%	6.8	2.5	6.8	3.5	2.2	11.4	2.3	1.7	6.8	2.0	1.3	3.5

40° NORTH LATITUDE

SLOPE	N			NE			E			SE		
	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8	4.8	2.0	4.8
5%	5.7	2.2	5.7	4.8	2.2	6.2	4.1	2.0	5.7	3.8	1.9	4.8
10%	7.2	2.5	7.2	4.8	2.3	9.1	3.6	2.0	7.2	3.2	1.8	4.8
15%	9.6	2.9	9.6	4.8	2.6	16.6	3.2	2.0	9.1	2.8	1.7	4.8
20%	14.5	3.4	14.5	4.8	2.8	97.5	2.8	2.0	14.5	2.4	1.6	4.8

45° NORTH LATITUDE

SLOPE	N			NE			E			SE		
	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2
5%	9.6	2.9	9.6	7.2	2.8	11.2	5.7	2.5	9.6	5.3	2.3	7.2
10%	14.6	3.4	14.6	7.2	3.1	25.6	4.8	2.5	14.6	4.2	2.2	7.2
15%	30.3	4.1	30.3	7.2	3.5	---	4.1	2.6	30.3	3.5	2.0	7.2
20%	---	5.2	---	7.2	4.0	---	3.6	2.6	---	2.9	1.9	7.2

		S			SW			W			NW	
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5	3.5	1.6	3.5
5%	3.1	1.5	3.1	3.5	1.5	3.0	4.0	1.6	3.1	4.2	1.7	3.5
10%	2.8	1.4	2.8	3.5	1.5	2.6	4.6	1.6	2.8	5.3	1.8	3.5
15%	2.5	1.3	2.5	3.5	1.4	2.3	5.5	1.6	2.5	7.2	2.0	3.5
20%	2.3	1.3	2.3	3.5	1.3	2.3	6.8	1.7	2.3	11.4	2.2	3.5

		S			SW			W			NW	
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2
5%	4.1	1.8	4.1	4.8	1.9	3.8	5.7	2.0	4.1	6.2	2.2	4.8
10%	3.6	1.7	3.6	4.8	1.8	3.2	7.2	2.0	3.6	9.1	2.3	4.8
15%	3.2	1.6	3.2	4.8	1.7	2.8	9.6	2.0	3.2	16.6	2.6	4.8
20%	2.8	1.5	2.8	4.8	1.6	2.4	14.5	2.0	2.8	97.5	2.8	4.8

		S			SW			W			NW	
SLOPE	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM	AM	NOON	PM
0%	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2	7.2	2.5	7.2
5%	5.7	2.2	5.7	7.2	2.3	5.3	9.6	2.5	5.7	11.2	2.8	7.2
10%	4.8	2.0	4.8	7.2	2.2	4.2	14.3	2.5	4.8	25.6	3.1	7.2
15%	4.1	1.9	4.1	7.2	2.0	3.5	30.3	2.6	4.1	---	3.5	7.2
20%	3.6	1.7	3.6	7.2	1.9	2.9	---	2.6	3.6	---	4.0	7.2

APPENDIX 6

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3. Findley, S. Chapter 9 illustration of day care center.

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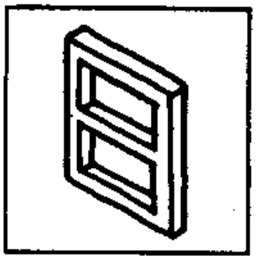

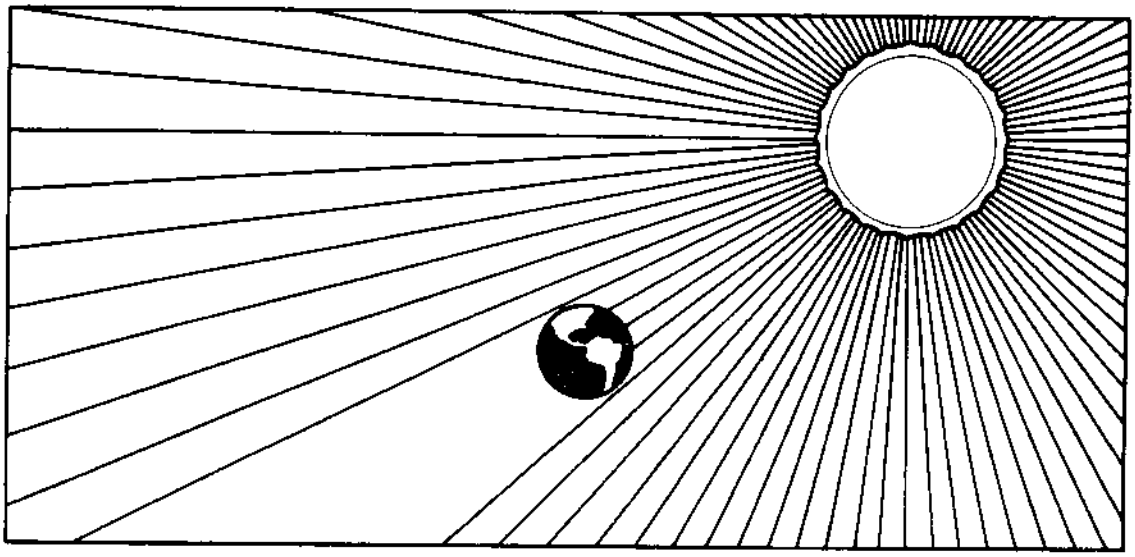

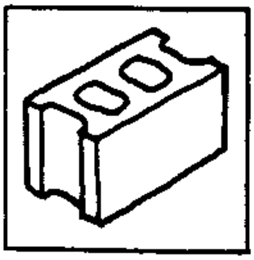

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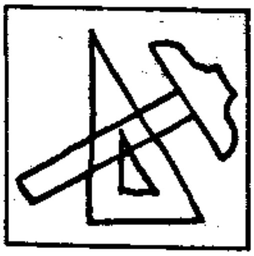

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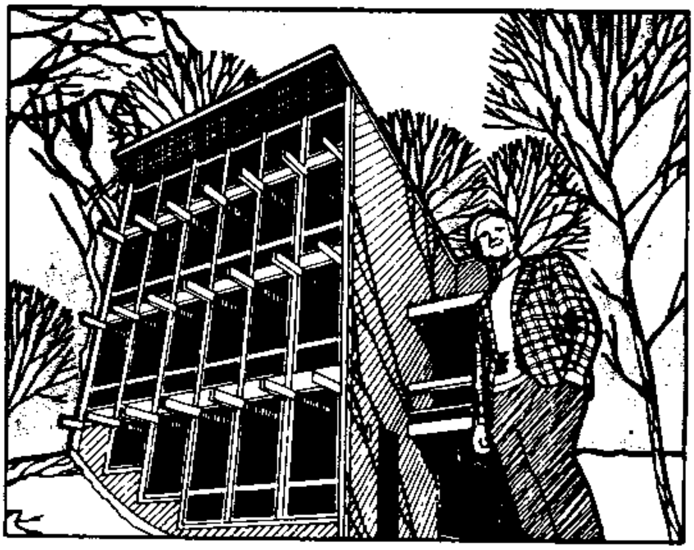

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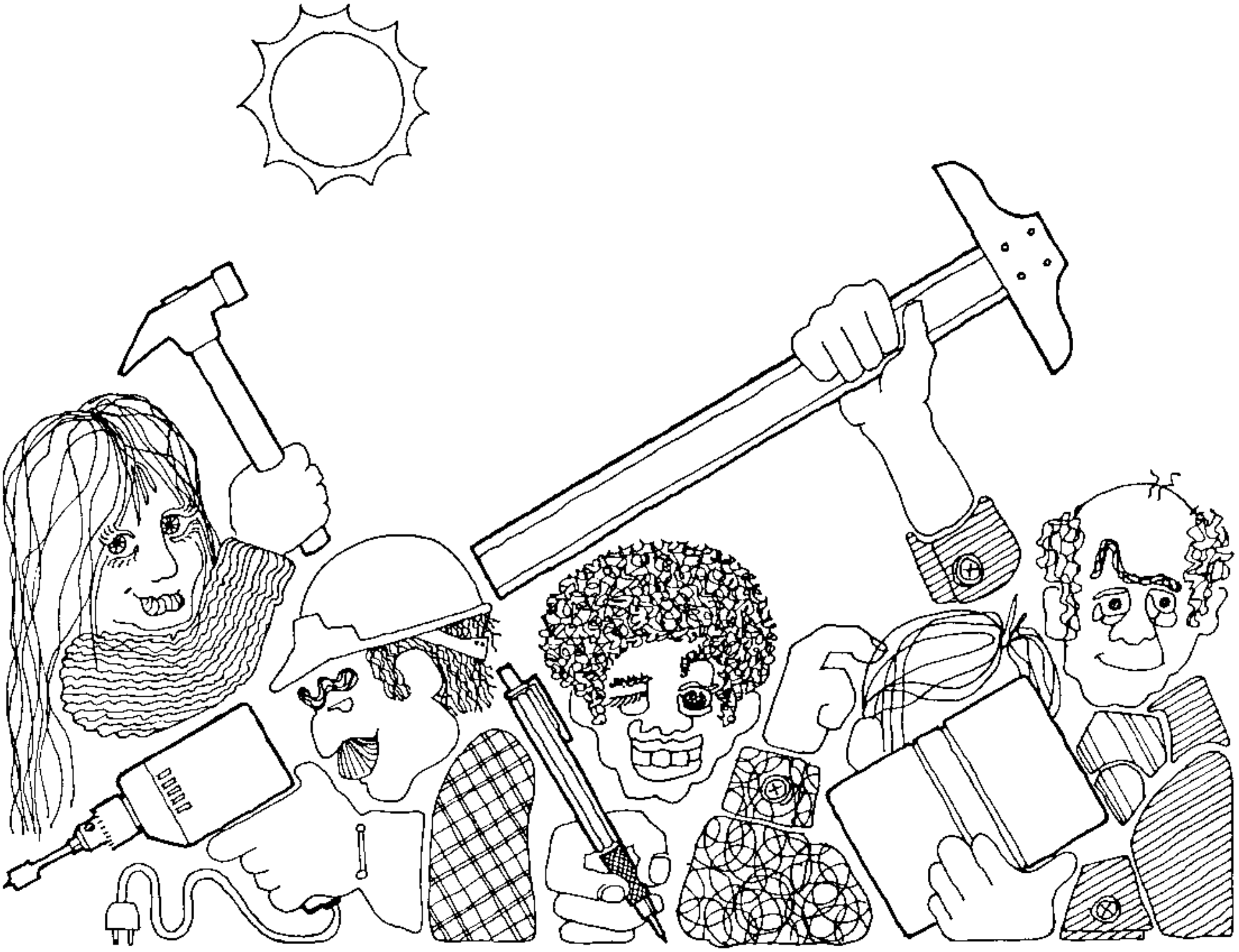
"Destiny is not a matter of chance,
it is a matter of choice;
it is not a thing to be waited for,
it is a thing to be achieved."

William Jennings Bryan

NEBRASKA'S PASSIVE SOLAR PRIMER IS A TESTAMENT TO THE DEDICATION AND EFFORT OF A SMALL BAND OF FACULTY AND STUDENTS FROM THE UNIVERSITY OF NEBRASKA. KNOWN COLLECTIVELY AS THE PASSIVE SOLAR RESEARCH GROUP (PSRG), THEY HAD A VISION OF THE FUTURE AND THE ROLE THAT PASSIVE SOLAR ENERGY COULD PLAY IN RESHAPING IT. TO THE PAST AND PRESENT MEMBERS OF THE PASSIVE SOLAR RESEARCH GROUP, IS THIS BOOK DEDICATED.



A BOOK FOR THE ARCHITECT, ENGINEER, BUILDER-CONTRACTOR AND THE HOMEOWNER

HOW TO USE THIS BOOK

The purpose of this Primer is to provide the reader with information required to make a decision on an important issue: whether or not to build an energy efficient passive solar heated home. As fossil fuel energy becomes more scarce and costly, the number of energy source options available to a homebuilder becomes limited as far as the conventional sources of energy are concerned. However, the possible variations for energy conservation and passive solar energy techniques are limited only by the imagination of the homebuilder. The Primer should be used as an introductory guide to stimulate new ideas and to avoid pitfalls which have been common to this newly emerging field. The Primer should not be regarded as the final treatise. It will undergo revisions and evolve as new knowledge enters the mainstream of passive solar energy.

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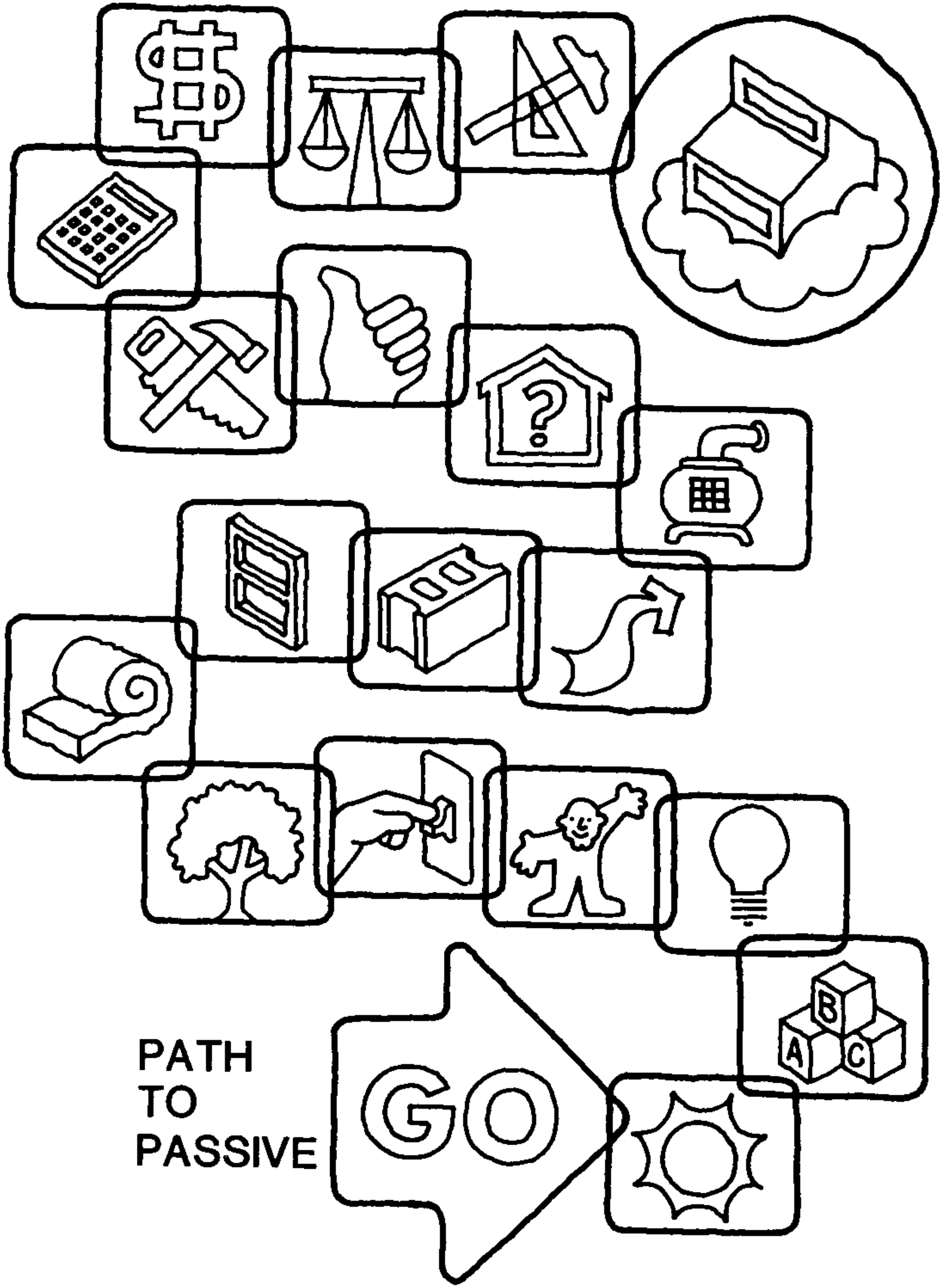
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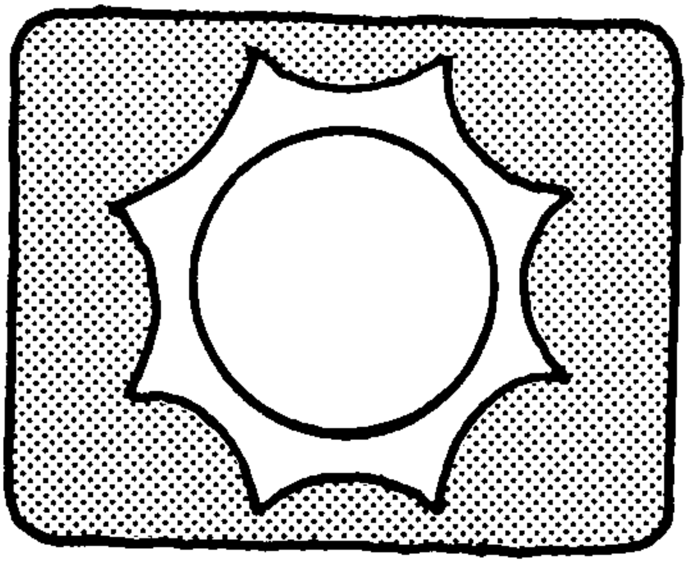
CHAPTER 0
INTRODUCTION

This chapter is a brief philosophical and historical perspective of passive solar energy.

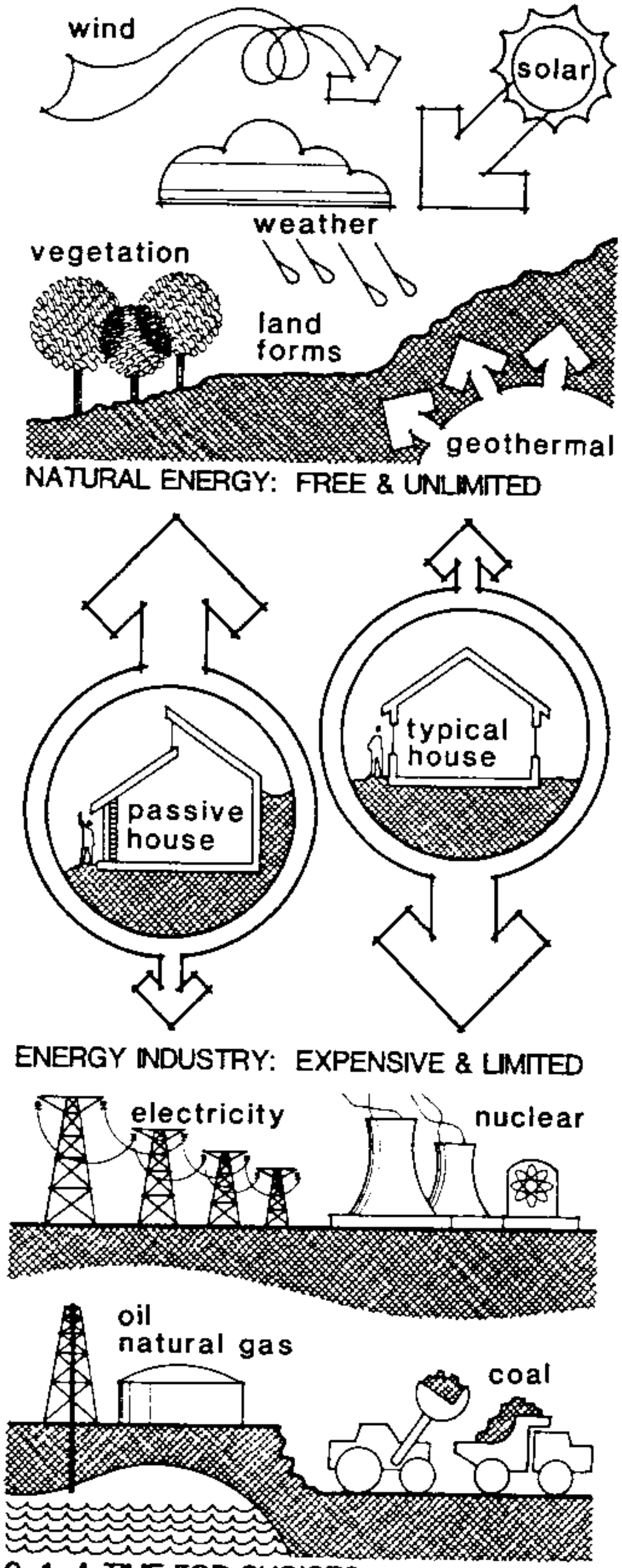


INTRODUCTION

The sun is the principal source of energy for all life on this planet: the complex interwoven web of life on this planet is dependent upon the sun for its survival. For example, the sun drives the weather patterns; it controls the various oxygen, nitrogen and carbon dioxide cycles. Man is the only species which has been able to substantially alter the environment, although only in the recent past have such actions been questioned. Our long term survival may very well rest upon our ability to temper this Promethean power endowed to us. We have yet to fully understand the lack of wisdom inherent in brokering our future with short-sighted, short-term economic gain at the expense of our environment. The "balance due in full" account with nature may be more than our heirs can pay.

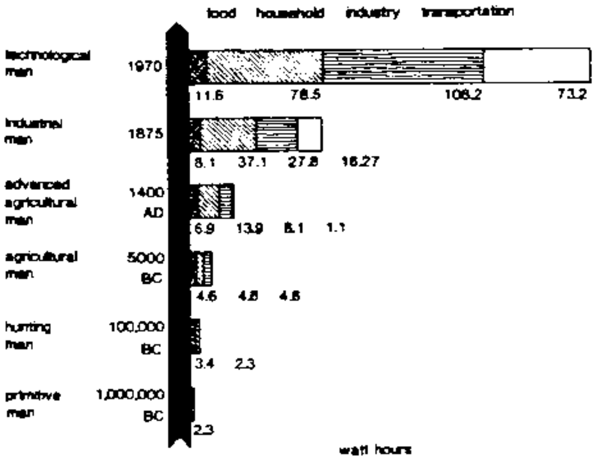
In the decades ahead, a number of fundamental decisions will have to be made with respect to our lifestyles and our responsibilities as the pre-eminent life form on Earth (FIG 0-1). The passive solar heated home is indicative of a choice made in favor of utilizing a plentiful and renewable energy source -- the sun. No other source of energy can make the claim of being unending or of being in harmony with nature.

At the beginning of this century, coal was the principal source of heat for most homes . Coal was to be supplanted by the newer and, at the time, seemingly inexhaustible reserves of oil and, later, natural gas. Generous government subsidies allowed the gas and oil industries to grow and proliferate; America grew and prospered. Our homes grew larger and their energy appetites for fossil fuels kept pace. An entire generation was nurtured on "cheap" fossil and nuclear fuels. The first storm clouds warning of energy problems gathering on the horizon were ignored in the "happy days" of the 50's. Economics has not tallied the true cost exacted

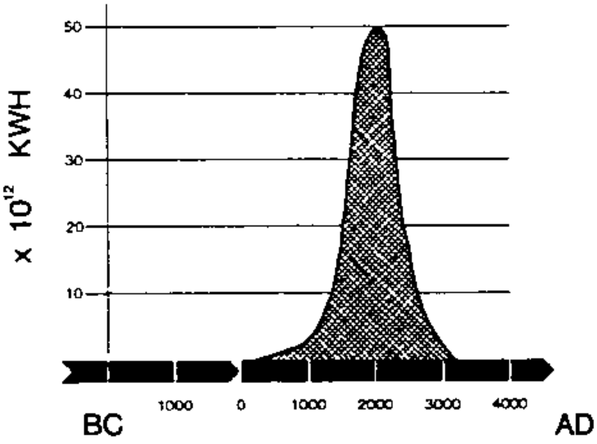


0-1 A TIME FOR CHOICES

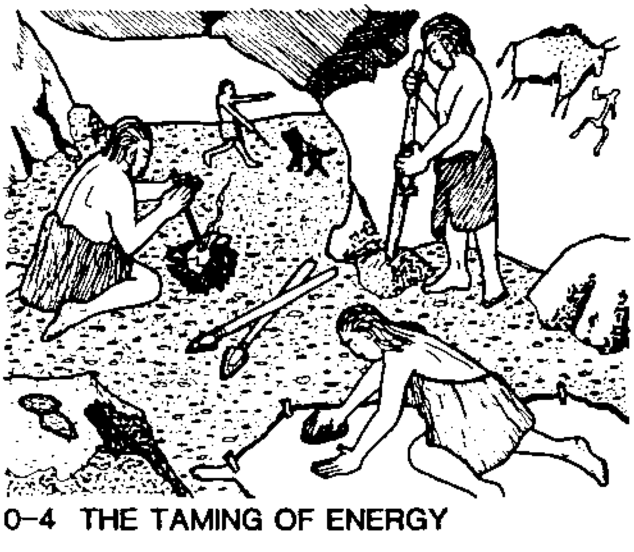
INTRODUCTION



0–2 ENERGY CONSUMPTION HISTORY



0–3 FOSSIL FUELS: A LIMITED FUTURE



0–4 THE TAMING OF ENERGY

upon our environment. As a result, we are faced with the following questions: Can future generations pay the balance due? Has the environment's maximum stress point been exceeded?

Per capita energy consumption of primitive man, whose energy needs were principally concerned with food, was modest (FIG 0-2). Energy consumption did not increase significantly until the Agricultural Revolution. The Industrial Revolution, about 1875, brought about a quantum leap in consumption and the inclusion of a new sector -- transportation.

Each fossil energy resource is finite. At the initial stages of exploitation, supplies appear to be inexhaustible. Successful marketing increases the rate at which the fuel is consumed, and this process continues until the ease of discovery and extraction diminishes. Prices of the fuel then escalate as the resource base is depleted (FIG 0-3). At this point, threat of depletion may lead planners to consider substitution strategies such as coal gassification or shale oil for petroleum. The problem with this approach is that one is led to believe that a permanent solution has been found. However, if the substitution is another fossil fuel, the problem is only delayed, not solved. At best the substitution can only buy time until a permanent solution is developed.

Each stage in the ascent of man has involved fundamental changes in how the world is perceived and what role man plays in the scheme of life. Among our early ancestors, Peking Man had learned to use fire for cooking food and keeping warm during inclement weather (FIG 0-4). Wood was the chief source of fuel. In many parts of the world today, wood is still the principal source of energy.

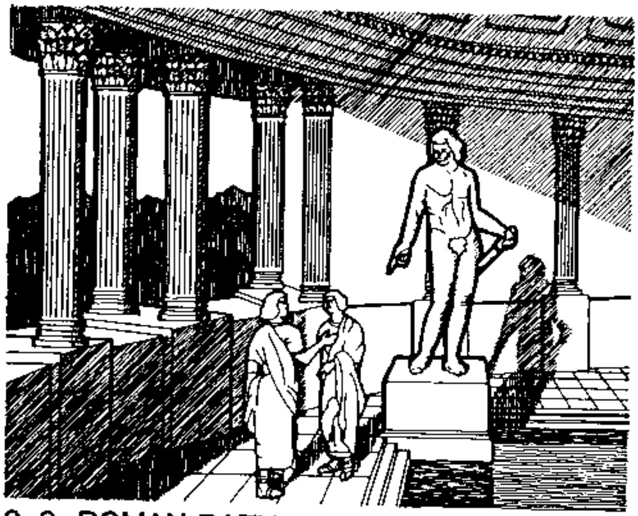
SOLAR ENERGY: A HISTORICAL OVERVIEW

Energy crises are not unique to our times. Rather, throughout history man has repeatedly been faced with the problem of finding sufficient energy supplies for warmth, to cook food, to power machines, etc. The first recorded energy crisis occurred in Greece about 500 B.C. (FIG 0-5). Wood was the principal energy source for heating, cooking, shipbuilding, and smelting. The competition for wood led to the denuding of many forests, resulting in higher prices as well as regulations to control consumption of wood. Olynthus, the first solar community using passive solar heating techniques, was built. Homes were built to capture the sun's heat through south-facing courtyards. Windowless north walls and common east-west walls completed the energy conservation package.

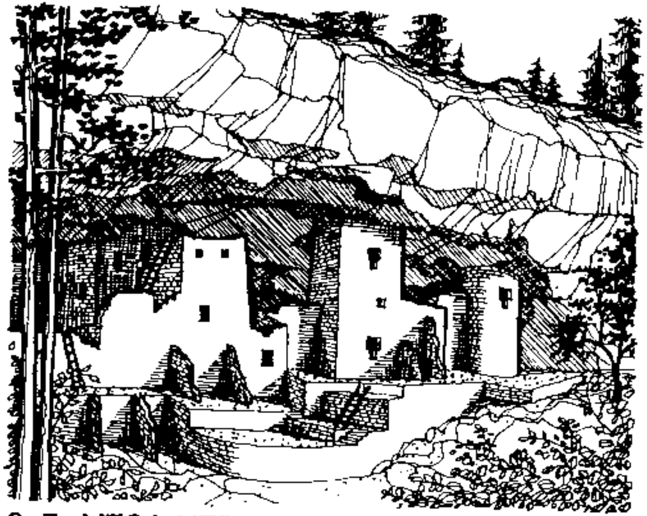
The scene for the next energy crisis shifts to ancient Rome (FIG 0-6). Demand for wood came from industry, shipping, and residential heating -- central heating systems in some homes consumed up to 280 pounds of wood per day. Heavily forested areas near Rome disappeared and wood was imported from as far as 1000 miles away. To extend wood resources, passive solar heating techniques were refined to include south-facing glass and the use of water as thermal mass to store the solar energy. As passive solar heating became commonplace in public baths, residences, and greenhouses, the first solar access, or "right to light", laws were enacted.

During the eleventh and twelfth centuries A.D., the Pueblo Indian culture developed the first American solar communities (FIG 0-7). Every residence had a south-facing exposure to permit sunlight to enter through doors and windows, and entire communities were planned to provide maximum solar access. Adobe construction assured sufficient thermal mass to store the heat during winter and to moderate temperatures

0-5 OLYNTHUS, GREECE: 500 BC
FIRST SOLAR COMMUNITY

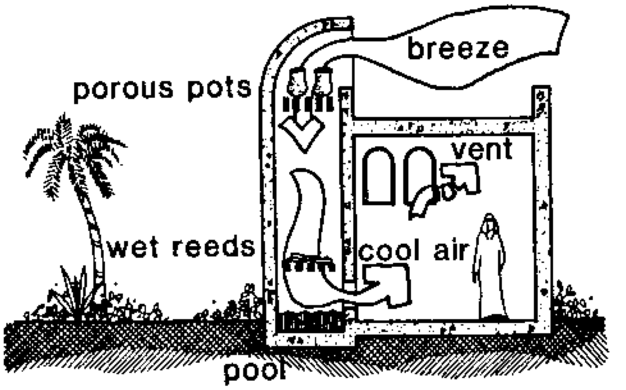


0-6 ROMAN BATH: ca. 100 AD
FIRST SOLAR ACCESS RIGHTS

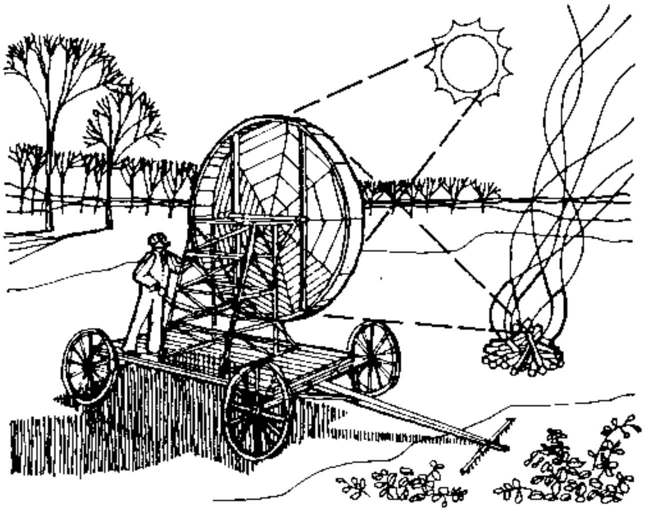


0-7 MESA VERDE: 1000-1200 AD
NATIVE AMERICAN SOLAR DWELLINGS

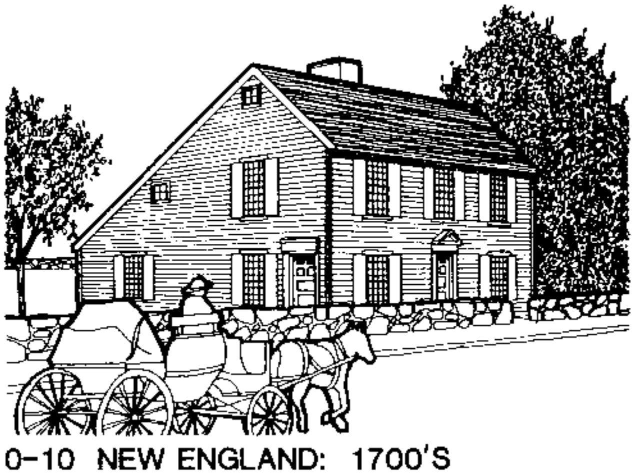
INTRODUCTION



0-8 PERSIA: 900 AD TO PRESENT
COOLING TOWER



0-9 GERMANY: 1700'S
EARLY CONCENTRATING COLLECTORS



0-10 NEW ENGLAND: 1700'S
EARLY AMERICAN SALTBOX

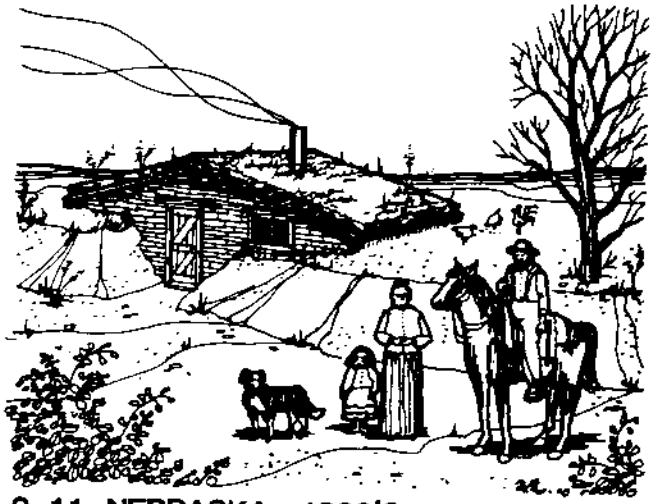
during the hot summer months. Shutters and roof insulation helped retain heat in the winter, and eaves were used to shade the sun in the summer.

The sun's energy can be used to cool as well as to heat. All wind currents are sun driven, and the Persians took advantage of this fact to keep their interior spaces cool during summer months (FIG 0-8). Breezes are ducted from roof openings down through porous pots and wet reeds and over a pool at the bottom of the chimney. In picking up moisture, the air current is cooled so air entering the living space is cooler than indoor air temperatures.

The use of the sun's energy is not limited to heating and cooling applications alone. Ancient Chinese, Greek, and Roman civilizations developed curved mirrors to concentrate the sun's rays onto a single point. Archimedes is said to have used mirrors in 221 B.C. to destroy an enemy fleet attacking Syracuse. Da Vinci conceptualized the idea of using mirrors to supply industrial hot water. In place of single piece mirror fabrication, Peter Hoesen fabricated his mirrors with brass-covered wood sections that were fitted together (FIG 0-9). The power of the mirrors was such that copper metal would melt in one second.

Early American settlers built the New England "saltbox" (FIG 0-10). The buildings were two-story with most of the rooms facing south. Only one floor faced north. Sloping roofs carried cold northern winds up and over the building. Vines above the doors and windows kept summer sun out of the home, but would permit sunlight to pass through the windows when the leaves fell in autumn.

Each environment has unique characteristics. The prairie pioneers of a century ago faced cold winters with fierce north winds (FIG 0-11) and hot, unpleasant summers. Wood was not in abundance to serve as a primary fuel. The solution was the sod house. Earth berms on the north kept out winter winds. South-facing doors and windows permitted solar gain. Dirt and sod provided roof insulation year round. The thick walls moderated temperatures, and the earth floor contact provided the additional bonus of summer cooling.



0-11 NEBRASKA: 1800'S
EARTH SHELTERED SODDY

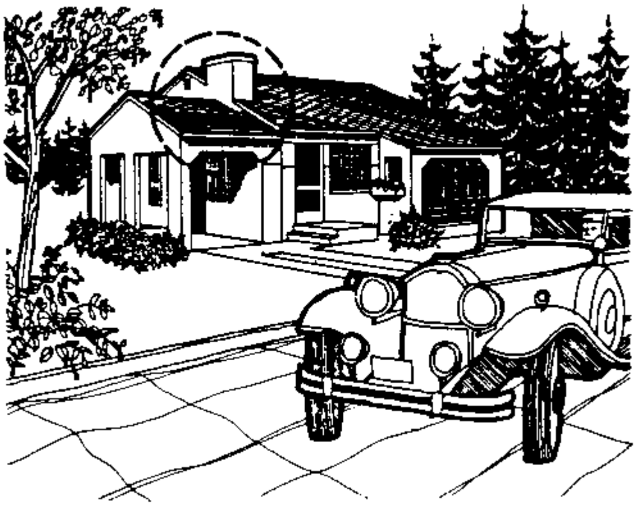
In 16th century Holland, greenhouses were utilized for horticultural purposes, which resulted in the perfection of window angles and thermal storage techniques. It was not until Victorian England, however, that the idea of the glassed-in garden, or conservatory, gained popularity . Sun-warmed and plant-moistened air could be drawn into homes which otherwise were usually cold and gloomy (FIG 0-12).

0-12 LONDON: 1890'S
VICTORIAN GREENHOUSE

Although personal bathing was popular in Rome, the practice was discontinued in Europe , primarily because heating water was a laborious and tedious process. However, in 1891, Clarence Kemp marketed the "Climax", the first commercial solar hot water heater unit. It consisted of a hot box with exposed bare metal tanks operating under city water pressure. Bathing became practical again. In 1911, the "Day and Night" solar hot water heater by William Bailey revolutionized the industry (FIG 0-13). Its insulated storage tank was separated from the collector, and the collector included a metal absorber plate operating on thermosiphon principles.

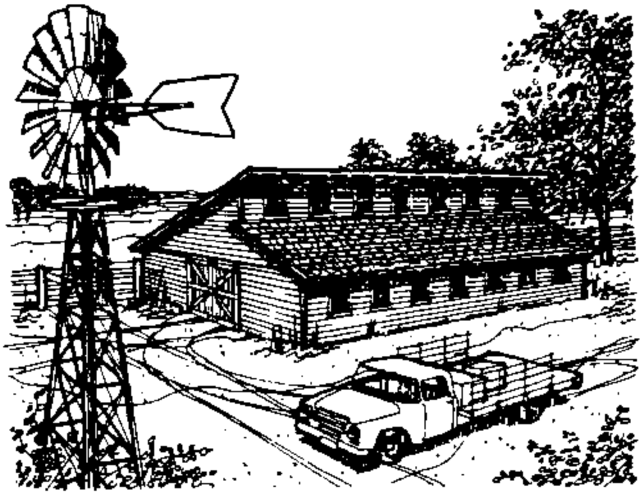
0-13 SOUTHERN CALIFORNIA: 1911
SOLAR WATER HEATER

INTRODUCTION



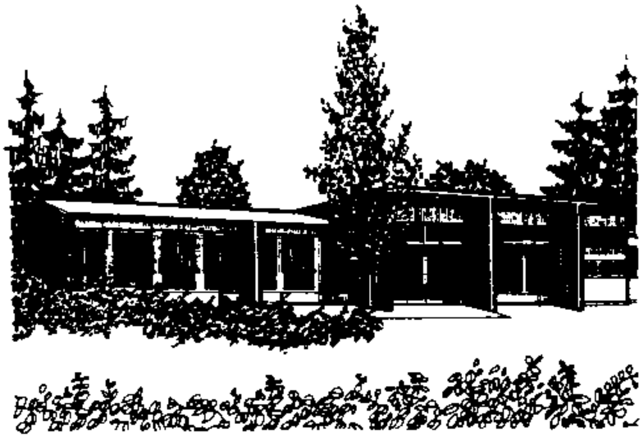
0-14 FLORIDA: 1930'S
IMPROVED SOLAR WATER HEATER

Florida's population grew rapidly during the Roaring 20's and by 1941 more than half of Miami's population was using solar heated hot water (FIG 0-14). A popular model of solar hot water heater was the "Duplex", an improved version of the "Day and Night". Soft copper replaced steel tubing, the spacing between tubing was reduced, and the collector box was insulated and further improved by switching to steel construction.



0-15 NEBRASKA: 1940'S
LIVESTOCK SHELTER

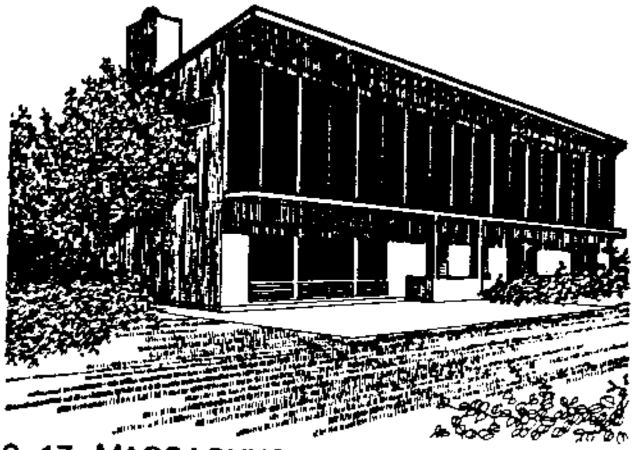
In the midst of the great Depression, a number of programs were instituted to benefit farmers, including one by the Farm Security Administration, in which an existing design of an animal facility was altered to reduce energy consumption (FIG 0-15). These alterations included windows and clerestories facing south to maximize solar gain and a long roof line pitched to deflect the cold winter winds up and over the building. Many of these animal barns dotted the prairie landscape of the 30's and 40's. The famous architect Saarinen is said to have commented: "Kids should be able to live as well as these chickens".



0-16 ILLINOIS: 1941
PASSIVE DESIGN BY KECK

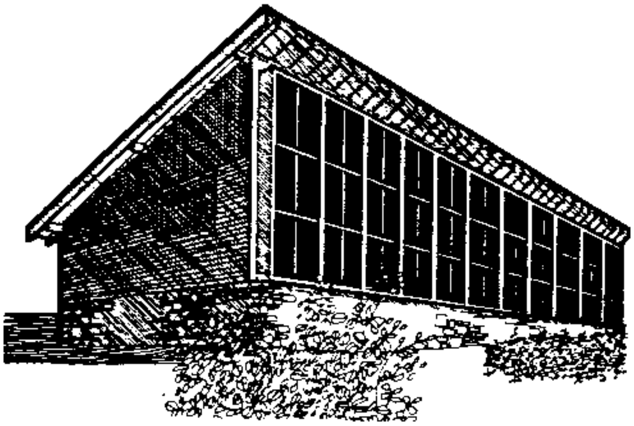
The modern passive solar era began in the 1930's and 1940's with George Fred Keck, who designed homes with a southern orientation. Keck used double paned glass which allowed the home to retain more heat in winter and overhangs to prevent overheating in summer (FIG 0-16). In 1940 the first modern passive solar heated home with a complete south wall of glass was built for Howard Sloan, a real estate developer in Chicago, who, in 1941, built Solar Park, the first American solar development.

In 1948, Maria Telkes, then a research associate at MIT, worked with Amelia Peabody to design a 100% solar home without backup furnace. Called the Dover House (FIG 0-17) the structure had a vertical collector with 180 square feet of south-facing glass. Hot air was ducted from the air collector to a 470 cubic foot storage unit comprised of glaubers salt in five gallon steel cans. The storage capacity was 5 million btus, enough to heat the house through a week of cloudy days. Unfortunately, the system was only successful for 2-1/2 winters, after which problems developed in the salts.



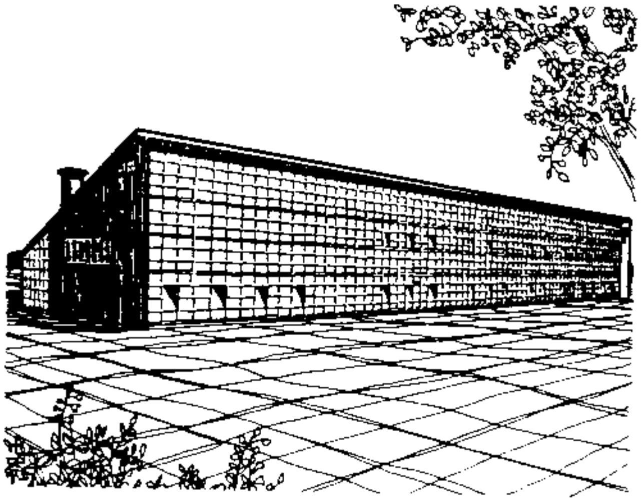
0-17 MASSACHUSETTS: 1948
DOVER HOUSE BY MARIA TELKES

In 1956 in the mountains of southern France, Felix Trombe built the first of a series of solar buildings (FIG 0-18). Today Trombe is recognized as one of the modern pioneers of passive solar energy, and the concept of placing thermal mass directly behind south-facing glass is frequently referred to as a Trombe wall. Concrete one-foot thick and painted black serves two purposes: it provides thermal storage and acts as a structural element. Heat absorbed by the concrete migrates to the inner wall and radiates into the living space during the evening.



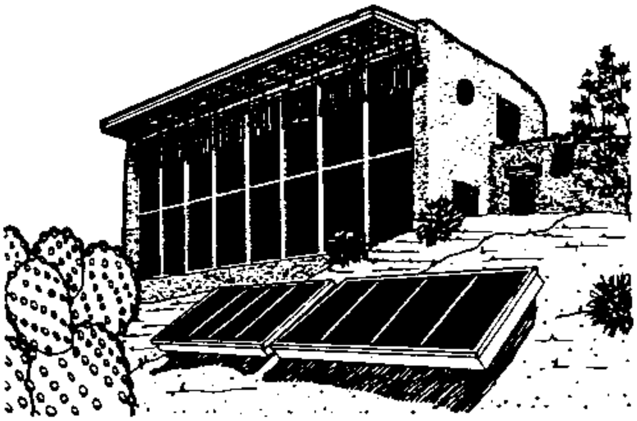
0-18 PYRENEES, FRANCE: 1956
FELIX TROMBE HOUSE

The Wallasey school in Liverpool, England is another early example of passive solar energy design (FIG 0-19). Built in 1961, the school's entire 230' by 27' south facade is in two glass layers. The inner layer diffuses the impact of direct sunlight. This diffused light strikes concrete floors, ceilings, and brick walls directly and these contain sufficient mass to limit the daily temperature swing to 6°F. The school has yet to require auxiliary heating.



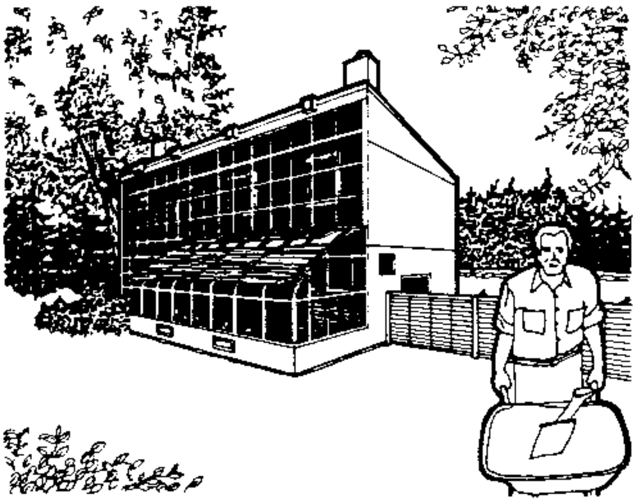
0-19 WALLASEY, ENGLAND: 1961
SOLAR HEATED SCHOOL

INTRODUCTION



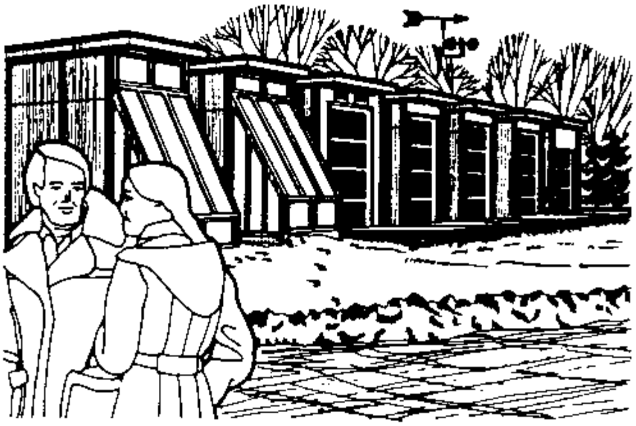
0-20 NEW MEXICO: ca. 1970'S
DAVID WRIGHT DESIGN

The sun provides 90% of the annual energy requirements of a home built in 1974 by David Wright (FIG 0-20). Most of the nearly 500,000 btus collected each day are stored in the 2' thick adobe floor and 13" to 17" thick adobe wall, insulated with 2" of polyurethane foam, and enough heat can be stored to provide heat to the house for three to four sunless days. The interior space fluctuates between 58°F and 80°F during the winter.



0-21 PRINCETON, NEW JERSEY: 1975
DOUG KELBAUGH HOUSE

The Doug Kelbaugh home, (FIG 0-21) built in 1975 in Princeton, N.J., combines a Trombe wall with greenhouse. It overcomes the chief objection to placing thermal mass between the living space and the south-facing view by providing for windows to be installed in the Trombe wall. During 1976-77, the average temperature was 63°F downstairs and 67°F upstairs.

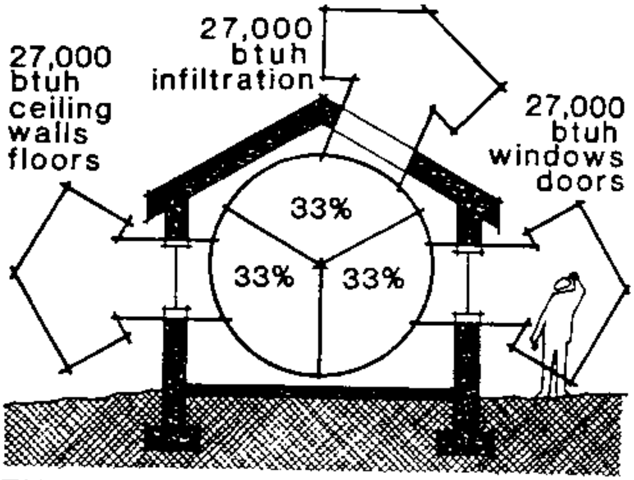


0-22 OMAHA, NEBRASKA: 1978
UNO PASSIVE SOLAR TEST PROJECT

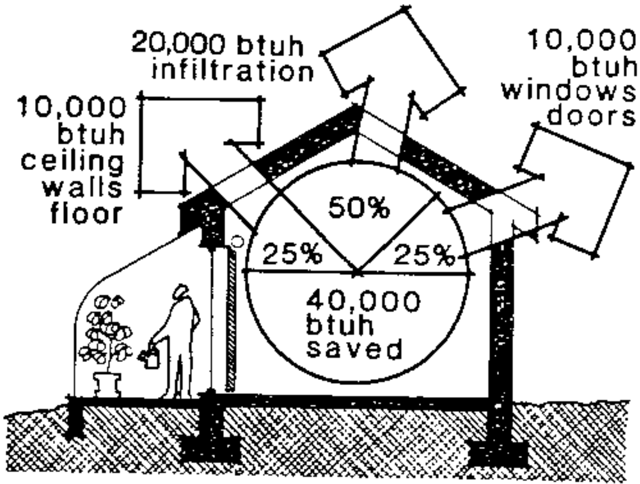
Begun in 1978, the Passive Solar Energy Test Facility, located at the University of Nebraska at Omaha, now ranks as one of the largest passive solar test facilities in the world (FIG 0-22). The study of different passive solar heating techniques has been heavily emphasized, especially those that are suited to northern climates. Greenhouse, earth sheltered, and super-insulated test rooms have been built at the test site. The only double shell or continuous thermal envelope test room known to be in existence has been undergoing monitoring since 1979. Experiments with cooling tubes and testing of commercial products are planned. The Passive Solar Research Group (PSRG), consisting of volunteer faculty and students, manages the test facility.

WHY PASSIVE SOLAR ENERGY?

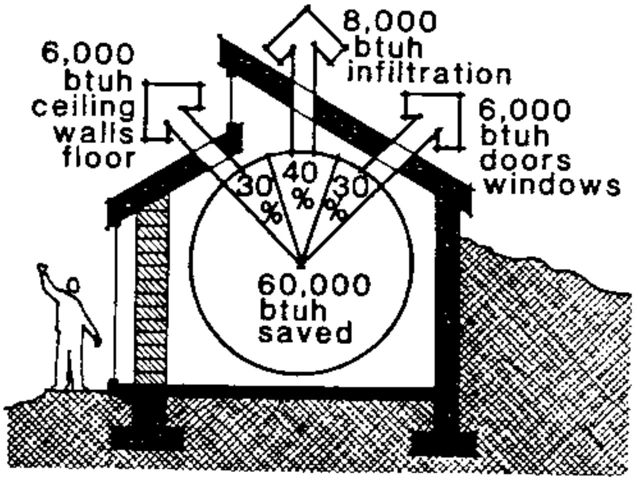
Passive solar heating technology has been proven to be a viable, cost-effective, maintenance-free, low technology, and almost universally applicable strategy in the field of energy efficient house design (FIG 0-23). Because conservation is a cornerstone of any passive solar energy strategy, a solar-conscious home will reduce energy consumption by 50% or more. For those solar structures which have been optimally designed, the savings can amount to 80% or better compared to a conventionally-designed home. It appears that passive solar energy is one of the principal strategies which will be utilized by the homeowner to combat the inevitable upward spiral of home energy costs.



TYPICAL HOUSE IN JANUARY
(80,000 btuh loss)



SOLAR CONSCIOUS HOUSE
(40,000 btuh loss)

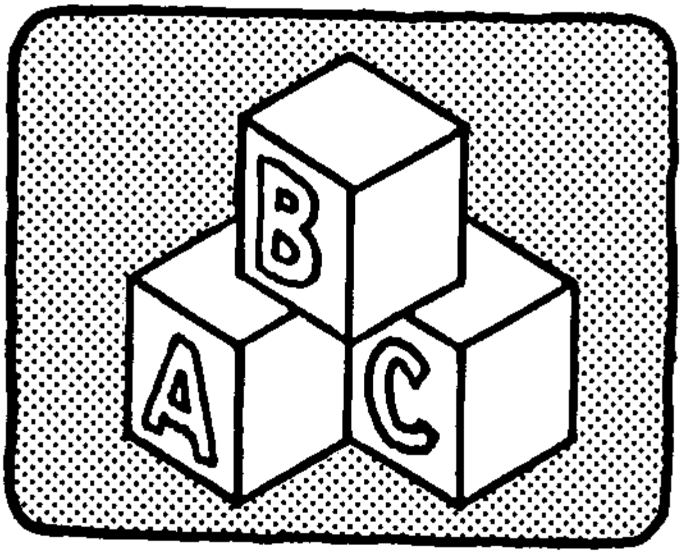


OPTIMUM SOLAR HOUSE
(20,000 btuh loss)

0-23 WHY SOLAR?

CHAPTER 1
FUNDAMENTALS

This chapter is an introduction to energy concepts and terms.



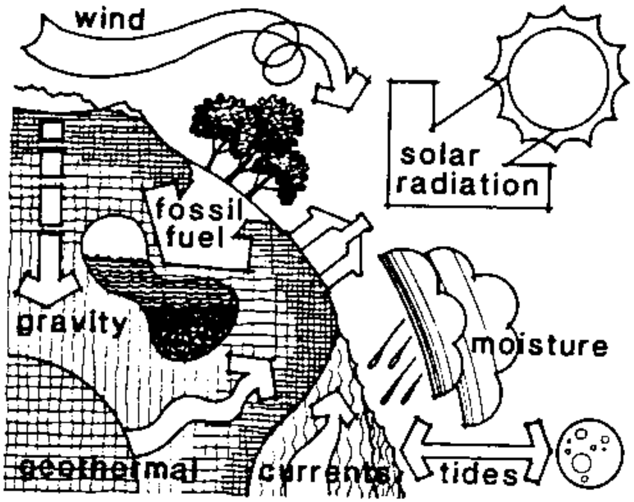
FUNDAMENTALS

In order to understand the processes at work in a passive solar building, it is important to understand the basics of heat energy and its behavior. A good knowledge of these topics will further aid in understanding the various solar techniques, and a good base in theory can also permit intelligent modification or adjustments to proven techniques.

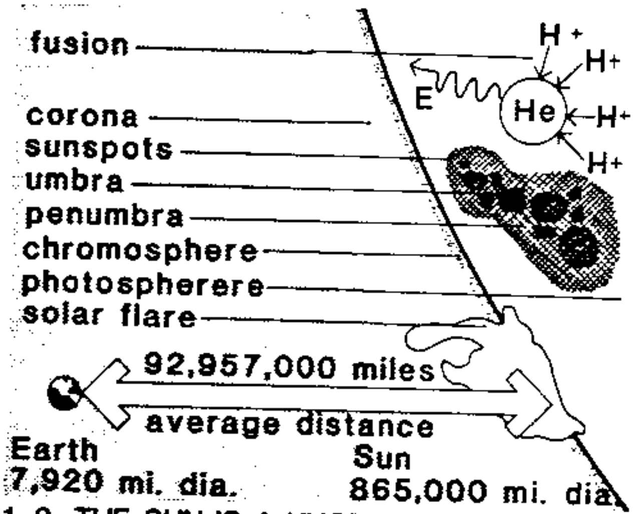
THE SUN AS A SOURCE OF ENERGY

Before examining the concept of heat, it is important to first put concepts into perspective. Energy from the sun manifests itself in many different forms (FIG 1-1). For example, the sun heating the various parts of the atmosphere to different temperatures causes the air movements we call winds. Ocean currents are due in part to similar causes, and hydroelectric energy is energy from the sun that evaporates water from oceans and lakes and then transports it so that it may fall as rain or snow at a higher elevation. The water has gained potential energy by gaining altitude and this energy is released as kinetic energy as the water flows to a lower level.

The fossil fuels owe their chemical energy to a prehistoric photosynthesis dependent on solar energy; buried for millions of years beneath sand, rock and sediment, partially decomposed organic matter is eventually converted through pressure, heat, and aging into fossil fuels such as coal and petroleum or into a by-product of the same process, natural gas.

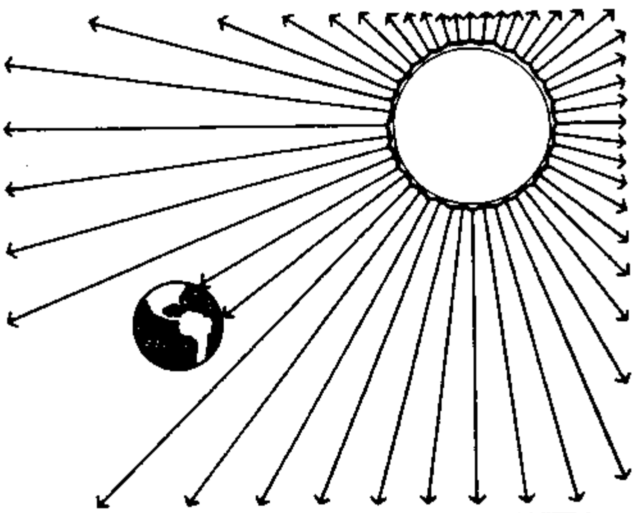


1-1 NATURAL ENERGY MANIFESTS ITSELF IN MANY FORMS

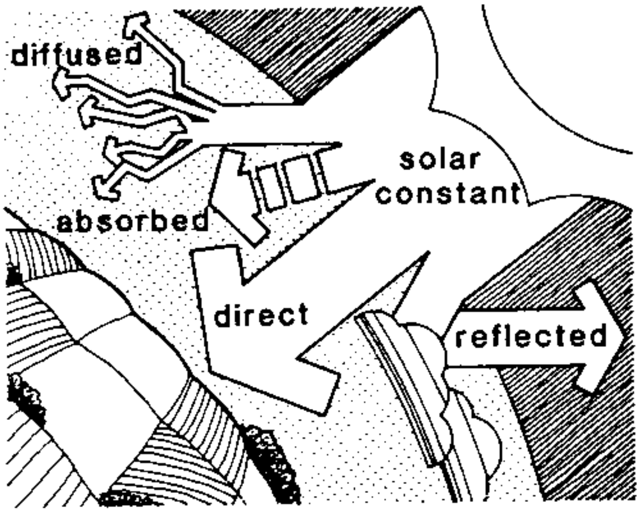


1-2 THE SUN IS A HUGE FUSION REACTOR

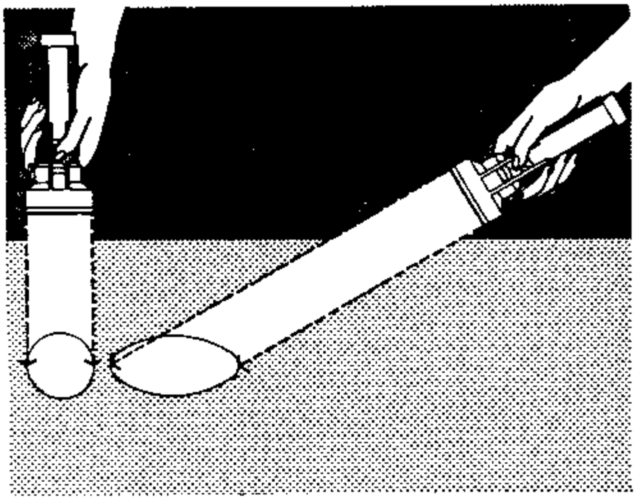
Our sun (FIG 1-2), which provides virtually all of the energy required by life on earth, is a middle-aged, medium-sized star -- Sol -- located near the outer edge of the Milky Way galaxy. The earth orbits around Sol at an average distance of about 93 million miles. This seemingly huge distance is relatively small on the scale of the stars, the next nearest star being many millions of times farther away. The sun is also very much larger than the earth -- containing about a million times the earth's volume. The huge gravitational forces in the sun's interior generate extremely high temperatures, causing hydrogen atoms to combine to produce helium in a process called nuclear fusion. This reaction involves the loss of a small amount of mass which is converted directly into energy and is the same process that makes possible the H-bomb.



1-3 SOLAR ENERGY IS REDUCED WITH DISTANCE



1-4 WE RECEIVE ONLY PART OF THE EXTRATERRESTRIAL SOLAR ENERGY



1-5 ENERGY DENSITY IS MAXIMUM WHEN THE BEAM IS PERPENDICULAR

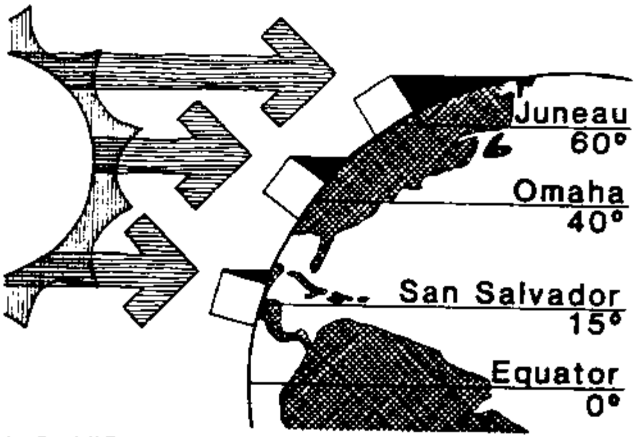
Energy, the product of the nuclear reactions on and in the sun, is radiated into space, mainly in the form of heat and light. It travels outward at "the speed of light", some 186,282 miles per second, taking about eight minutes to reach the outskirts of the earth's atmosphere.

On its journey to earth, the sun's energy changes little, other than weakening (FIG 1-3), until it reaches the outer limits of our atmosphere. Some of the light and heat entering the atmosphere is reflected back into space by clouds and other debris in the air, and some of the energy is absorbed by various components of the air, making the air warmer (FIG 1-4). The energy that makes it to the ground arrives either directly from the sun (the 'direct' or 'beam' component), or after one or more reflections from clouds, airborne debris, or air molecules (the 'indirect' or 'diffuse' component). The diffuse component of the total energy received can range from 10-20% on a clear day to 100% on an overcast day.

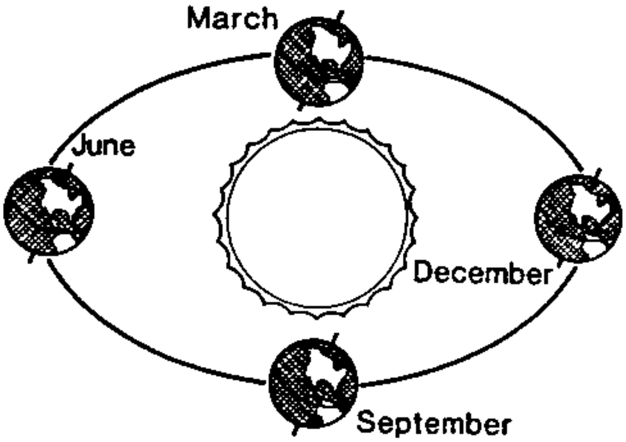
The amount of energy received on the earth's surface is also affected by the angle at which the beam component arrives (the diffuse component is coming from all unshaded directions). This can be compared to the beam of a flashlight, held vertically, shining onto a horizontal table top. A given amount of energy is spread over a given area (FIG 1-5). If the flashlight is moved so that the beam strikes the table at an angle, the area where the light strikes the table increases in size. Since the same total energy is being delivered to a larger area, there is less energy per square inch of table top where the light is shining. As the flashlight is moved further from the vertical position , the beam dims as it spreads.

Several factors affect the angle of sunlight coming to earth. The normal progress of the sun through the sky is the most obvious. Also, sunlight arrives at lower angles at higher latitudes (FIG 1-6). This latitude effect is complicated by the fact that the earth's axis is inclined, or "tipped", approximately 23 degrees from vertical, the direction at right angles to the plane in which the earth orbits the sun. The revolution of the earth around the sun causes the northern half of the earth to lean toward the sun at one point in the orbit, and to lean away exactly one-half orbit (one-half year) later (FIG 1-7). When the northern hemisphere is tipped toward the sun, the middle north latitudes receive solar energy more nearly head-on, and, therefore, intercept more energy per square foot than the southern hemisphere, which is tipped away. This, of course, explains the changing seasons. In the example, the northern hemisphere is experiencing summer, and the southern hemisphere winter.

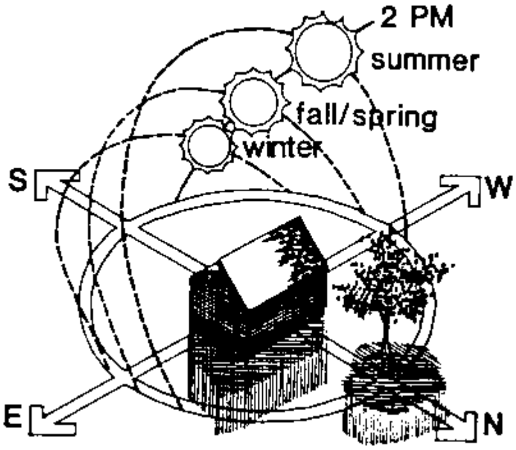
Receiving sunlight "head-on" means the sun is higher in the sky, or more nearly directly overhead, as in the flashlight example; in the summer, the sun seems to pass more nearly overhead, while in the winter, its path is low in the southern sky (FIG 1-8). The farther north, the lower the winter sun's path: at some northern latitudes the sun will not rise for part of the winter. In the southern hemisphere the situation is similar, though reversed -- the sun is low in the northern sky in June.



1-6 HIGHER LATITUDES HAVE LOWER SUN ANGLES



1-7 EARTH TILT IS RESPONSIBLE FOR CHANGING SEASONS

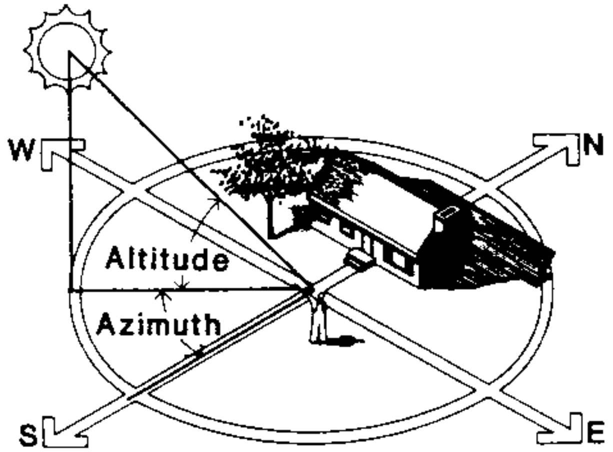


1-9 SEASONAL SUN PATHS

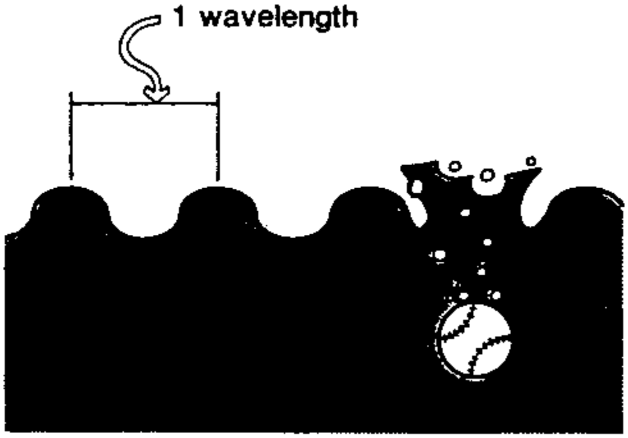
FUNDAMENTALS

The position of the sun in the sky is measured by two angles -- altitude and azimuth (FIG 1-9). "Altitude" is a measure of how "high" the sun is. An arm pointed directly at the sun and dropped to a horizontal position has moved through the sun's altitude angle. Kept horizontal and swung to true south, the arm moves through the sun's second position angle -- the "azimuth" angle, or the variation from true south.

It is the sun's maximum daily altitude -- which occurs at "solar noon" -- that changes with the seasons, a fact which takes on great importance in designing a workable solar house.



1-9 THE SUN'S POSITION CAN BE DETERMINED BY TWO ANGLES



1-10 WAVELENGTH IS THE DISTANCE BETWEEN CRESTS

SOLAR RADIATION

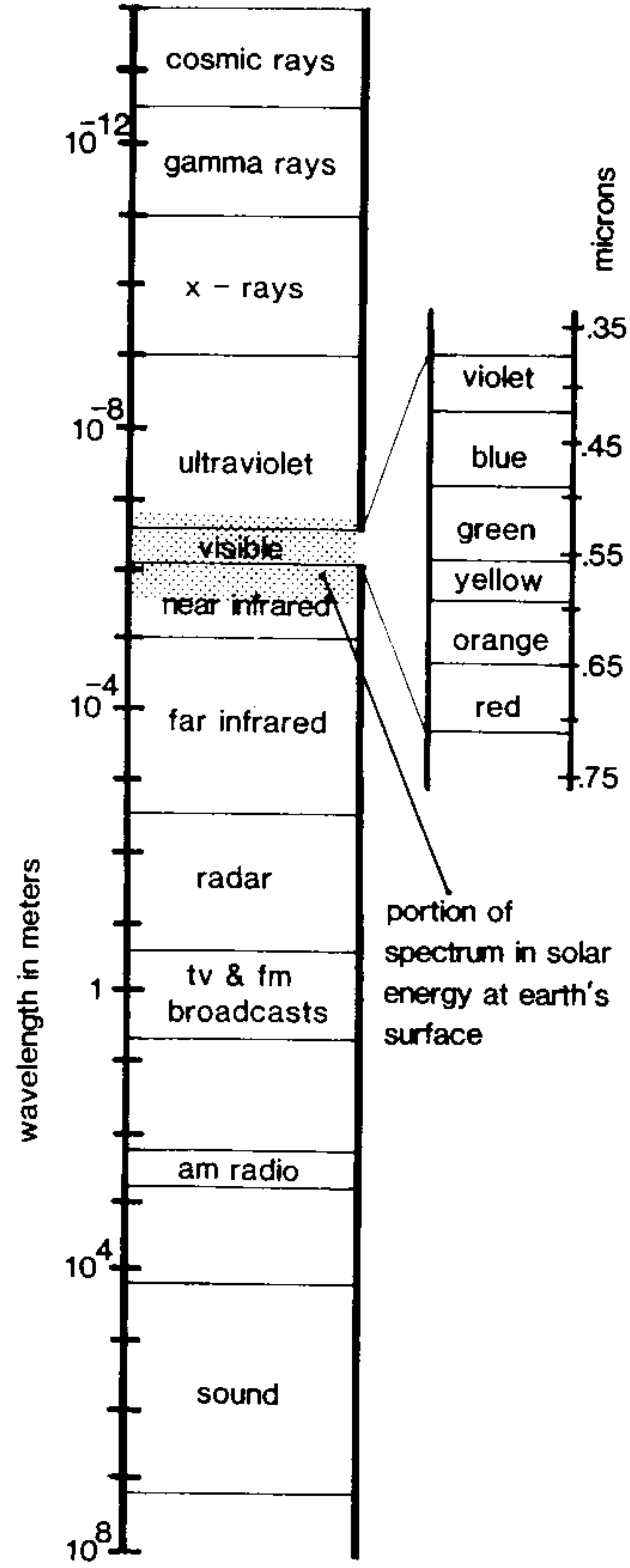
Solar energy is a form of "electromagnetic radiation", which means that the energy has wave-like properties allowing it to travel in the vacuum of space. Wave-like properties include wavelengths -- the distance from one wave crest to the next (FIG 1-10). Electromagnetic waves differ from pond waves in that the former need no physical material to travel in.

Electromagnetic waves of various wavelengths comprise the "electromagnetic spectrum" (FIG 1-11). Energy emanating from the sun is a collection of wavelengths, all concentrated in a small span of the electromagnetic spectrum called the "solar spectrum".

Energies with different wavelengths can produce different effects, e.g., eyes are directly sensitive to only the tiny portion of the entire electromagnetic spectrum with wavelengths between about 0.35 microns and 0.75 microns (micron is a millionth of a meter). "Visible light" is the term given to this band of energy, which is further divided into smaller ranges of wavelengths. Violet and blue are the shortest wavelengths seen. Red is the longest. Electromagnetic energy with wavelengths longer than red are called "infrared", and are sensed as heat from the sun, a radiator, a hotplate, etc.

The greatest portion of the electromagnetic spectrum is not directly detectable by the human body, however, it is evidenced through the use of various devices, e.g., television broadcasts. On the other end of the visible spectrum are ultraviolet light, X-rays, and gamma rays, all of which are harmful to life in large doses.

As solar radiation passes through the earth's atmosphere, certain components of air -- mainly ozone, carbon dioxide, water vapor, and nitrogen -- absorb specific wavelengths of energy, or small



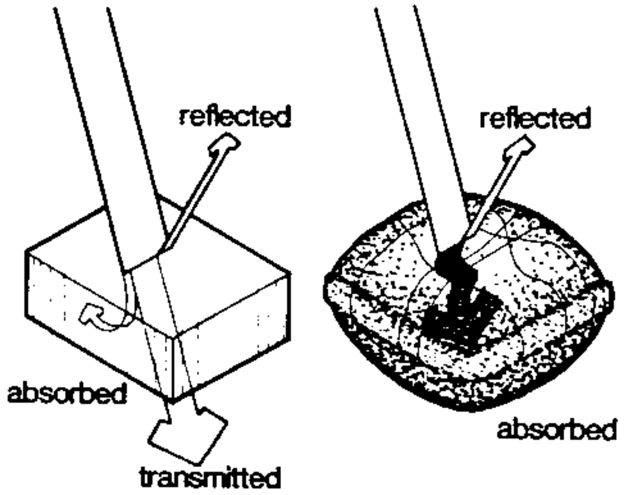
1-11 THE ELECTROMAGNETIC SPECTRUM

bands of wavelengths. Thus, the spectrum reaching the ground is quite different from the solar spectrum in space. Because most of the X-rays and other short wavelengths are eliminated along with the longer part of the infrared, the solar energy finally reaching the ground, consists almost totally of visible light, and what is called "near infrared" radiation.

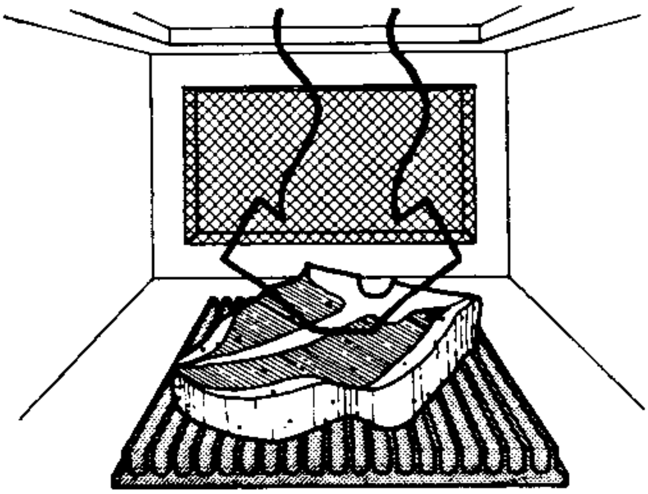
Because the actual amount of solar energy reaching the earth depends not only on complicated but predictable factors like time of day, season, and latitude, but also on very unpredictable factors like weather, solar radiation is usually not predicted by calculation. Rather, tables based on actual measured values averaged over a number of years are used. Tables can be found for many U.S. locations, sometimes with other variables, such as data for vertical and tilted surfaces, hourly solar radiation, etc.

REFLECTION, TRANSMISSION, ABSORPTION

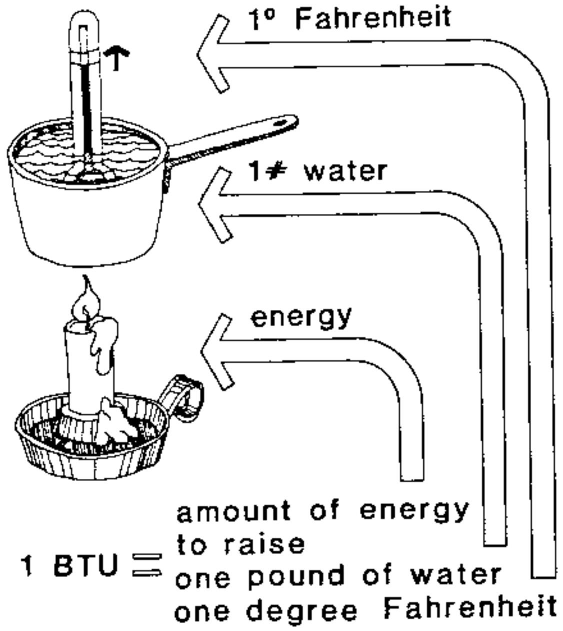
Only three things happen to solar radiation when it encounters a physical material: 1) it can be transmitted through the material, e.g., glass or air, 2) it can be reflected by the surface of the material, e.g., mirrors, or 3) it can be absorbed by the material (FIG 1-12) . Typically, a



1-12 ABSORPTION, REFLECTION, AND TRANSMISSION DIFFER WITH MATERIAL combination of all three things happen. For example, a pane of clear glass will transmit the majority of any visible light energy falling on it, but it will also reflect and absorb small portions of the energy. Infrared energy, however, is mostly absorbed, with smaller amounts transmitted and reflected. Ordinary glass has a high transmittance for visible light, but lower transmittance for infrared. Accordingly, a mirror has a high reflectance (for visible light), and a lump of charcoal -- which does not reflect or transmit much visible light -- has a high absorptance.



1-13 ABSORPTION OF RADIANT ENERGY PRODUCES HEAT



1-14 BRITISH THERMAL UNIT

When radiation energy is reflected or transmitted, it continues unchanged until it encounters another body. Energy that is absorbed, however, undergoes a very basic change -- it becomes heat, which is why infrared radiation is identified with heat. The human body absorbs large amounts of infrared radiation, which acts to raise the temperature of the skin. In reality, however, any type of electromagnetic radiation which is absorbed by a material is converted to heat, e.g., the water in food cooking in a microwave oven has high absorptance for the wavelength being used (FIG 1-13). Heat, then, is a form of energy that is internal to a substance in the agitation of its atoms or molecules. Materials which contain a large amount of heat energy have very "excited" molecules or atoms.

HEAT AND TEMPERATURE

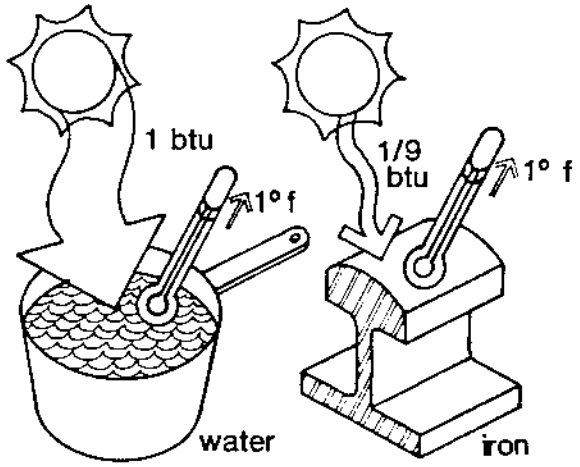
A confusing concept for many people is that heat and temperature are not the same thing. Heat is a measure of energy, while temperature is a measure of the molecular agitation caused by the energy.

HEAT UNITS

There are two common units for the measurement of heat energy: the British Thermal Unit, or btu and the calorie. A btu is the quantity of heat required to raise the temperature of one pound of water by one Fahrenheit degree (FIG 1-14). The calorie is the quantity of heat needed to raise the temperature of one gram of water by one Centigrade degree. (Note that the Calorie -- with capital "C" -- which is used in dietary terms is equal to 1000 calories). It should be noted that heat and temperature are not the same.

SPECIFIC HEAT

When a material absorbs heat, it gets warmer, unless it melts, boils, or decomposes. However, two different materials, each absorbing the same amount of heat energy, will not necessarily show the same rise in temperature (FIG 1-15). For example, if a pound of water and a pound of iron each absorb one btu, the water temperature goes up by one degree Fahrenheit, while the temperature of the iron goes up by nine degrees Fahrenheit. Iron has a smaller heat capacity than water, since only 1/9 btu will raise a pound of iron one degree in temperature, while nine times as much heat -- 1 btu -- is required to produce the same change in water. This number -- 1/9, or 0.11 -- is called the Specific Heat of iron. Specific Heat is expressed in units of btu/^{o}F-lb. The Specific Heat of water is 1.0, very high compared with most materials. Water's high heat capacity makes it a very good heat storage material in a passive solar home.



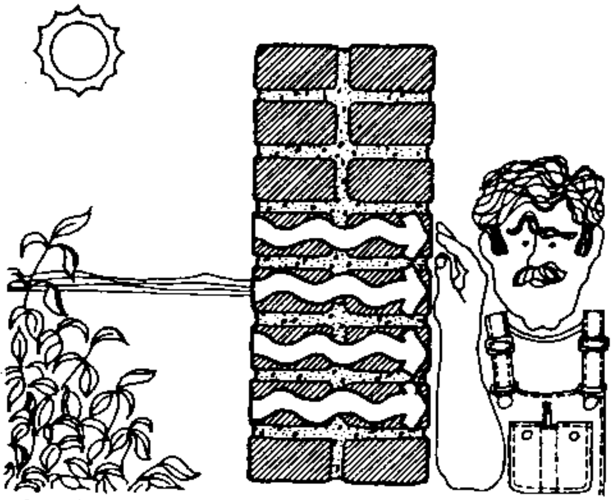
1-15 SPECIFIC HEAT

HEAT TRANSFER

In some ways, heat behaves like a fluid in that it has a natural tendency to "flow" from high to low, the high and low here referring to temperature. This natural flow from warm to cold is achieved by three distinct mechanisms: conduction, convection, and radiation.

CONDUCTION

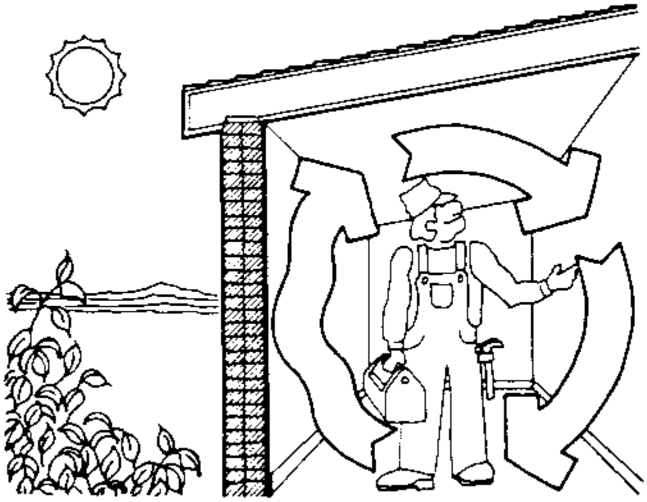
If one side of a brick wall is warm it means that the molecules in the bricks are more excited or agitated on the warm side than other, cooler parts of the bricks (FIG 1-16). These "warm" molecules can pass on some of their energy by physically "bumping into" neighboring cooler molecules, thereby agitating them. Heat energy can be passed on this way, molecule to molecule, until eventually the opposite side of the wall becomes warm. This kind of heat movement is called conduction.



1-16 CONDUCTION

The physical properties of some materials are such that this conduction process proceeds very efficiently with little opposition to the heat flow. These materials, including most metals, are called good thermal conductors. Other materials offer high resistance to heat conduction, and are poor thermal conductors. They are called thermal insulators.

A way to measure the ease with which heat conducts through a material is called thermal conductance, or "U value". The U value of a material is the number of btus of heat which will conduct through a one square foot section of the material in one hour, if there is a one degree Fahrenheit temperature difference between the two sides. The units of a U value, then, are btus per hour per square foot, per degree Fahrenheit. The U value refers to a specific thickness of material -- if the thickness of the material is doubled, the thermal opposition is doubled, and the conductance is one half the previous value. For this reason, conductivity values should identify the U value for a one-inch thickness of material. The U values of other thicknesses of the same material can be found by dividing the conductivity by the thickness in inches.



1-17 CONVECTION

A more familiar measure of the conduction properties of materials is the "R value", a measure of the resistance, or opposition to heat flow. It is the reciprocal of the U value:

$$R=1/U, \text{ and } U=1/R.$$

R values are useful because they can be added "in series"; the total R value for a wall made up of several different layers of different materials is the sum of the R values of each layer.

Values for conductance, conductivity, and resistance of common materials can be found in Appendix 3 and Chapter 5.

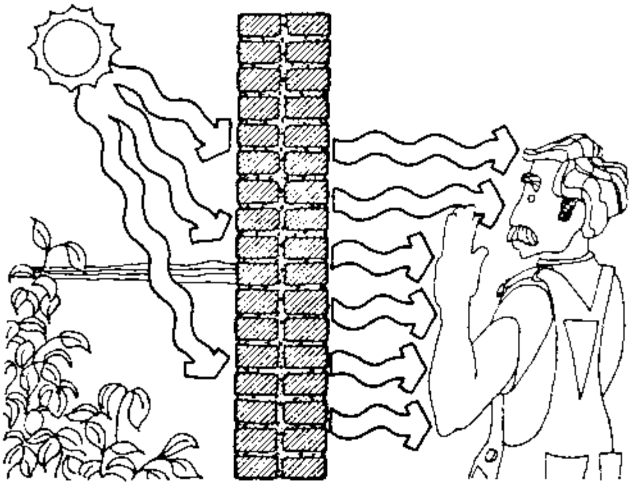
CONVECTION

If the inside surface of the brick wall is warmed by conduction of heat from the outside, air next to the inside surface will also be warmed by conduction (FIG 1-17). Air expands as it is warmed, which makes it lighter. As light, warm air rises, it is replaced by cooler, heavier air. If the wall is one side of a closed room, the warm air rises to the ceiling, where it may lose some of its heat (by conduction to the ceiling) and start to sink. The heat is being moved from the inside wall surface to other parts of the room by convection -- the transfer of heat by the physical movement of a warm substance. This example is one of "natural convection", since the movement is due solely to natural forces. "Forced convection" occurs where warm air (or water, or other substance) is moved by the use of a pump, e.g., warm air furnaces with blowers distribute heat by forced convection.

RADIATION

The third kind of heat transfer is electro-magnetic radiation -- the mechanism by which heat from the sun reaches the earth.

All objects radiate energy. The amount and kind (wavelength) of radiation depends on two things -- the temperature of the object and its emissivity. Warmer surfaces radiate more energy at shorter wavelengths. This is why it is possible to feel the warmth of a brick wall at a distance, independent of conduction and convection effects (FIG 1-18). Hot water or steam "radiators" give a feeling of warmth largely due to radiation, although conduction and particularly convection play a role also. Studies have shown that a source of radiant heat, such as a warm wall, will give a sense of comfort even at air temperatures which would otherwise feel chilly. The old pot-bellied stove is another example of this effect.

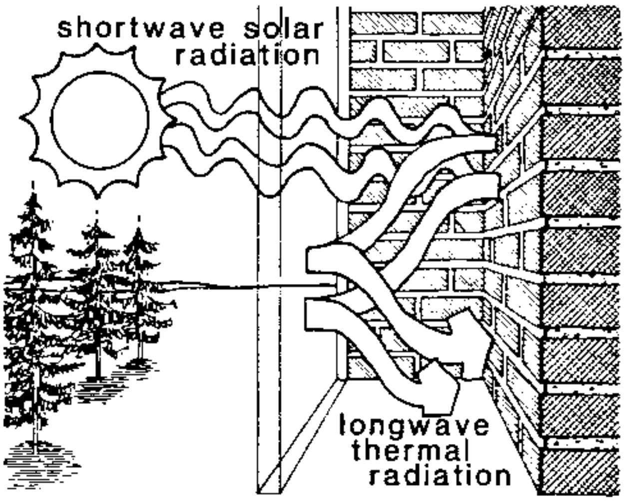


1-18 RADIATION

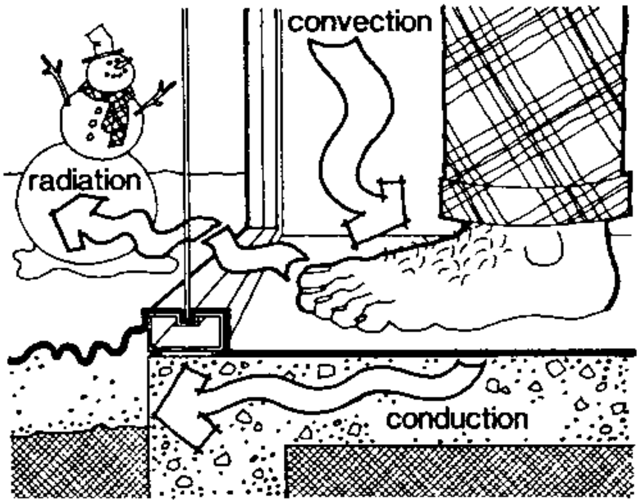
Emissivity is a property of a surface. An emissivity value of 1.0 means that 100% of the possible radiation at a given temperature is radiated by the surface. Similarly, an emissivity value of 0.5 means that only 50% of the possible radiation at the given temperature is radiated.

GREENHOUSE EFFECT

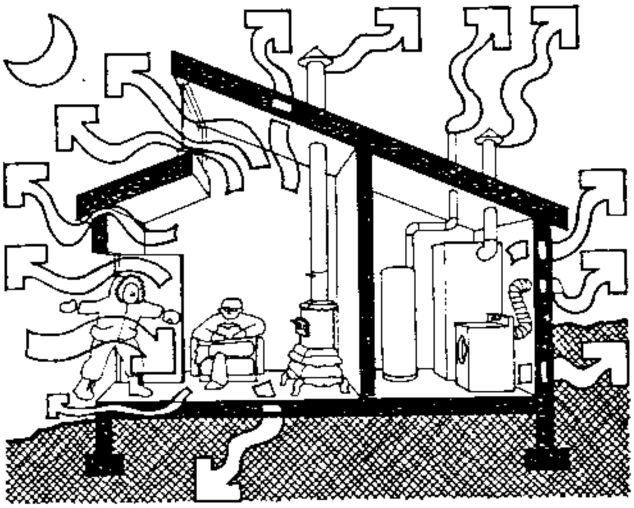
As noted previously, ordinary window glass is relatively transparent to visible light and more opaque to infrared, or heat radiation. When sun energy, which is mostly in the visible region, encounters a pane of glass, most of the energy is transmitted. If the light then strikes a surface where it is absorbed, the surface will be heated (FIG 1-19). This hot surface will radiate infrared energy. This heat radiation cannot pass through the glass and is reflected back into the space between the glass and the absorbing surface. (In practice, some of the infrared energy radiated by the wall will be absorbed by the glass, heating it). This is known as the greenhouse effect, a very important mechanism in the operation of a solar house, and special glasses and glass coatings have been developed to enhance this effect.



1-19 GREENHOUSE EFFECT



1-20 HEAT IS OFTEN MOVED BY ALL THREE MEANS



1-21 HEAT LOSS PATHS

LOSSES AND GAINS

Ideally, a home should maintain a constant comfortable indoor temperature regardless of outside conditions. Indoor temperature in a home is determined by the balance of the various heat flows into, out of, and within the building. Heat flows which tend to raise the temperature in a building are called gains, and flows which tend to lower the temperature are called losses.

On a cold winter day, a heated home will lose heat to the outside because heat flows from warm to cold by conduction, convection, and radiation (FIG 1-20). To maintain a constant indoor temperature, this loss must be replaced by an equal heat gain, either from the sun, a furnace, or other internal sources.

HEAT LOSSES

Heat losses are of various types and causes (FIG 1-21), including air leaks, called infiltration losses, and conduction losses through exterior walls, ceilings and roofs, windows, doors, slabs, and basement walls. In a reasonably well constructed house, half the winter losses are due to infiltration and half are due to conduction through exterior surfaces although this may vary.

Infiltration is a form of convection, and includes air movement through cracks and seams, as well as through open doors and windows. Infiltration, measured in air changes per hour (ACH), reflects how many "housefuls" of air leak into or out of the structure in an hour. Values can be as high as 3 ACH and even higher in loosely-constructed homes.

Despite the potential for heat loss through infiltration, very low infiltration rates are not desirable. Problems with odor control and moisture buildup can occur with infiltration rates below 0.4 ACH.

HEAT GAINS

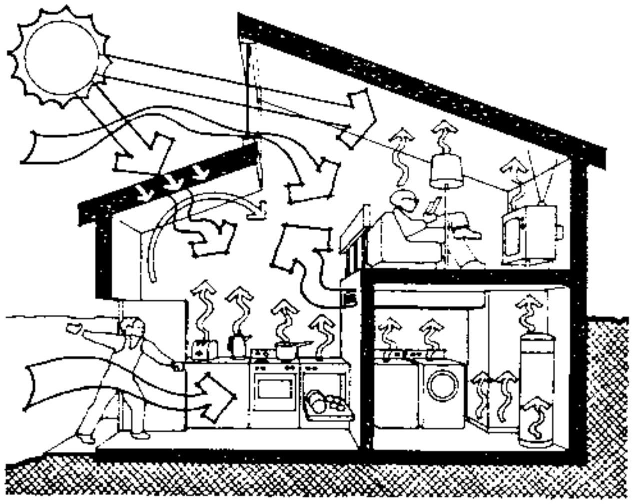
Heat gains in winter include solar (intentional and otherwise), conventional home heating equipment such as a gas furnace (called "auxiliary heat"), and what are called "internal gains" (FIG 1-22). Internal heat gains are due to the actual operation of the home, and come from lights, appliances, cooking, bathing, and from the body heat of the occupants themselves. Internal gains for a typical family of four can amount to as much as 80,000 btus per day. Internal heat gains are free btus in a sense, since this heat is really a by-product of some other process.

SOLAR HEATING

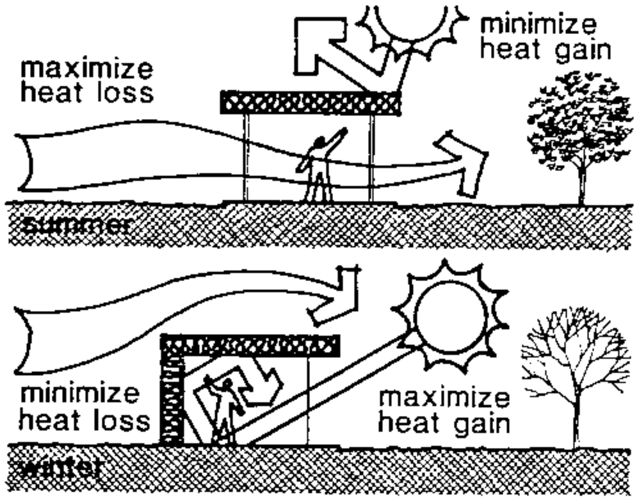
Another source of "free" energy is the sun (free in the sense that there are no ongoing fuel costs). Every btu gained from the sun is one less btu that must be supplied by the furnace or other auxiliary heating unit. Obviously, a most important factor in an energy efficient house -- solar or otherwise -- is minimum winter heat loss. It is folly to build a loose, poorly insulated house, with the idea of letting solar energy make up the difference. A solar house should begin as a well-constructed, well-insulated house. This will insure maximum benefit from every square foot of solar window.

SOLAR DESIGNS

There are an infinite number of ways to achieve a useful heat gain from solar energy. The most practical of these tend to group themselves into categories according to details of energy collection, storage, and transport. The first broad distinction between types of solar heat systems are the so-called active and passive types. The classical definition of a passive solar system is one in which all energy flows are caused by natural forces. Active systems, on the other hand, are usually characterized by the use of pumps or fans to aid in the transport of energy.



1-22 SOURCES OF HEAT GAIN



1-23 PASSIVE SOLAR PHILOSOPHY: DESIGN WITH NATURE

Between these two pure classes are "hybrid systems", which use some elements of both types.

PASSIVE SOLAR SYSTEMS

Purely passive solar energy systems operate independently of any outside power source other than the sun: the use of fans and pumps is downplayed or eliminated (FIG 1-23).

Within the class of passive systems, a number of basic types can be identified, usually based on different configurations of collection, storage, and distribution elements. There are, however, some basic characteristics common to all types.

In Nebraska, in winter, the potential for solar heat gain exists for only roughly one third of the 24 hour day. Homes, however, lose heat over the entire day. While it is a relatively easy matter to design a system which would admit the proper amount of solar energy for the immediate needs of a home while the sun is shining, the goals in a solar home should be: 1) to admit significantly more solar energy than is immediately required for space heating, and 2) to store the excess for use during the time that the sun is not shining.

The most obvious feature of a solar concious house is its unique use of glass. To capitalize on the solar energy available in the winter, substantial areas of south-facing glass are a solar standard. Unwanted summer heat gains and winter heat losses are avoided by the reduction of the number and size of windows on the west, east, and north.

The storage medium in a passive system is called "thermal mass". It is usually a material which is capable of storing large quantities of heat in a relatively small volume without becoming excessively hot, i.e., a substance with high specific heat properties. Concrete, brick, masonry materials, and water are commonly used as thermal mass. The function of thermal mass in the system is to absorb excess solar energy during the day, store it as heat, and release it to the air when the inside room temperature begins to fall. Thus, thermal mass inhibits, or "damps out" temperature fluctuations in the air.

In a successful solar house, the glass area and the thermal mass work in harmony. One is of limited use without the other.

SOLAR PERFORMANCE

There are a number of quantitative measures involved in solar design. Among these are some climatic variables which affect thermal performance (heating and cooling degree-days, and outdoor design temperature). The remaining measures to be discussed are calculated values which describe various aspects of thermal or solar performance.

HEATING DEGREE-DAYS

A home in a cold climate will lose more btus of heat through a winter season than will an identical home in a more moderate climate, because of the larger average temperature difference between inside and outside for the cold climate house. The larger the average temperature difference, the faster the rate of loss. Thus, the performance of a particular solar design is very dependent on its geographical location and related climate.

One of the most common and useful measures of winter climate is that of heating degree-days (FIG 1-24a). Assume the average temperature over a one day (24 hour) period in Ogallala is 12°F . To maintain living space at 65°F (ignoring internal gains), heat must be supplied to sustain an average temperature difference of 53 degrees for one day. In weather terminology, this translates into 53 degree-days of heating for that day. The degree-day values for each day in a month are totaled to derive the degree-day total for that month. Degree-day totals for an entire heating season can be similarly calculated. (Temperatures above 65°F are ignored for these calculations, since under such conditions, no heating is needed). Monthly and heating season degree-day tables listing values which are averages over a number of years for various locations are available (Appendix 2).

From these it can be seen that even within Nebraska the severity of winter climate varies considerably (FIG 1-25).

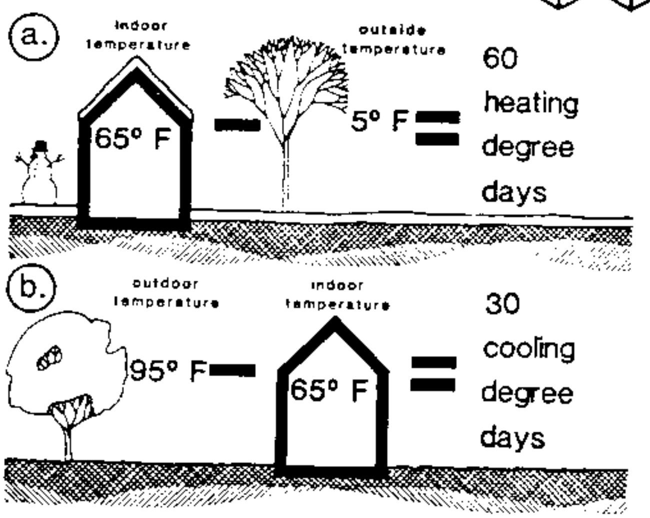
The 65°F indoor temperature in the example is called the "base temperature" for the degree-day calculations. Although other base temperatures are sometimes used, the 65°F base is most common, and will be most readily available. 65° was chosen as the base temperature because, in a typical house-family combination, the internal heat gains (which were ignored in the example) will account for about 7 degrees of indoor heating -- bringing the actual indoor temperature to 72°F. Although 72°F is historically considered normal room temperature, recent trends in lower indoor temperatures and higher levels of insulation make this approximation questionable.

COOLING DEGREE-DAYS

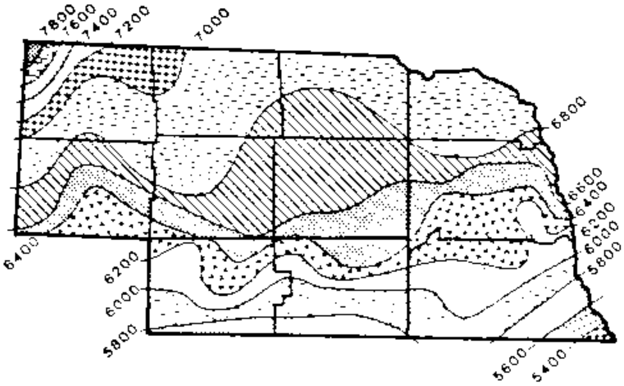
In the cooling season, the severity of the summer temperatures is specified in the degree-day format also, as cooling degree-days. Their calculation is analogous to that of heating degree-days (FIG 1-24b, 1-26).

DESIGN TEMPERATURE

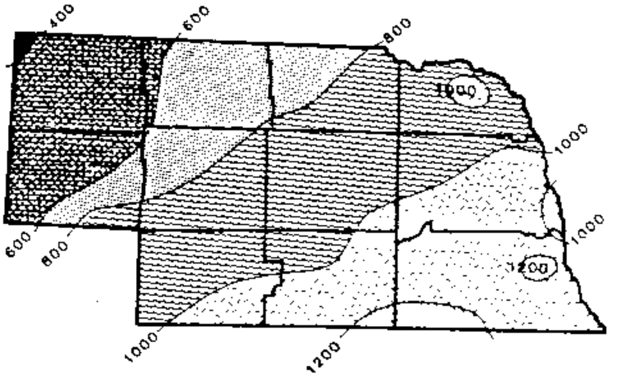
Every locale also has a specific outdoor winter design temperature, the description of how low the outdoor temperature will get with any regularity. For example, a 97.5% outdoor design temperature of -3°F for Omaha means that, on the average, the temperature will be below -3°F only about 2.5% of the time during the heating season.



1-24 DEGREE DAY



1-25 NEBRASKA HEATING DEGREE DAYS



1-26 NEBRASKA COOLING DEGREE DAYS

FUNDAMENTALS

BUILDING LOAD COEFFICIENT (BLC)

Sometimes called heating load coefficient (HLC), the building load coefficient (BLC) is a measure of how easily the structure loses heat. It is the number of btus lost by the house per degree-day, or btus per day per degree temperature difference between inside and outside. From this number, the total number of btus lost in a month or season can be found by multiplying by the total degree-days for that month or season.

DESIGN HEATING LOAD (DHL)

The design heating load (DHL) is the number of btus lost from a building per hour, when the outdoor temperature is at the outdoor design temperature. Because heat must be replaced at the same rate at which it is lost in order to maintain a constant indoor temperature, the design heating load is used to specify the size of the furnace or other heating unit in a conventional home.

LOAD-COLLECTOR RATIO (LCR)

The load collector ratio (LCR) is a measure of how much of the building load must be handled by each square foot of solar glazing. It is the ratio of the building load coefficient (BLC) to the number of square feet of solar aperture, i.e., solar windows.

SOLAR HEATING FRACTION (SHF)

The solar heating fraction is the fraction of the building's heating requirement supplied by the solar system over a specified period -- usually a month or an entire season. The use of the solar heating fraction (SHF) has fallen in disfavor in some circles because the solar system is credited for offsetting a heating load for which it is partially responsible. That is, adding solar glazing to a home will normally increase the heating load, due to the increased glass area of low R value. The solar gains from a system must compensate for these losses, in addition to offsetting part of what would be the load of a non-solar house. If a solar system only provided enough heat to offset its own losses, it would still get credit for a significant SHF, although the home owner is no better off than with an equivalent non-solar house.

SOLAR SAVINGS FRACTION (SSF)

A more accurate measure of solar performance is the solar savings fraction (SSF), which specifies the fraction of auxiliary heat (from furnaces or other space heating units) which is saved in the solar house, in comparison with an identical house with the solar glazing replaced by a thermally neutral surface (one through which no heat is lost or gained).

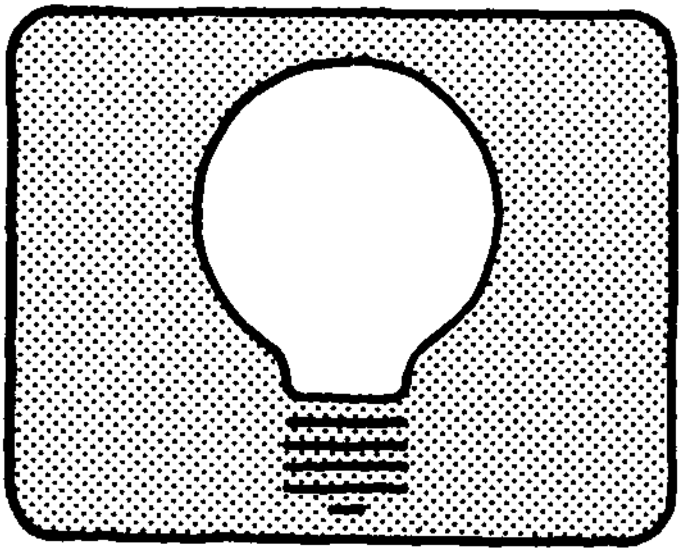
The strength of this measure is that a comparison is made with an identical non-solar house. In this case, if the solar system were able only to offset its own losses it would be the equivalent of a neutral surface; the solar and non-solar homes would have identical performance, thus leading to a solar savings fraction of zero for the "solar" house.

THERMAL INTEGRITY FACTOR (TIF)

In the final analysis, that solar house is best which demands the least auxiliary heat, and a measure of auxiliary heat requirements is needed to be able to compare houses of different sizes and in different climates. The thermal integrity factor (TIF) is a measure of the number of btus of auxiliary heat required per hour for each square foot of floor area in the house, for each degree-day of heating requirement. The real strength of this measurement is that direct comparison between solar and other energy efficient but non-solar houses (earth sheltered, super-insulated, etc.) can be made directly.

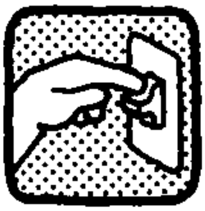
CHAPTER 2
DESIGN IDEAS

This chapter is an examination of the elements of comfort and a discussion of various design ideas that should be utilized in a passive solar home.



2.1 COMFORT

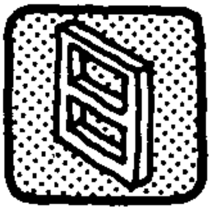
2.2 CONSERVATION



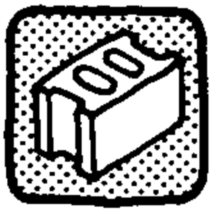
2.3 SITE PLANNING

2.4 INSULATION

2.5 WINDOWS

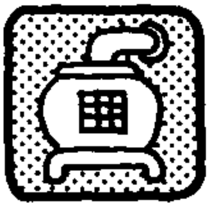


2.6 MASS



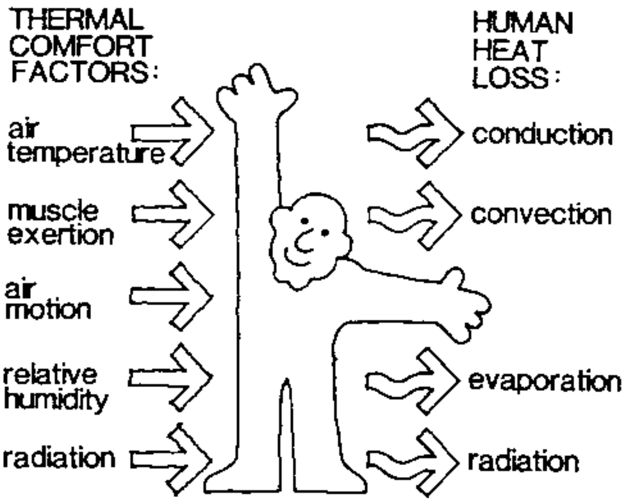
2.7 VENTILATION

2.8 MISCELLANEOUS



COMFORT

One of the primary functions of a well-designed house is to provide comfortable living space for its occupants and, therefore, it is important to look closely at the concept of comfort and some of the factors that influence how it is perceived. The focus of this section is on factors that affect feelings of warmth and coolness -- thermal comfort (FIG 2.1-1).



2.1-1 HUMAN COMFORT FACTORS

The human body is a heat generator that converts chemical energy from food that is eaten in a slow, controlled burning process. The rate of burning, and thus the amount of heat produced, depends on the level of physical activity, ranging from about 300 btus per hour for sleeping, to about 4000 btus per hour for heavy work. The human body is like any other system which produces heat -- if heat is removed from the system at a slower rate than it is produced, the temperature will rise. Conversely, if heat is removed faster than it is produced, the body will cool down. It is this rate of heat removal which is of obvious concern in the perception of thermal comfort.

The body loses heat in a number of ways. One of the most important is through convection. If the surrounding still air is cooler than skin temperature, the air is heated by the skin, and convects naturally, carrying away body heat. Moving air, such as a draft or breeze, enhances this effect by moving the air away more quickly.

Another major heat loss process of the body is radiation. Because skin is warm, it continually radiates energy. This effect can be partially or completely offset by the fact that the body is also absorbing radiation given off by all surrounding surfaces because, in general, warm surfaces radiate more energy than cool ones.

Finally, a significant amount of body heat is lost by the process of evaporation of skin surface moisture. When water evaporates, it absorbs heat in order to make the change from liquid to gas. The majority of this heat is taken from the skin, cooling it. One of the body's own automatic temperature regulating systems involves the production of skin moisture (perspiration) when extra cooling is needed.

A number of related factors that influence the heat loss rates by each of these mechanisms will be examined in more detail in the chapter (FIG 2.1-2). A good house design should try to maximize these factors when they are helpful and limit these factors when they are not helpful.

COMFORT

AIR TEMPERATURE

The most obvious factor which influences thermal comfort is surrounding air temperature. Lower air temperatures increase the driving force for convective losses, since the body/air temperature difference is greater. Convective losses diminish and decrease as the air temperature rises to and exceeds the skin temperature.

BODY HEAT GENERATION

The amount of heat that the human body can or must lose in order to maintain a comfortable skin temperature depends heavily on the amount of heat produced. This heat production is mainly determined by physical activity; the air temperature required for comfort is much lower when a significant amount of activity is involved.

AIR MOTION

Convective heat loss from the skin surface can be enhanced by "helping" the natural convection. Moving air picks up heat as it contacts the skin and removes it faster than natural convection, creating a perception of cooler surrounding temperatures. This forced convection effect is desirable in warm weather, when the moving air is called a "breeze", and undesirable in the winter, when it is called a "draft".

Moving air also affects the amount of evaporative cooling. Air which has already picked up moisture is removed and replaced by drier air more rapidly than with still air. Studies have shown that a significant cooling effect can be gained from air that is moving even at an imperceptible rate -- 10' to 50' per minute (about 0.1-0.5 MPH). The optimal direction seems to be from the front and above the subject.

HUMIDITY

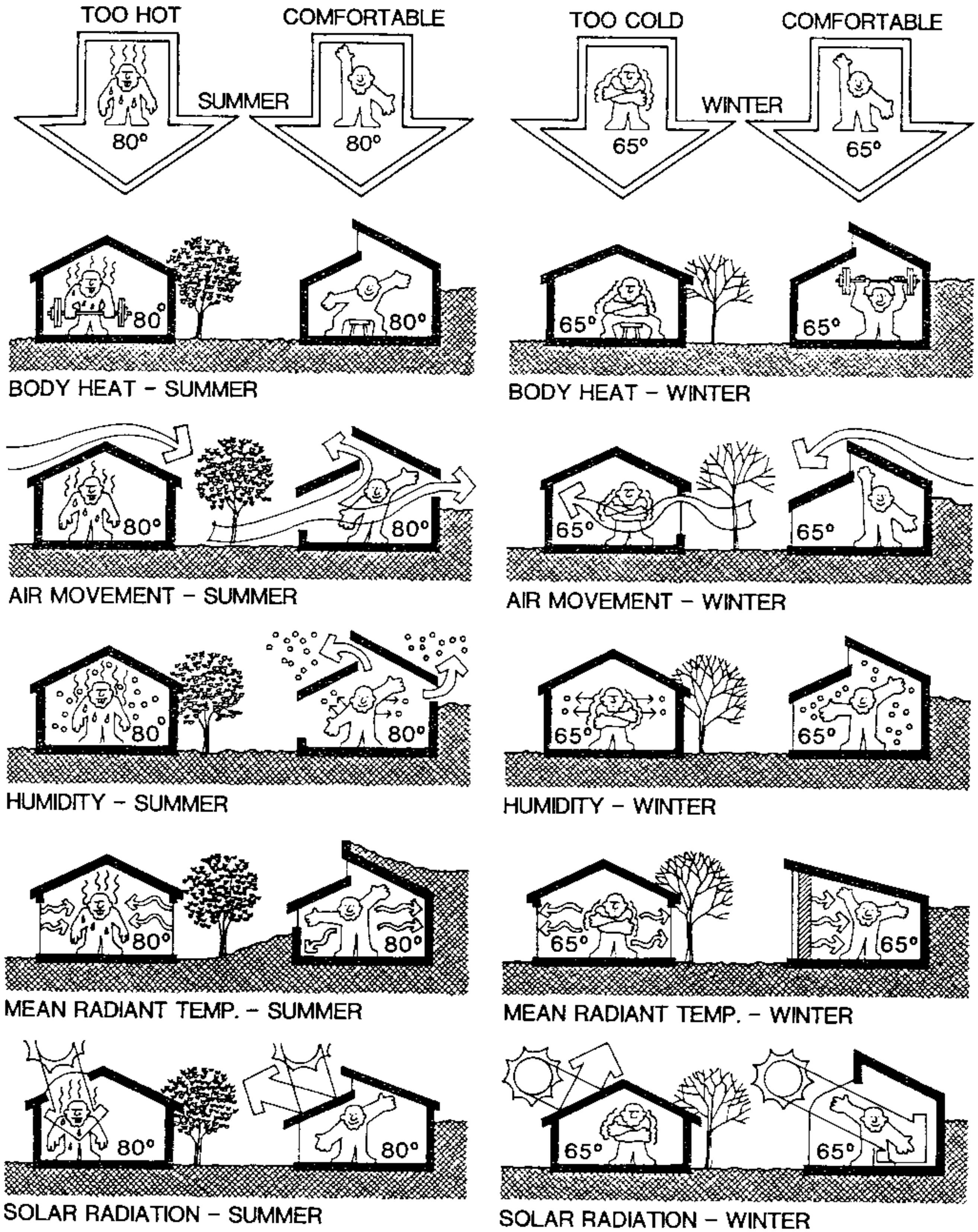
Humidity is a measure of the moisture content of air. The maximum amount of water vapor that air can hold depends on the temperature: the warmer the air, the more moisture it can hold. The relative humidity of air is the description, expressed in percentage, of the amount of water in the air compared to this maximum. For example, a relative humidity of 50% indicates that the air contains one-half the moisture that it can hold at this temperature.

Humidity affects the rate of evaporative cooling. Moisture-laden air does not readily absorb additional water vapor. Dry air, however, readily absorbs skin moisture, cooling the skin (FIG 2.1-3).

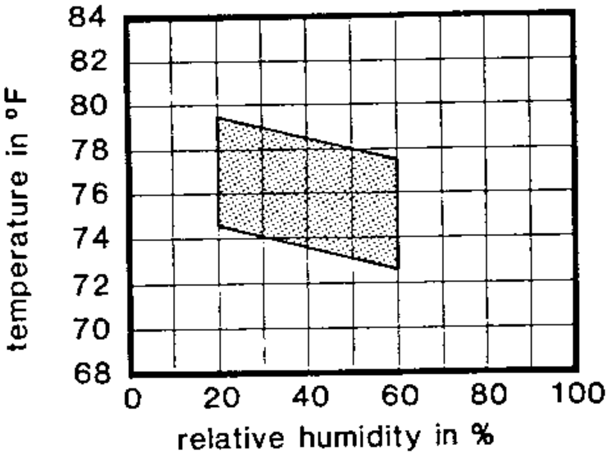
Although it would seem that a 0% relative humidity is desirable in summer, and 100% relative humidity is desirable in winter, this is not the case. Humidity values below 20% produce such problems as dry skin and hair, drying and cracking of furniture, and excessive static electricity. Very high humidity values give a "dank" or "muggy" feeling to the air. Humidity levels above 50-60%, even though comfortable, can cause winter moisture problems in the home, due to excessive condensation on windows and within walls.

In the winter months, particularly during very cold weather, indoor humidity levels can drop to a very low level, even when the outdoor relative humidity is high. This is because as outside air is heated, its total moisture capacity increases, while the actual moisture content remains the same. From the definition of relative humidity, it should be clear that the final humidity value must be lower than the outdoor value. For this reason, some sort of air humidification is a valid energy saver in the winter, as it can reduce body heat loss and thus allow a lower air temperature.

The summer months present the opposite problem in some areas of eastern Nebraska because of relatively humid summer conditions. Conventional refrigeration-type air conditioners and



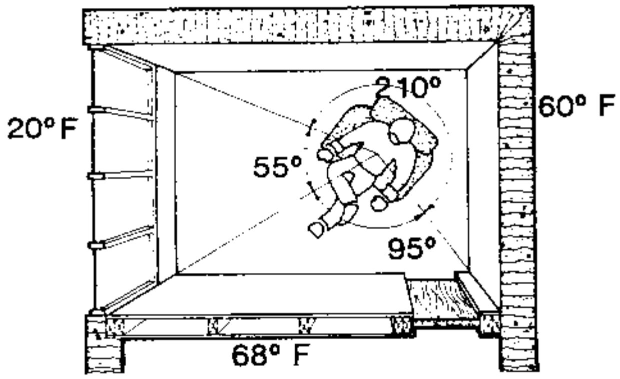
2.1-2 SEASONAL COMFORT FACTORS



2.1-3 COMFORT ZONE: TEMPERATURE VS. HUMIDITY

$$\mathrm{MRT} = \frac{210 \times 60 + 95 \times 68 + 55 \times 20}{360}$$

$$\mathrm{MRT} = \boxed{56^\circ \mathrm{F}}$$



2.1-4 MEAN RADIANT TEMPERATURE

heat pumps usually alleviate the humidity problem by cooling the outside air to well below room temperature, so that much of the water vapor condenses on the cooling coils. This cold, low moisture air is then mixed and warmed with warmer room air, so that the final relative humidity is usually within comfortable limits.

MEAN RADIANT TEMPERATURE

As discussed earlier in this chapter, the human body loses significant amounts of heat by radiation. At the same time, it receives and absorbs heat energy radiated by all surfaces around it. If most or all of the surrounding surfaces are warmer than the skin, the body may have a net heat gain due to radiation. Conversely, if the body is surrounded by cold surfaces, it will experience a net heat loss due to radiation.

This concept is quantitatively described by the mean radiant temperature (MRT). The MRT is an expression of the average temperature of the surfaces surrounding a certain point (FIG 2.1-4). The temperature of each surface which is in direct view of the location of interest is multiplied by the angle covered by the surface from that viewpoint. These products are added and divided by 360 to give the average surface temperature, weighted for the extent of exposure. In these calculations, the ceiling and floor are normally ignored, a simplification which does not significantly compromise the value of the MRT as a prediction tool.

If a room has one wall at a temperature different than the other walls, the MRT will vary according to location in the room. In a room with one cold window, for example, points close to the window will show lower MRTs due to the larger angle of exposure to the window. A similar but opposite effect would be noticed if there were a hot radiator or stove in the room.

In a passive solar house, the MRT may be raised significantly by a warm thermal mass wall on one side of the room. A mass floor or ceiling would have the same effect, although this would not affect the simplified MRT calculation.

A drape or curtain hung over a cold window will moderate the MRT effect of the cold window, as the winter covering replaces the window as the radiating surface. The window covering will normally be closer to room temperature than the glass surface.

A better treatment of the cold window surface would be some type of inside insulating device, which not only raises the MRT, but also reduces conduction losses through the glass. These insulating devices work best if they fit tightly all around the window frames. (More about this kind of window treatment later in Chapter 2).

The advantage of a high MRT in the winter is that lower air temperatures can be used. In the summer, a low MRT can allow comfortable conditions with higher air temperatures (FIG 2.1-5).

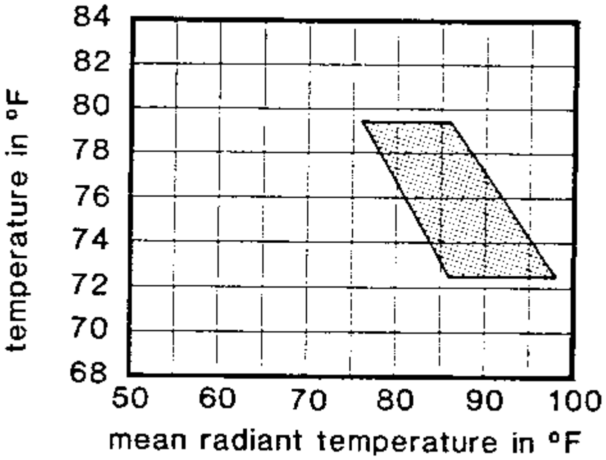
DIRECT SOLAR RADIATION

The effect of direct solar radiation on the body is, in reality, the effect of an extremely high MRT. Air temperatures of 40°F and below can feel comfortable in direct sunshine if other conditions are favorable.

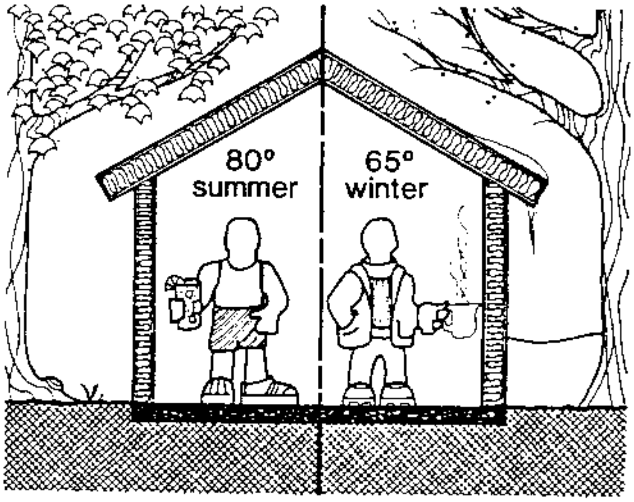
CLOTHING

Insulation helps to retain heat. Similarly, body heat can be conserved with clothes that are good insulators (FIG 2.1-6).

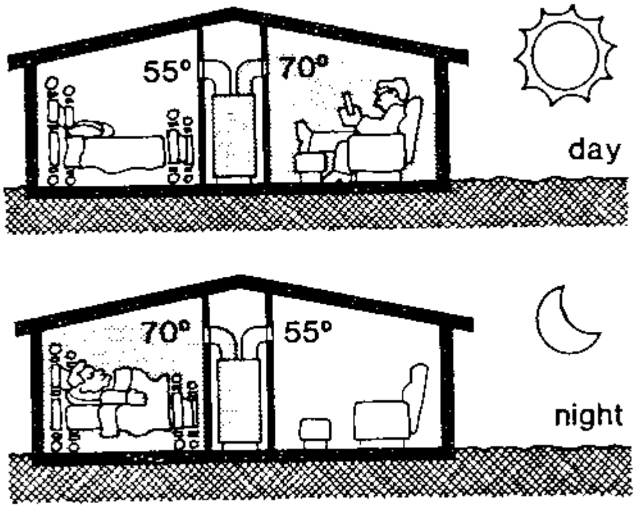
An extra sweater or jacket prevents body heat loss in several ways. First, it prevents significant convection losses by controlling air flow. Also, it drastically cuts radiation losses on parts of the body that are covered. Finally, it reduces evaporative cooling by controlling air movement next to the skin.



2.1-5 COMFORT ZONE: TEMPERATURE VS. MRT



2.1-6 DRESS FOR COMFORT



2.1-7 ZONED HEATING

TEMPERATURE ZONING

For all of the foregoing reasons, and because different areas of the home inherently are associated with different levels of activity, it seems reasonable that various areas of the home would have different temperature requirements. Kitchens, for example, are areas of relatively high activity which could benefit from a somewhat lower air temperature than a family room, where the main activity may be reading or watching television. Bedroom temperatures are subject to personal preference, but often can be lower than other living spaces (FIG 2.1-7).

Some kinds of heating systems, such as electric baseboard units, lend themselves well to room-by-room temperature control if individual room thermostats are installed. For this reason, and because they are very easy and inexpensive to install, baseboard units are a popular source of back-up auxiliary heat for solar homes. Such a system, with time-controlled thermostats, offers the most flexible programming of indoor space temperatures. Even without this type of automatic control, manual operation of thermostats and dampers in a forced air system can yield similar results.

Before investigating some of the methods used to optimize the solar performance of a house, it is important to discuss those techniques which make a house more energy efficient. All these techniques reduce the winter heating requirements of a home so that the smallest possible heating system -- whether solar, conventional, or a combination -- can be used effectively. Most of these conservation tips are equally applicable to existing homes (FIG 2.2-1).

1) Sill sealer. A sill sealer reduces heat loss between the foundation and the wood sill.

2) Weatherstripping. Air leaks around doors and windows -- even if they cannot be felt -- contribute significantly to infiltration heat losses. Replacement of damaged, worn, or missing weatherstripping can often make a noticeable difference in heating bills.

3) Airlock entry. As much as 10% of a home's total winter heat loss is due to warm air that exits every time an outside door is opened. These losses can be greatly reduced by using an airlock, or double door entry, properly designed so that only one door will be opened at a time.

4) Wall insulation. Insulation is a home's prime defense against heat loss. It is not uncommon to find older homes in Nebraska that have no wall insulation at all. This may have been a prudent and sensible way to build a home at a time when fuel was cheap and insulation was relatively expensive, but it makes no sense now.

5) Windows. Assuming reasonably well-insulated walls and ceilings, windows typically account for the largest heat-loss in a typical home. Window insulating devices are useful, particularly at night. These insulating window coverings should fit tightly all around to perform well.

6) Storm windows. Although not the optimum kind of double glazing that should be used in our climate, tight-fitting, sealed storm windows in good condition are of definite benefit.

7) Maintenance. A home cannot operate efficiently for long by itself. It is somewhat like a machine, with many parts that must work together to perform its task. Weatherstripping, caulking, siding, roofs, etc., all need periodic inspection and maintenance.

8) Caulking. Air leaking around door and window frames will bypass even the best weatherstripping -- even in brand new windows. Caulking around frames will drastically cut infiltration losses. Other areas, such as small foundation cracks, wall-piercing vents, etc. can benefit as well. A good quality exterior grade of caulking is recommended for outside work, as cheaper types will not last more than a season or two.

9) Exterior wall outlets. If codes permit, electrical outlets can be eliminated on exterior walls as outlet boxes eliminate needed insulation and also provide an easy path to the inside for infiltration drafts. An alternate measure is to provide foam outlet seals behind wall plates.

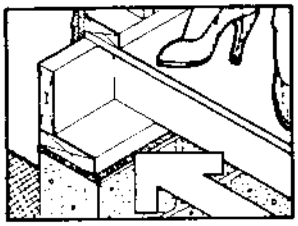
10) Special thermostats. Thermostats with a clock or timer can be set to lower the indoor temperature automatically during times when the house is empty, or during sleeping hours.

11) Tankless water heaters. Much of the energy provided to heat water in a conventional water heater is lost through the walls of the tank, from the surface of the hot water pipes, and up the flue of gas or oil models. Water heaters are available which heat the water at each point of use as it is needed. No hot water is stored, nor are long hot water pipes necessary.

12) Duct insulation. Hot air heating ducts passing through unheated areas lose heat by conduction through the duct material, or through leaks. Sealing and insulating these ducts will ensure that more hot air flows to its intended destination.

13) Attic insulation. Heat loss through the ceiling of a home is a major factor in total building loss. Many

CONSERVATION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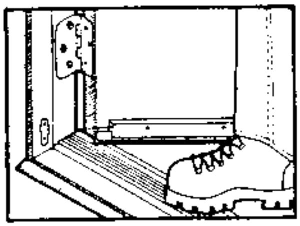
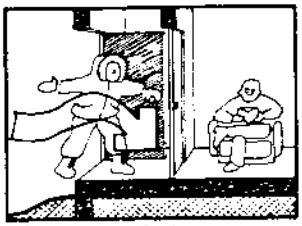
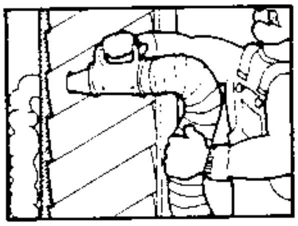
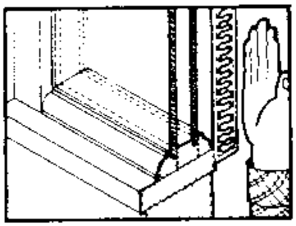
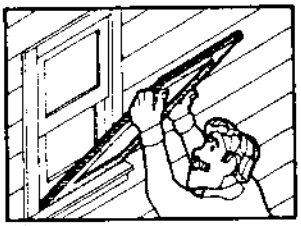
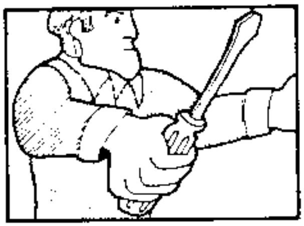

2) WEATHER-STRIPPING

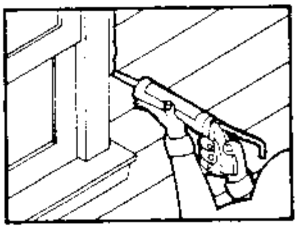

3) AIRLOCK

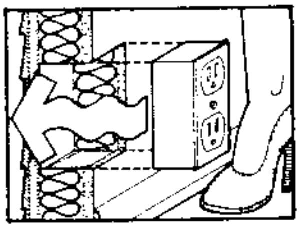

4) WALL INSULATION

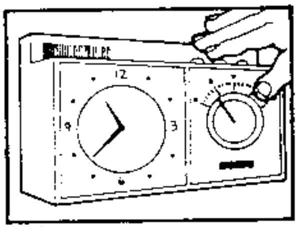

5) MOVABLE INSULATION

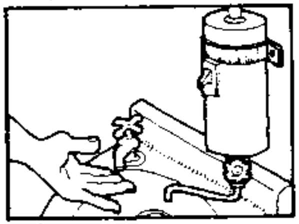

6) STORM WINDOWS

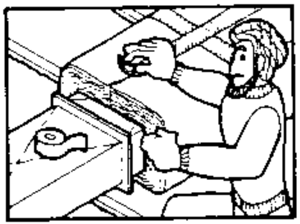

7) MAINTENANCE

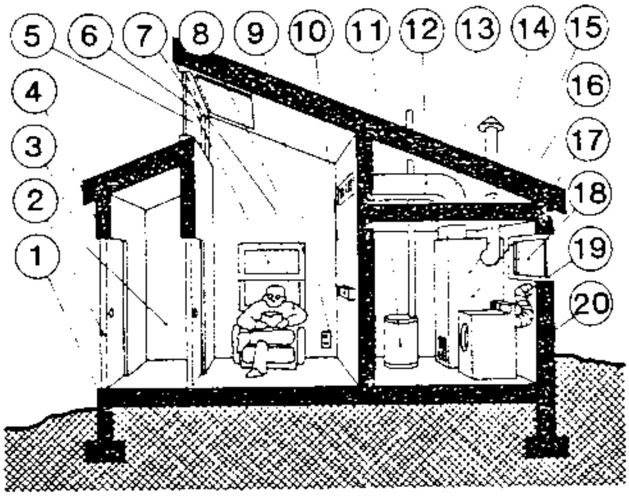

8) CAULKING


9) EXTERIOR WALL OUTLETS


10) SPECIAL THERMOSTAT

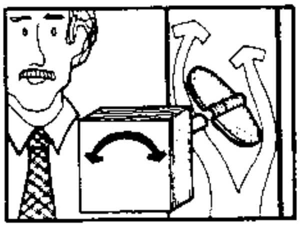

11) TANKLESS WATER HEATER

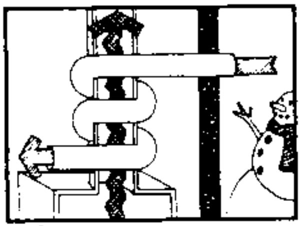

12) DUCT INSULATION

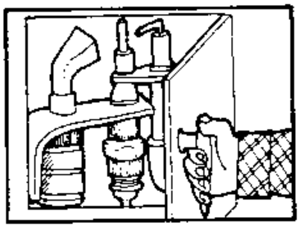


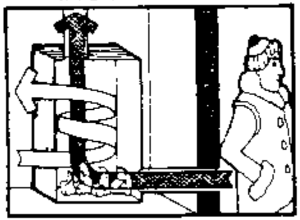
2.2-1 CONSERVATION IDEAS

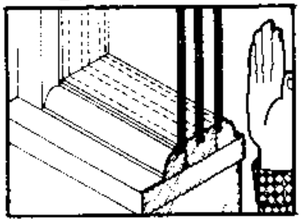

13) ATTIC INSULATION

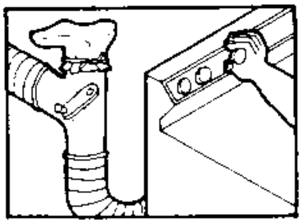

14) FURNACE DAMPER

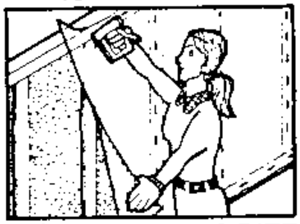

15) HEAT EXCHANGER


16) ELECTRIC IGNITION


17) OUTSIDE COMBUSTION AIR


18) TRIPLE GLAZING


19) DRYER HEAT RECOVERY


20) VAPOR BARRIER

Nebraska homes have grossly inadequate attic insulation. Many insulation contractors currently recommend a minimum R value of 40 for attic insulation. Attention to detail around the edges of the attic can also be beneficial.

14) Furnace dampers. When a gas or oil furnace is not running, warm air continues to escape through the flue. Automatic dampers which prevent this effect are relatively cheap, easy to install, and are approved in most areas.

15) Air-to-air heat exchanger. Some of the heat from hot gas or oil furnace flue gasses can be recaptured by an air-to-air heat exchanger. The same technique can be used on gas or oil water heaters.

16) Electronic ignition. Gas or oil furnaces and water heaters typically use a small continuous flame called a pilot light to ignite the main burners. This continuous use of fuel can become expensive over several months. Many newer appliances use a pilotless ignition system which lights the main burners with a small, quick electric spark.

17) Outside combustion air. The air that a gas or oil furnace, water heater, or fireplace use to supply oxygen for fuel combustion is lost up the chimney. It makes more sense to use unheated outside air instead of heated indoor air, to supply oxygen for the fire.

18) Triple glazing. Triple glazed windows are an effective measure to prevent heat loss, particularly on the north side of a house or where night insulation is impractical.

19) Clothes dryer heat recovery. Inexpensive two-way valves are available which allow the release of hot, moist air from a clothes dryer vent into the house. A lint trap should be part of the system (a fine screen or nylon stocking is often used).

20) Vapor barrier. In the winter months, the air inside a home has more moisture than outside air, due to cooking, bathing, respiration, etc. If this moist inside air gets inside an exterior wall and gets to a point near the outside where the temperature drops far enough, the moisture will condense inside the wall. Wet insulation loses much of its insulating ability, and can cause water damage to wood and other materials. A vapor barrier applied just under the inside wall covering will prevent this and will aid in infiltration control. For the vapor barrier to be most effective, all rips and other penetrations must be minimized.

Although this is not an exhaustive list of conservation techniques, it serves to illustrate what can be done to new or existing homes to maximize the use of every heating dollar.

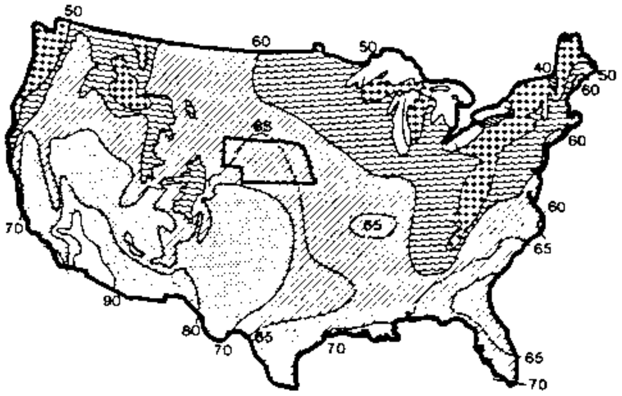
SITE PLANNING

Intelligent planning of the home site can have a dramatic effect on the thermal performance of a house, both in the heating and cooling sesons. On the large scale, the geographical location of the site dictates several important factors affecting day to day weather, e.g., mean annual cloudiness (FIG 2.3-1) and rainfall (FIG 2.3-2). On the small scale, local land contours and vegetation affect natural wind patterns and velocities, which also affect the heating and cooling of the house.

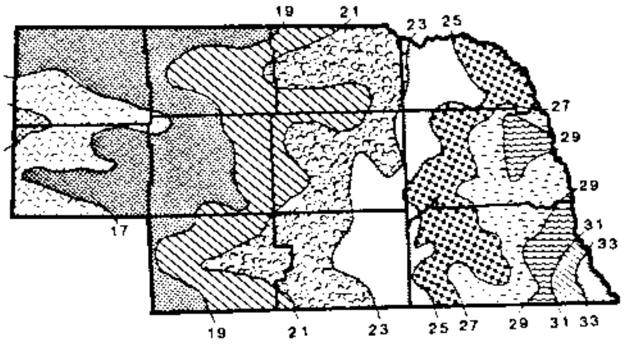
Seasonal winds in Nebraska are influenced by many factors, including the geographical layout of mountains, and tend to be either from the southeast or northwest (FIG 2.3-3).

Wind characteristics at a particular location are often described by a "wind rose". A wind rose is actually a circular graph with the various wind directions distributed around the center, with north at the top, and east to the right. The distances from the center of the graph represent average wind velocity and frequency for each direction. It can be seen that in our state, summer breezes are often from the south or southeast, while winter winds are more commonly from the north or northwest (FIG 2.3-4 and 2.3-5).

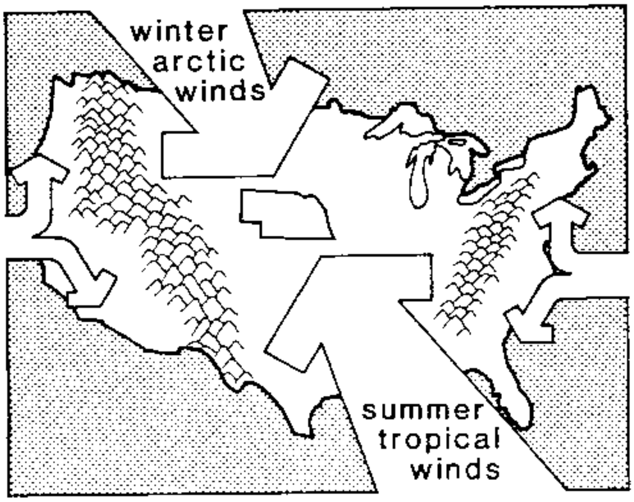
Homes in much of Nebraska, particularly in the west, can make good use of summer breezes for cooling (FIG 2.3-6). In the winter season, protection from cold north winds can reduce heating requirements, largely by cutting infiltration losses. To accomplish this, local wind patterns can be influenced by terrain features and by vegetation such as large bushes or trees.



2.3-1 MEAN PERCENTAGE OF POSSIBLE SUN

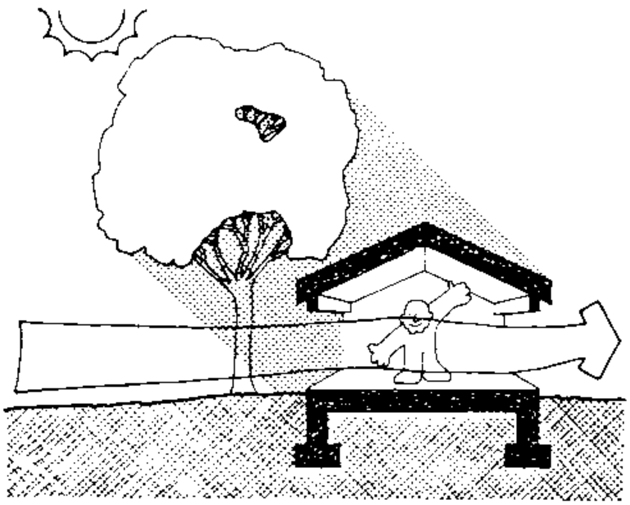


2.3-2 NEBRASKA MEAN ANNUAL PRECIPITATION

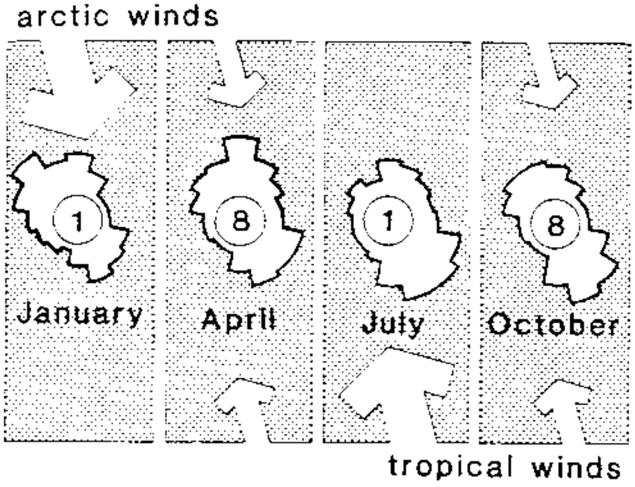


2.3-3 PREVAILING WIND DIRECTIONS

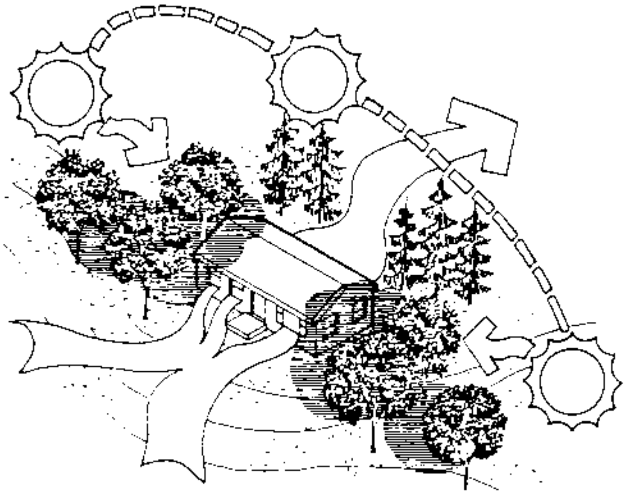
In addition to channeling and blocking wind, trees and other vegetation can be used as solar control devices. The roof and east and west sides of a building receive the most unwanted solar energy in the summer months. Summer shading of these surfaces will cut gains (FIG 2.3-7). Broadleaf (deciduous) trees should be used for this purpose since some winter gains can still be realizd through the bare branches. Note, though, that all trees are not created equal in this regard. Bare-branch densities vary widely among species, and transmit differing amounts of direct solar energy (FIG 2.3-8).



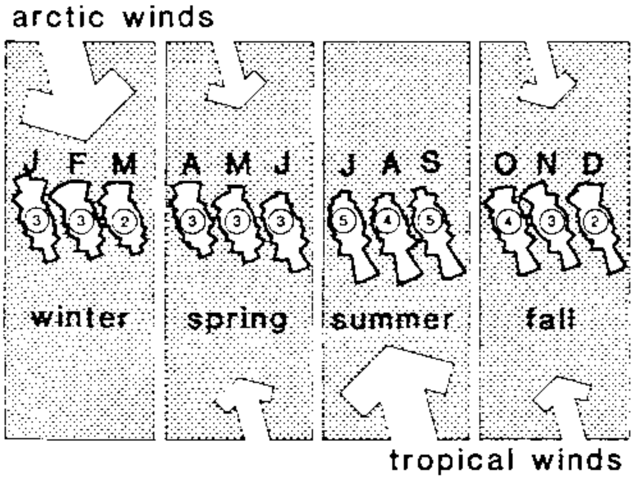
2.3-6 SUMMER SHADING AND VENTILATION



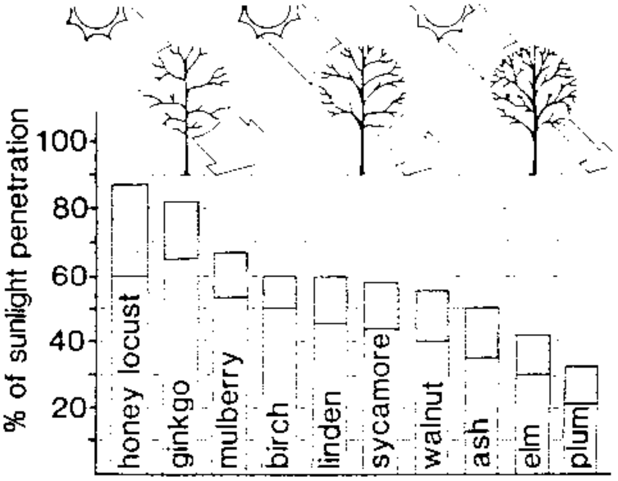
2.3-4 WIND ROSES: NORTH PLATTE



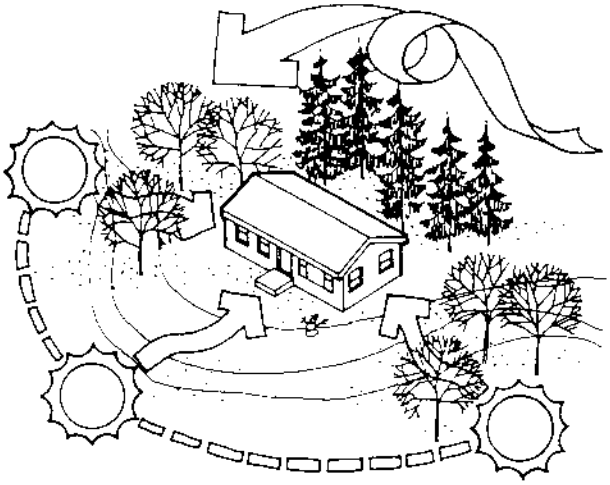
2.3-7 PLANTING STRATEGY: SUMMER



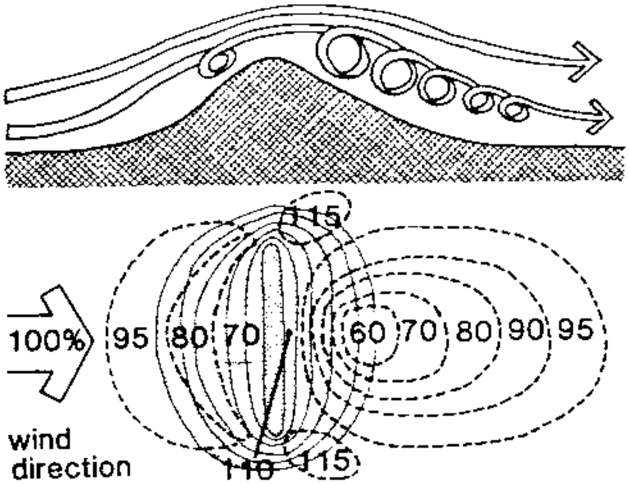
2.3-5 WIND ROSES: OMAHA



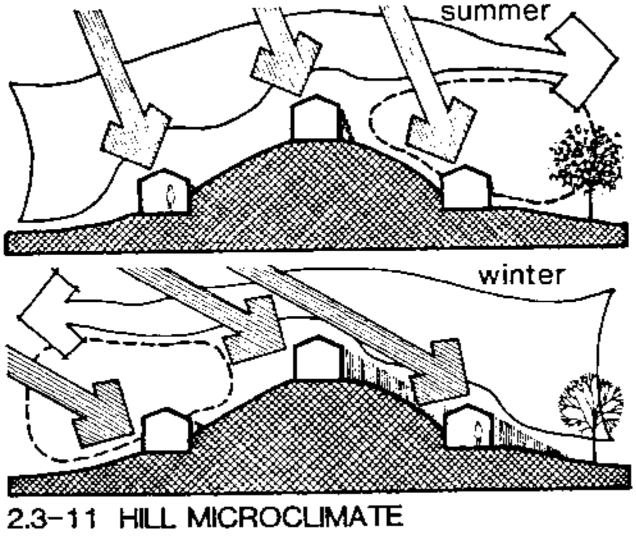
2.3-8 BARE BRANCH SUN PENETRATION



2.3-9 PLANTING STRATEGY: WINTER



2.3-10 WIND SPEED CHANGES AROUND HILL



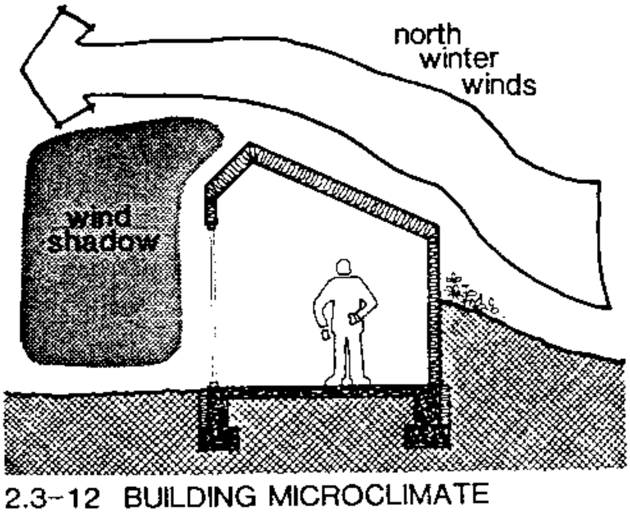
2.3-11 HILL MICROCLIMATE

Conifer trees (evergreens) can be used to advantage to block or channel cold winter winds around or over a house (FIG 2.3-9).

Building location in relationship to the local terrain is another important consideration. When wind encounters a small prominent hill, for example, a calm protected area, or "wind shadow", is formed on the opposite side (FIG 2.3-10). A house located on a south or southeast-facing slope will be situated in the winter wind's shadow, but will receive the full effects of summer breezes (FIG 2.3-11). This is also consistent with good solar placement, since a south slope is conducive to some degree of earth sheltering of the north wall, and it allows a maximum penetration of the incoming winter solar energy (FIG 2.3-12).

The concept of wind shadow is also useful in planning outdoor spaces and placement of glazing areas. Windows protected from the wind will lose less heat due to convection effects.

Another important factor in site selection is unwanted solar blockages from buildings or vegetation (FIG 2.3-13). A row of large spruce trees immediately outside a direct gain solar window may provide an attractive view but is not an example of good site



2.3-12 BUILDING MICROCLIMATE

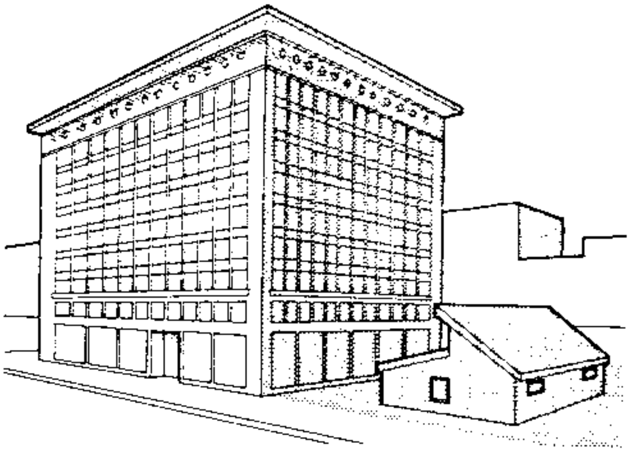
design. The future growth of vegetation should be considered as should possible construction that could affect access to solar energy.

BUILDING ORIENTATION

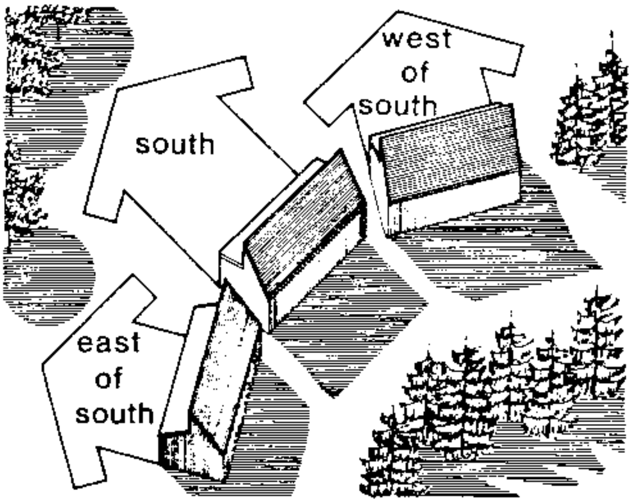
Once an appropriate building site has been selected, the next decision concerns the orientation of the building.

Although a due south-facing solar window will collect a maximum amount of energy on a clear site, some deviation can be tolerated for aesthetics or other site considerations. These other considerations include factors which may actually favor orientations other than due south, e.g., if the site receives unavoidable shade in the afternoon hours, a solar aperture facing east of south would take better advantage of the morning sun. Also, in an area where morning cloudiness or fog is common, a west of south orientation is suggested.

Of non-south orientations, east of south is preferable to west of south, to prevent summer solar gains in the late afternoon, when the house can tolerate it least. In general, on a clear site, orientations within 30 degrees of south will intercept about 90% or more of the maximum amount of solar energy (FIG 2.3-14).



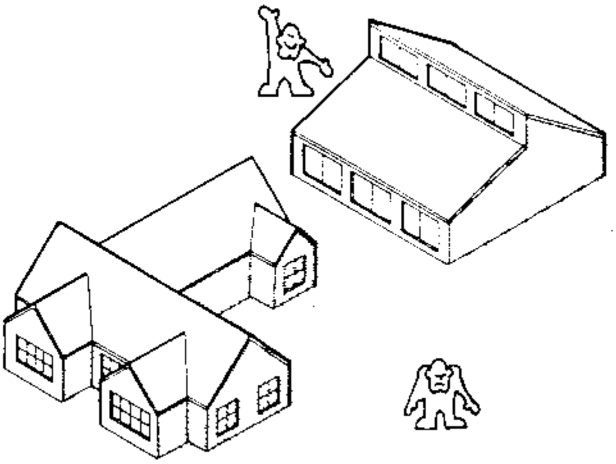
2.3-13 NOT A GOOD SOLAR SITE



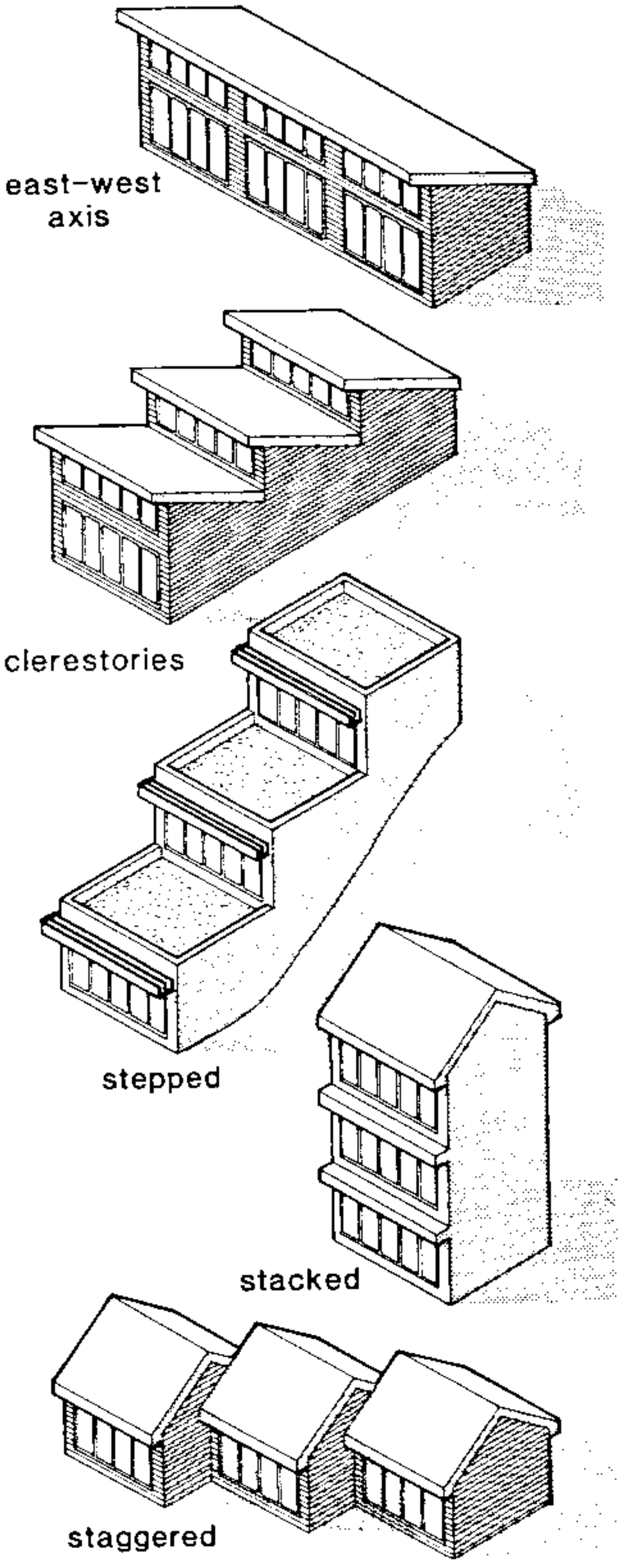
2.3-14 SOME VARIATION FROM DUE SOUTH IS ACCEPTABLE

BUILDING SHAPE AND LAYOUT

Most winter heat losses of residences are so called "skin losses", which occur through the exterior skin of the building -- exterior walls, roof, basement floor and walls, etc.; the more skin area the more heat loss. It is, therefore, important to keep skin area to a minimum to aid in controlling heat loss. Cube and square perimeter shapes offer the least surface area for a given volume. Buildings with more complicated perimeters will have larger skin areas and show larger heat flows through the skin than a structure of simpler perimeter (FIG 2.3-15).



2.3-15 MINIMIZE EXTERIOR SKIN



2.3-16 ORIENTATION OPTIONS FOR GATHERING SOLAR HEAT

This square perimeter rule can be modified a bit by including the effects of sun load on the house.

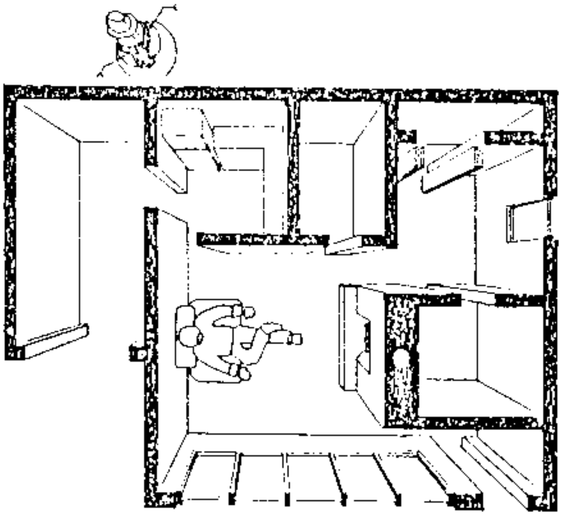
As discussed previously, of the four outside walls of a simple building, the east and west receive most of the summer sun heat. In the winter, the south receives the largest amount. Reduction of the east and west outside wall areas and expansion of the south results in year-round benefits. The optimal shape, then, is a simple rectangle with the short sides facing more or less east and west. The most effective ratios between long and short sides for Nebraska are between 1.6 and 2.4.

Alternate perimeter shapes for special terrain or site constraints might be considered, but the best rule remains to avoid perimeter twists and turns (FIG 2.3-16).

INTERIOR SPACE ARRANGEMENT

A factor that will affect the final choice of perimeter shape will be the arrangement and size of interior spaces. Although rooms should be laid out to fit particular lifestyles and tastes, additional considerations can have an impact on the energy performance of the building.

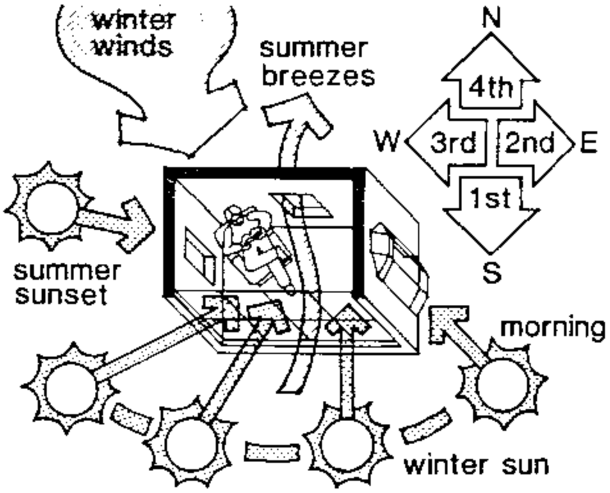
It makes good sense to locate heavily used living spaces along the south side of the house, since this area will require the most direct solar energy heat gains. Non-living spaces -- hallways, closets, laundry rooms, utility rooms, pantries, storage rooms, garages, entryways, and the like -- should be located on the north side of the house, which is generally cooler in the winter. These areas act as "buffer" spaces, in that they isolate the living spaces from the full effects of the outside temperature on the north (FIG 2.3-17).



2.3-17 BUFFER SPACES TO NORTH, SOLAR SPACES TO SOUTH

WINDOW PLACEMENT

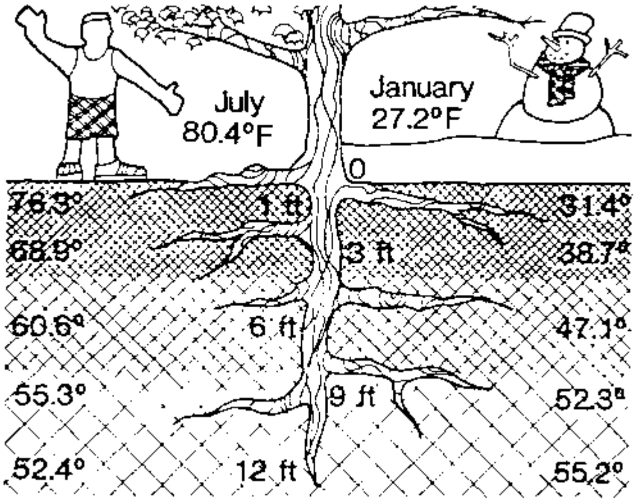
Although all windows are heat losers, some windows can provide a net energy gain by admitting solar energy. Unshaded windows on the west, east, and south have this capability. However, part-time insulating devices need to be used in conjunction with east and west windows to show a net gain. As indicated earlier, east windows are preferred to west to reduce summer cooling requirements (FIG 2.3-18).



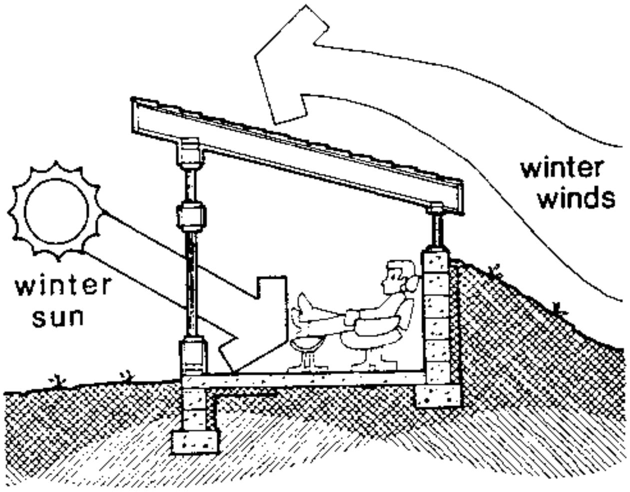
2.3-18 PREFERRED WINDOW LOCATIONS

PROTECTING THE NORTH WALL

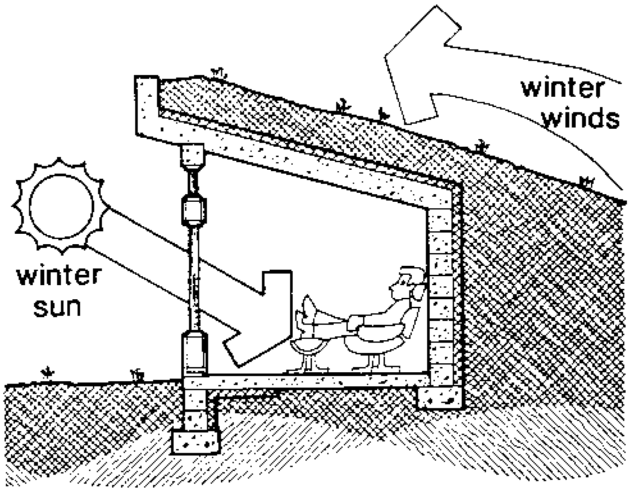
The north side of a house has the potential for the greatest heat loss of any skin surface, since it gets no direct sun for several months in the winter and is continually assaulted by cold winter winds. One effective treatment for the north wall is earth sheltering. Earth directly outside the north wall seals the wall against infiltration and diverts wind up and over the building. Another factor in the effectiveness of earth sheltering is the fact that sub-surface earth temperatures are moderate throughout the year (FIG 2.3-19). Structures that are



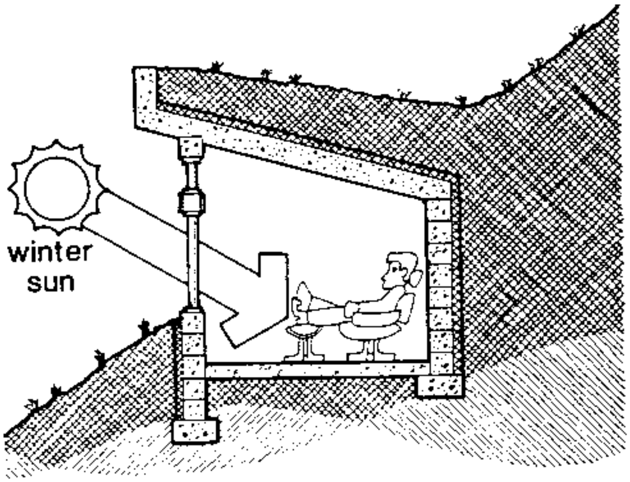
2.3-19 SEASONAL NEBRASKA EARTH TEMPERATURES



2.3-20 EARTH BERMED



2.3-21 EARTH COVERED



2.3-22 BUILT INTO SOUTH SLOPE

built into the earth, rather than being bermed, take best advantage of the earth temperature effects (FIG 2.3-20, 2.3-21 and 2.3-22).

The only thing worse than a north wall -- as far as heat loss is concerned -- is a north wall with a window in it. A north window cannot even partially offset its losses with solar gains. Although building codes and aesthetics may prevent the complete elimination of north windows, their numer and size should at least be minimized. Well-built, triple glazed windows should be used in conjunction with part-time window insulating devices.

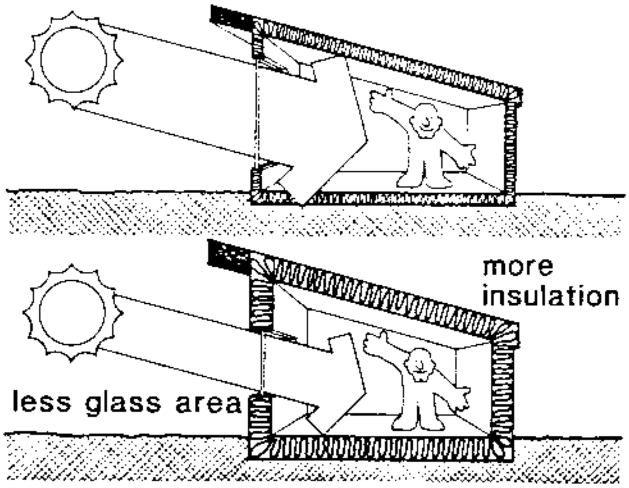
INSULATION

Insulation is the primary means of reducing conduction heat loss in the home.

Insulation comes in many forms, each designed for a specific purpose, however, all insulating materials have in common a high resistance to the flow of heat. The more insulating material that heat must pass through on its way out of the house, the less heat is lost per hour; increasing insulation cuts heat loss.

In theory, a home could be built that is so well insulated that the total building heat losses could be replaced by internal gains alone, assuming, of course, that infiltration losses have been diminished. Some of these "super-insulated" houses exist, and appear to perform quite well. As with any other energy saving approach to home construction, however, economic performance is an entirely different question.

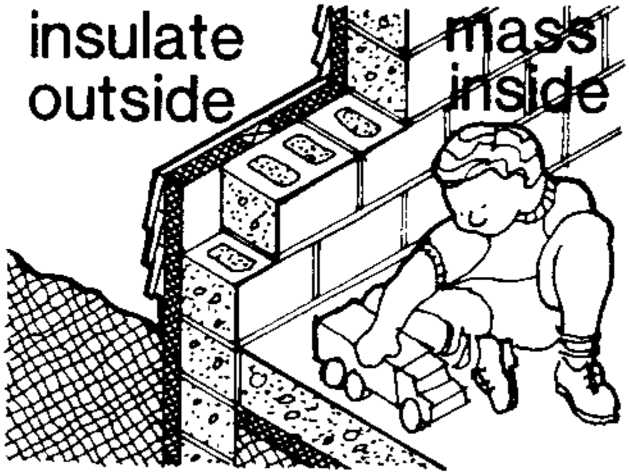
Solar homes derive a unique benefit from good insulation levels. More insulation gives lower heat loss (lower building heat load), and therefore permits smaller glass area to provide the needed replacement heat (FIG 2.4-1). Again, the optimum balance between level of insulation and solar system size is basically an economic question.



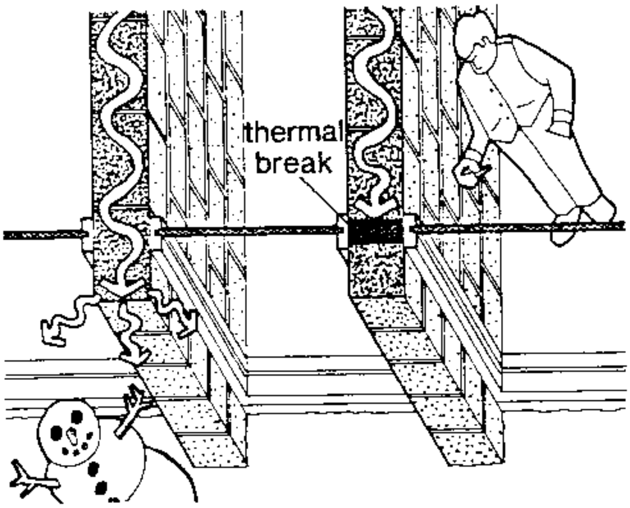
2.4-1 INCREASE INSULATION,REDUCE GLASS AREA

FOUNDATION INSULATION

One result of rising energy costs is the application of insulation where it was not considered necessary a few years ago. Insulation of foundations is an example. Significant heat loss can be eliminated by insulating foundation walls of heated basements. Since the basement walls are thermally massive, some benefit can be gained by including space on the inside of the heated space. For this reason, insulation on the outside of the foundation walls, rather than the inside, is desirable. Moisture-resistant insulation should be used in this application (FIG 2.4-2).



2.4-2 INSULATING MASS WALLS



2.4-3 THERMAL BREAKS REDUCE HEAT LOSS

THERMAL BREAK

A thermal break is an interruption of an otherwise unimpeded path for heat to flow to the outside through some building element. A good illustration is a metal window frame. Frames of solid metal provide a direct low resistance path for heat to leak to the outside. By separating the inner and outer parts of the frame with an insulating material, the heat flow is impeded. Another important location for a thermal break is in brick or concrete interior walls exposed to the outside (FIG 2.4-3).

TYPES OF INSULATION PRODUCTS

There are a number of types of insulation products, each with its own applications. Following is a description and table listing the most common types of insulation (FIG 2.4-4).

Blanket or roll. This kind of insulation is sold in widths that will fill the space between studs on either 16" or 24" centers, and in lengths of 16' to 64'. Thicknesses of 3-1/2", and 5-1/2" are available. Fiberglass is probably the most common material. The paper backing provides flanges at both edges for easy stapling to studs. Some types have a built-in vapor barrier.

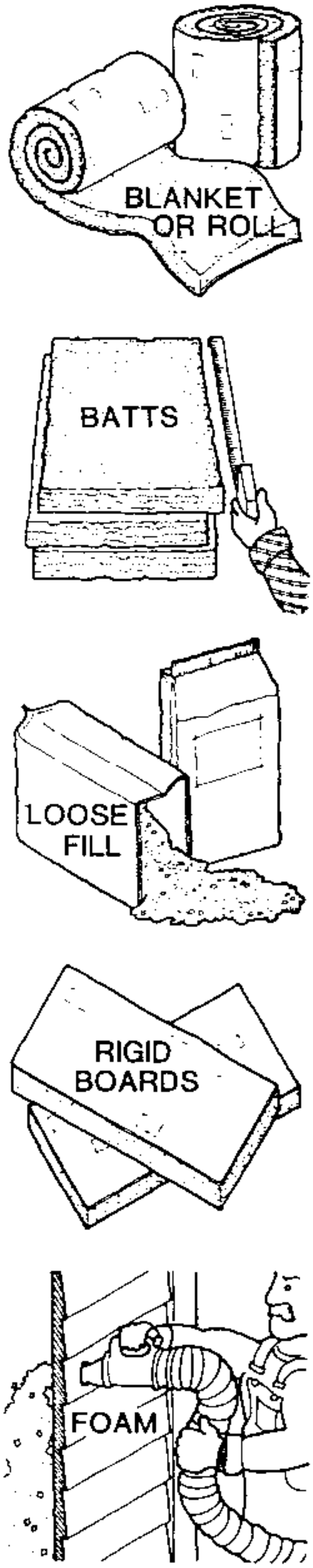
Batt. Batt insulation is blanket or roll insulation, cut to 4' or 8' lengths, which are easy to use.

Loose fill. This is loose or granular insulation packaged in bags and poured between ceiling joists or into walls. Alternately, the material can be obtained in bulk and blown in. The R value is usually specified as a "per inch" value.

Rigid board. These boards can be purchased in thicknesses from 1/2" to 4", and in sizes from 2x8 feet to 8x12 feet. They are often used as exterior sheathing under siding and waterproof types are used below grade walls.

Foam. Foam insulation is a two-part system which is applied or injected into wall cavities, where it hardens to a rigid, porous mass. It penetrates into hard-to-reach places and is a good sealing agent against infiltration. Efficient application requires experience, however, and should be entrusted to a reliable contractor.

Other unique insulation systems are beginning to appear in the marketplace. One such unconventional type of insulation consists of shredded cellulose (newsprint is one source) or other insulating medium, combined with a glue-like solution, and sprayed into wall cavities. The resulting wet pulpy mixture, correctly applied, can support its own weight until it dries to a rigid, fire-resistant insulating wall with good R value and good sealing properties.

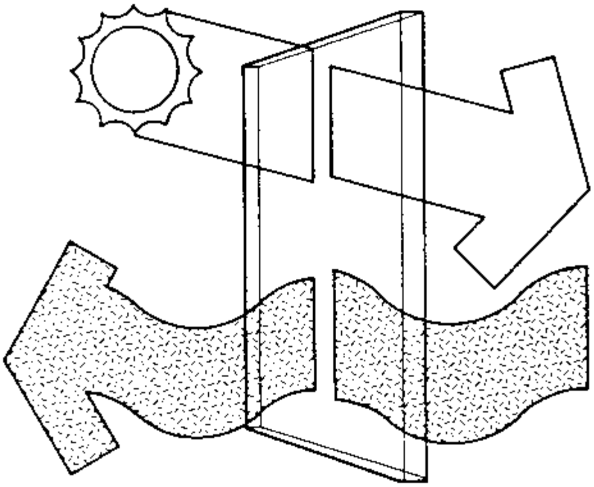


2.4-4 INSULATION TYPES

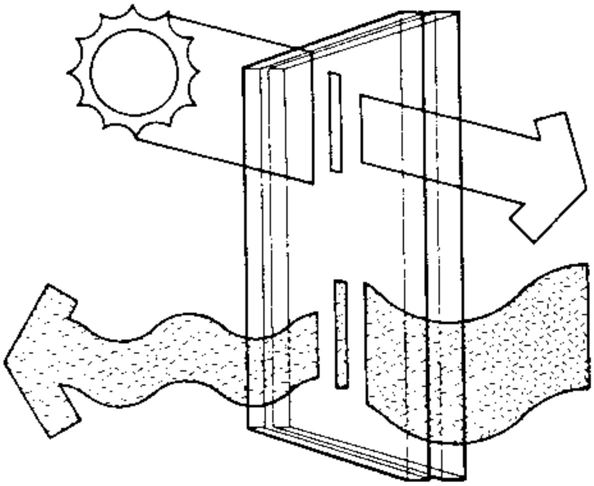
TYPES OF INSULATION PRODUCTS

MATERIALS	USE
Fiberglass Rock wool Cellulose	Walls Floors Roofs Attics
Fiberglass Rock wool Cellulose	Walls Floors Roofs Attics
Perlite Fiberglass Rock wool Polystyrene Cellulose	Walls Floors Ceilings
Polystyrene Urethane Isocyanurate Fiberglass	Walls Foundations
Urethane Urea-Formaldehyde	Walls

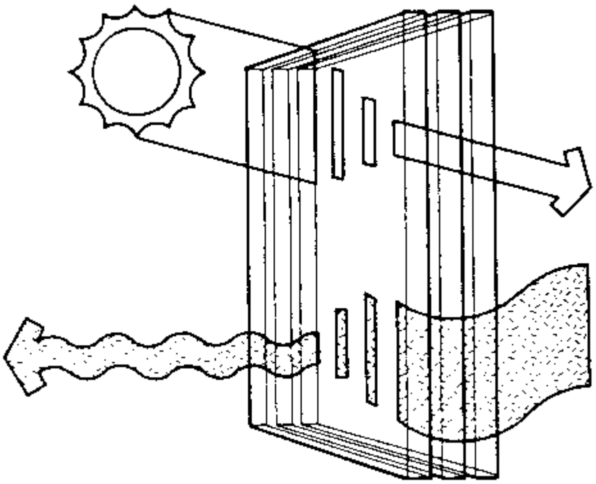
WINDOWS



2.5-1 SINGLE PANE: HEAT LOSS & SOLAR TRANSMITTANCE



2.5-2 DOUBLE PANE: HEAT LOSS & SOLAR TRANSMITTANCE



2.5-3 TRIPLE PANE: HEAT LOSS & SOLAR TRANSMITTANCE

One of the most critical choices to be made in the design of any home is the selection of windows. There are a number of issues which must be addressed before a decision can be made: site selection, cost, passive solar type, lifestyle, aesthetics, availability, and glazing material type are all factors which must be taken into consideration.

One of the first decisions to be made is the number of glazings. Should the window be single, double, triple or even quadruple glazed? With a single glazed window (FIG 2.5-1), energy is gained by the sunlight shining through the window. At the same time energy is lost back through the window due principally to conduction. Not all the sunlight falling on the window passes through. This is due to the window's tilt with respect to the sun's rays and to the properties of the glazing material itself.

When a second glazing is added (FIG 2.5-2), the energy lost to the environment is reduced, however, this is achieved at the cost of reducing the solar penetration. Triple glazing (FIG 2.5-3) shows a further reduction in energy loss but an additional loss in solar transmission occurs. In Nebraska, double glazing is the minimum recommended standard.

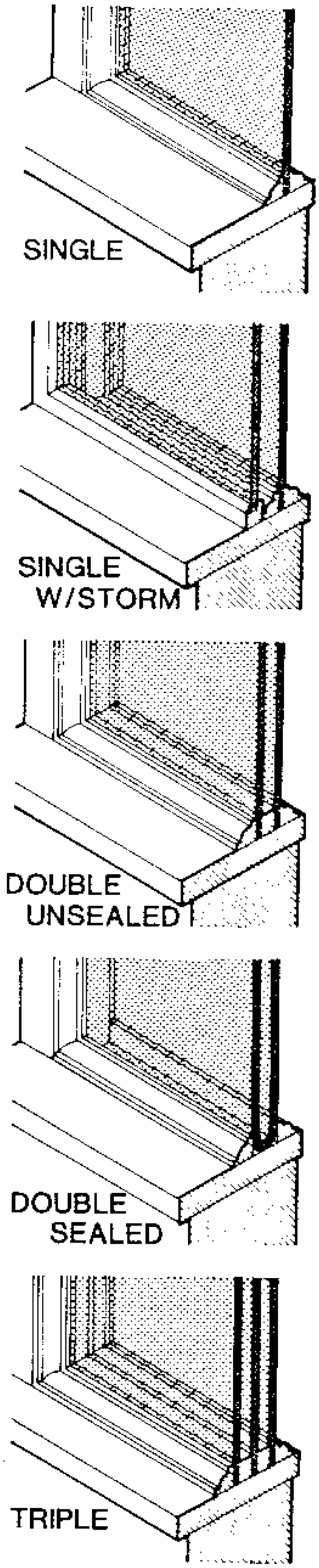
The series of drawings in FIG 2.5-4 show typical glazing arrangements. Single glazing is fairly typical in small windows. Since glass is a good conductor of heat, single glazed windows are not a desirable feature for energy efficient homes.

A single glazing with a storm window provides a dead air space. Motionless air conducts heat very poorly, and this arrangement improves the insulating value between the outdoor and indoor temperature.

A double unsealed glazing arrangement also provides a dead air space. The width between glazings is usually between 3/16" and 3/4". It is important that the width be narrow to prevent air circulation patterns from occurring, since moving air is a good conductor of heat.

The double sealed window has the advantage of preventing any outdoor or indoor air leakage into the dead air cavity between glazings. This ensures that the air space is truly dead. Some commercially-produced thermal windows contain a moisture free gas or desiccant granules to absorb moisture.

Triple glazing is now available. The extra dead airspace further improves the insulating properties of the window. For large expanses of south-facing windows without night shutters, triple glazing is recommended. For additional insulating properties, quadruple glazing is now being introduced into the housing market.



2.5-4 GLAZING

The following table of characteristics identifies the different materials.

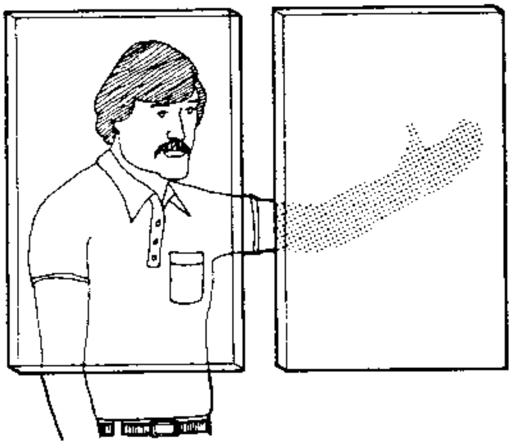
WINDOWS

COMPARISON OF GLAZING MATERIALS

	Thickness (inches)	Cost ($/ft^2)	Transmittance (lb/ft^2)	Weight	Thermal Expansion
GLASS					
Water white glass	0.125	0.99	0.90	1.60	0.47
Float glass	0.125	2.35	0.84	1.60	0.47
Window glass	0.090	1.80	0.91	1.20	0.47
FIBERGLASS REINFORCED POLYESTER					
Sunlite Premium 11 (Kalwall)	0.040	0.60	0.88	0.29	2.00
Filon with tedlar (Vistron)	-----	1.00	0.86	0.25	2.30
Flexiguard 7410 (3M)	7 mil	0.38	0.89	0.053	----
PLASTIC FILM					
Tedlar (Dupont)	4 mil	0.05	0.95	0.029	2.80
Teflon FEP 100A (Dupont)	1 mil	0.58	0.96	0.02	5.85
Swedcast 300 Acrylic (Swedlow)	0.125	0.81	0.93	0.77	4.00
RIGID PLASTICS					
Lucite Acrylic (Dupont)	0.125	1.14	0.92	0.73	4.00
Tuffak-Twinwall (Rhom & Haas)	-----	1.25 (2 layers)	0.89 per layer	0.25	3.3
Acrylite SDP (Cyro)	-----	2.15 (2 layers)	0.93 per layer	1.00	4.00
INSULATING PANELS					
Sun-lite Insulated Panels (Kalwall)	-----	2.50 (2 layers)	0.88 per layer	0.7	-----
Solar Glass Panels (ASG)	-----	2.99 (2 layers)	0.90 per layer	4.5	0.47

Ease in handling	Strength	Sheet Size	Remarks
poor	good when tempered	2x8,3x8,4x8	no degradation
poor	good when tempered	4x8	no degradation
poor	poor	4x7	fragile
excellent	very good	4' or 5' rolls	maximum temperature 300°F
very good	very good	4.25 x 16	maximum temperature 300°F
fair	good	4x150 roll	maximum temperature 275°F
fair	good, some embrittlement	up to 64" roll	4 to 5 year lifetime at 150°F
poor	fair, not for exterior glazing	58" wide roll	maximum temperature 300°F
excellent	very good	9' wide	maximum temperature 200°F
very good	very good	4x8	maximum temperature 200°F
very good	high impact strength fatigue cracking	4x8	5% reduction in transmittance over 5 years
very good	good	6x8	maximum temperature 230°F
good	good	4x8,4x10, 4x12,4x14	maximum temperature 300°F
poor	good	3x6,4x6, 3x8,4x8	very durable

WINDOWS



2.5-5 GLAZING CHARACTERISTICS

An important design consideration is the type of material used as glazing. Although glass is the most common material used, there are many other materials available on the market, including fiberglass reinforced polyester (FRP), plastic films, rigid plastics, and insulating panels. Deciding what material to use will be dependent upon cost, appearance, durability and performance. The glazing should be resistant to heat, light, and weather degradation, have a high solar transmittance, be easy to handle and install and attractive. A brief comparison of the advantages and disadvantages of each material is below. Some materials like fiberglass may not be transparent like glass (FIG 2.5-5).

MATERIAL	ADVANTAGES	DISADVANTAGES
GLASS	Rigid, chemical and weather resistant, no light deterioration	High cost, heavy weight, fragile
FIBERGLASS REINFORCED POLYESTER	Can be made ultra-violet (UV) resistant, easy to handle and install, can be cut and drilled	May have a wavy appearance, Potential thermal degradation and may require venting
FILMS	Inexpensive,high transmittance, good resistance to temperature	High expansion coefficient which can cause sagging when used as an inner glazing, can have short lifetime due to UV embrittlement
RIGID PLASTICS	Attractive, easy to handle, high impact and fracture resistant	Acrylics soften at 180°F high coefficient of expansion; polycarbonates have lower transmittance, are subject to UV degradation, and have a high expansion
INSULATING PANELS	Ease of installation	UV degradation, high thermal expansion, low transmittance when polycarbonates are used; low melting point and high thermal expansion when using acrylics

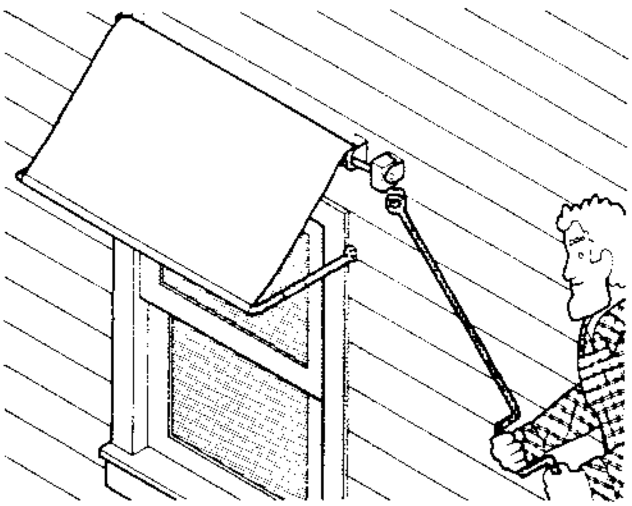
Although solar collection for space heating may be desirable in winter, it is not desirable during the summer. The use of an overhang helps to alleviate some of the problems of summer sun by blocking direct sunlight from entering the window (FIG 2.5-6). In the wintertime, however, the sun is lower in the sky and the overhang does not prevent solar penetration. Awnings provide an alternative technique for solar control (FIG 2.5-7). Movable awnings can be particularly valuable during the months preceding and following winter.

The use of insulating shutters is another way of adding insulation to windows. There are two principal types of shutters: interior and exterior.

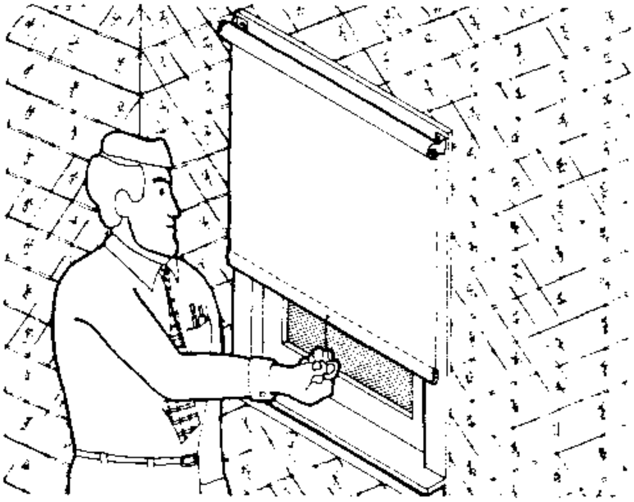
Interior Shutters

Canvas Roll Down Shade: Although they usually do not make a tight seal to keep wind out, canvas roll down shades (Fig 2.5-8) may reduce window losses by as much as 25%. An additional benefit is that they are inexpensive.

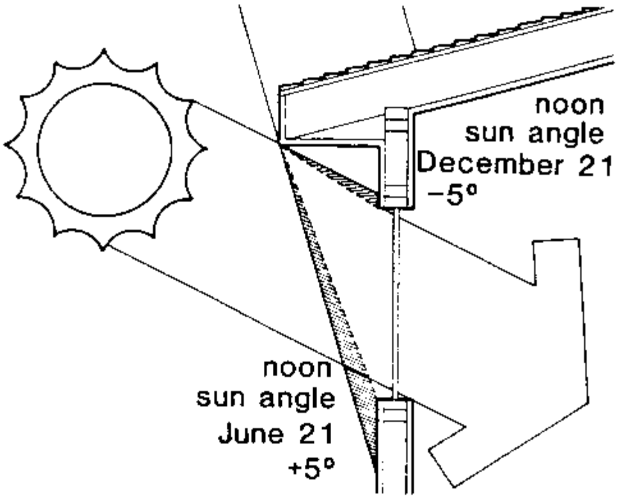
Wooden Shutter: Wooden shutters (FIG 2.5-9) may double the insulating value of single pane glass. Cost is $2 and up per sq ft. Tight fits are generally hard to achieve.



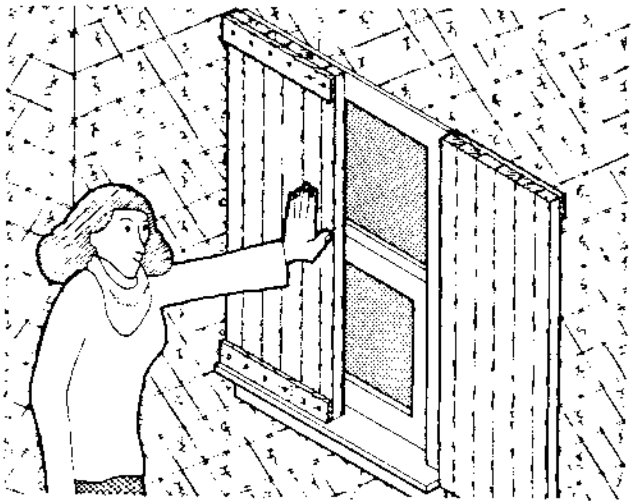
2.5-7 MOVABLE OVERHANG



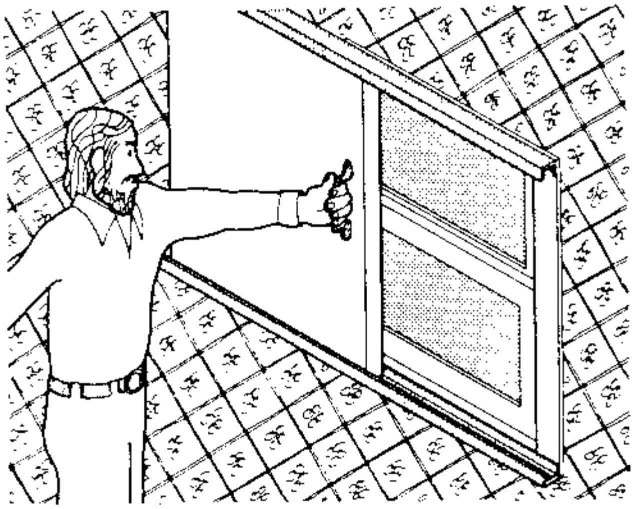
2.5-8 CANVAS SHADE: INSIDE



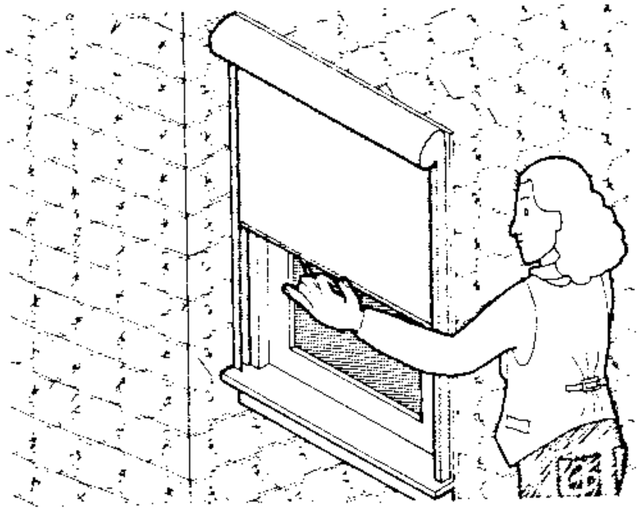
2.5-6 FIXED OVERHANG



2.5-9 WOODEN SHUTTERS: INSIDE



2.5-10 SLIDING INSULATED PANEL: INSIDE



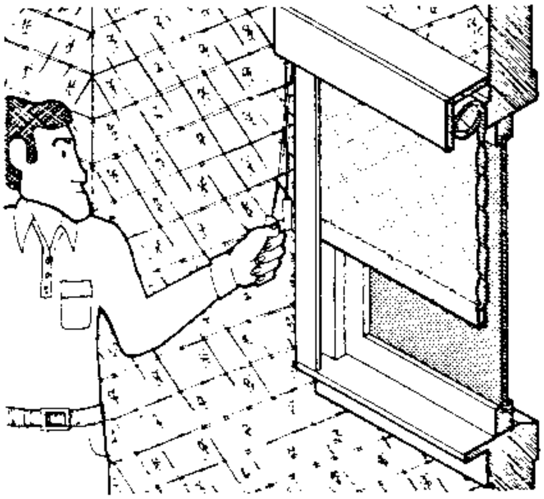
2.5-11 INSULATED SHADE: INSIDE

Sliding Insulated Panel: Depending on thickness and the material being used, sliding insulating shutters (FIG 2.5-10) can improve performance by factors up to 5 and more when compared with single pane glass. Tightness of fit may be a problem as well as flammability. An additional covering may be necessary for aesthetics. Such panels are inexpensive, approximately $1 per sq ft.

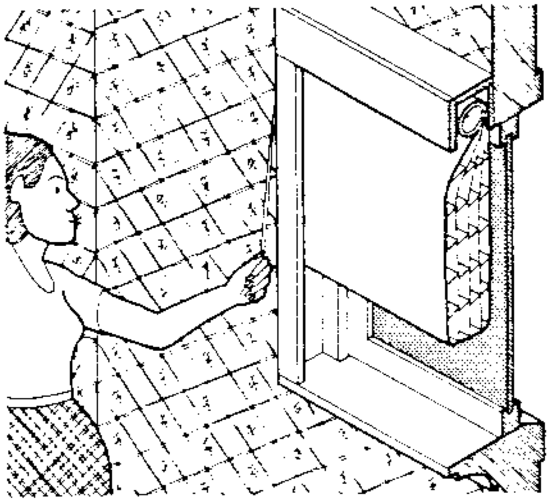
Insulated Shades: Insulated shades (FIG 2.5-11) improve insulating efficiency by a factor of 4. Such a system usually consists of a number of shades on guided tracks to provide a tight seal. Cost is typically $6 per sq ft and up.

Quilted Shade: Quilted shades (FIG 2.5-12) can improve insulating efficiency by a factor of 4. Such shades usually consist of an insulation sandwich with reflective Mylar at the center surrounded by layers of polyester batting and polyester rayon. Side tracks and weights assure tightness. Quilted shades generally cost $4 per sq ft and up.

Multiple Layer Shade: Multiple layer shades (FIG 2.5-13) can improve the insulating value by a factor of 15. The shade consists of five layers of aluminized mylar which expand to baffled air spaces when drawn.



2.5-12 QUILTED SHADE: INSIDE



2.5-13 MULTILAYERED SHADE: INSIDE

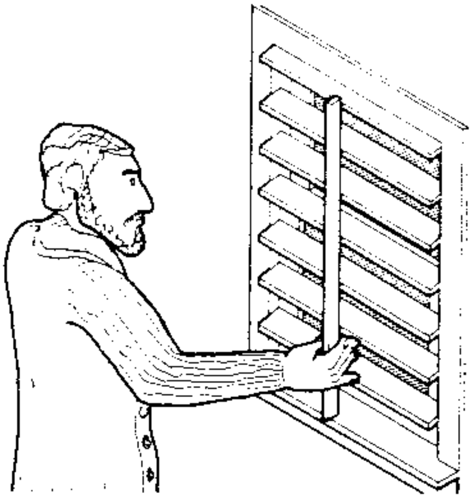
Beadwall: Styrofoam beads are blown into a cavity by means of a fan at night and are evacuated in the daytime (FIG 2.5-14). There is a central tank where the beads are stored.

EXTERIOR SHUTTERS

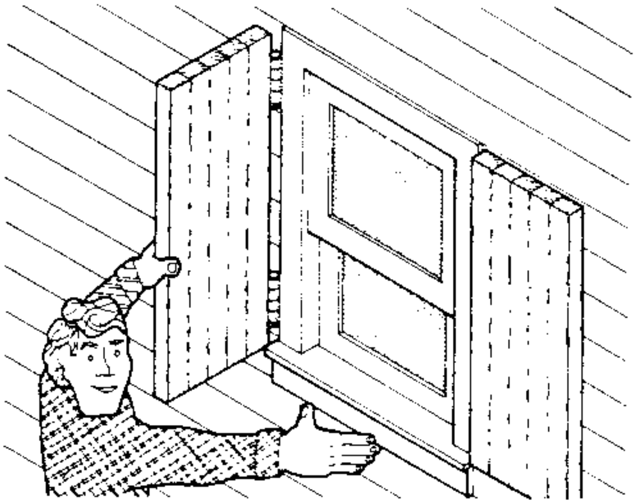
Wooden Louvers: Wooden louvers (FIG 2.5-15) can be used indoors as well as outdoors. They can be controlled to admit sunlight and fresh air. Sometimes aluminum is used as the material. Cost is approximately twice that of solid wooden shutters.

Wooden Shutters: Although tightness of fit may be a problem, wooden shutters (FIG 2.5-16) can reduce losses by one-half when compared with unprotected single pane glass.

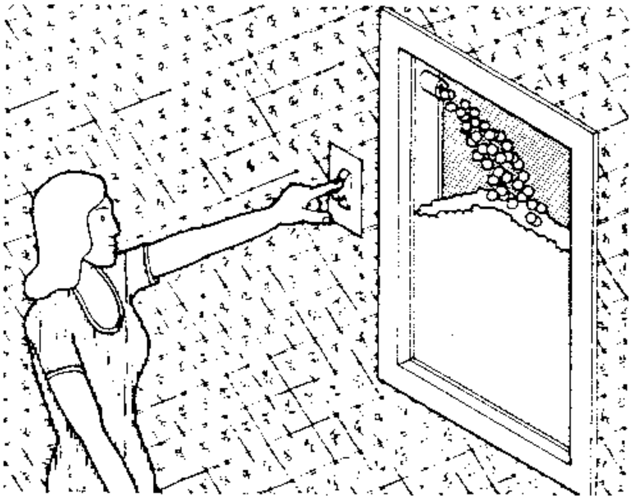
Insulated Reflector Panel: Insulated reflector panels (FIG 2.5-17) provide additional solar reflectance into the living space. The principal disadvantage may be due to snowloads and weight.



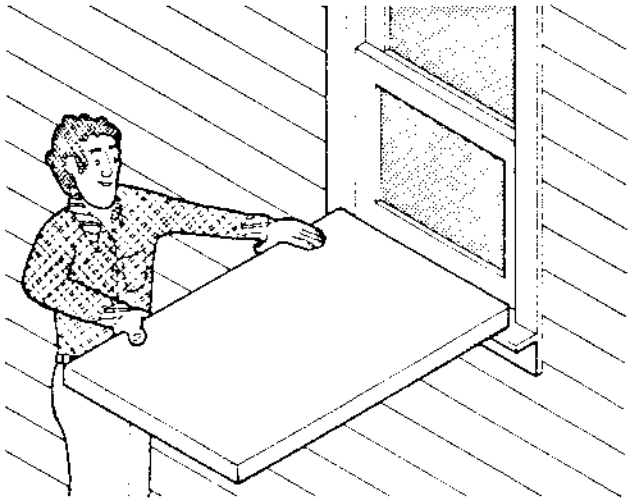
2.5-15 INSULATED LOUVERS: INSIDE OR OUTSIDE



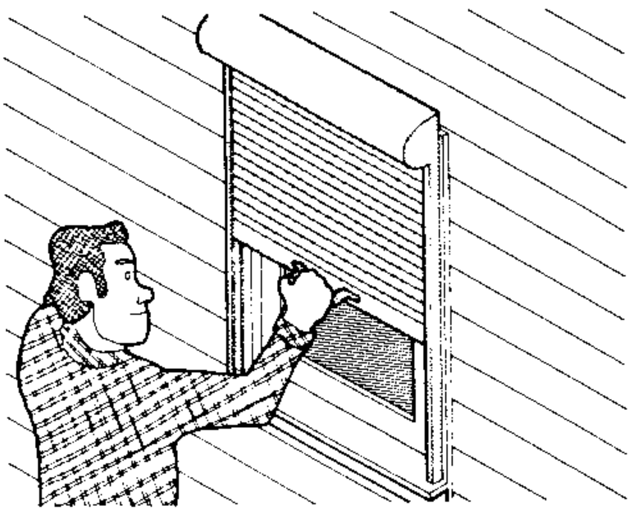
2.5-16 WOODEN SHUTTERS: OUTSIDE



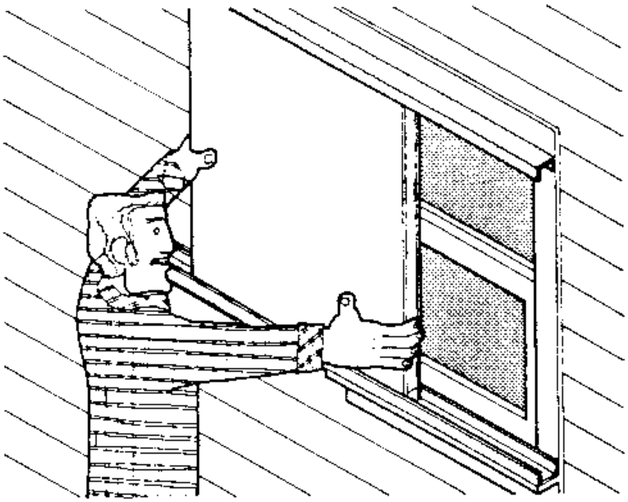
2.5-14 BEAD WALL



2.5-17 INSULATED REFLECTOR PANEL: OUTSIDE



2.5-18 ROLLING INSULATED SHUTTER: OUTSIDE



2.5-19 INSULATED SLIDING PANEL: OUTSIDE

Rolling Insulated Shutters: Rolling insulated shutters (FIG 2.5-18) have been popular in Europe under the product names of Rolladen and Roll-Awn. They are made from a variety of materials and may triple the insulation value of single pane unprotected glass. When cranked down, they provide a double air space between ambient environment and window. They can be arranged so that some light can be admitted when left in a loosely closed position.

Insulated Sliding Panels: Insulated sliding panels (FIG 2.5-19) can be inexpensive and have properties similar to interior sliding panels. The advantage to having the panel outdoors is that flammability and toxicity problems are reduced.

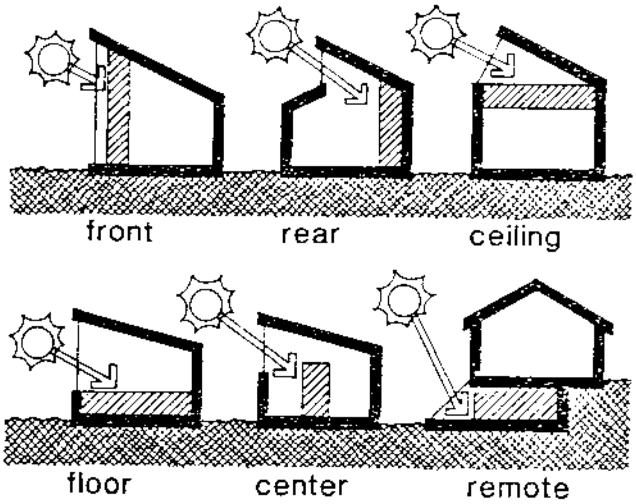
MASS

Thermal mass is an integral component of any passive solar design. Because air is not a good storage medium for heat, there is a potential problem of having a home overheat if there is insufficient thermal mass to absorb and store the solar gains. Mass can include brick, stone, block, earth, water, and phase change materials. The mass can be distributed for solar collection in a number of different ways (FIG 2.6-1).

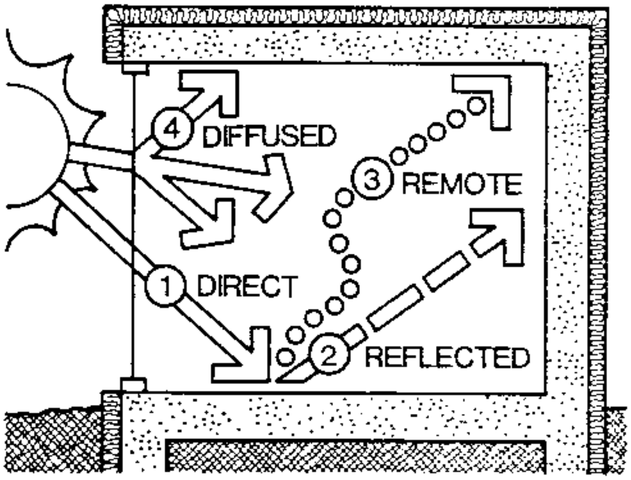
Solar energy entering a building may be absorbed by mass in a number of ways: it can be absorbed directly by a mass; it can be reflected onto a mass; sun-warmed inside air can transfer heat to a remote storage location where it is then absorbed; finally, the diffuse component of sunlight can also be absorbed (FIG 2.6-2).

Thermal lag, the time it takes heat to pass through the mass, is a characteristic of thermal mass which must be considered during the planning and placement phase. For example, it may take several hours for heat to pass through a thick masonry wall (FIG 2.6-3). This lag time is a function of the material used and its thickness. In certain instances it may be desirable to have the thermal wave delayed, e.g., to supply heat for a bedroom.

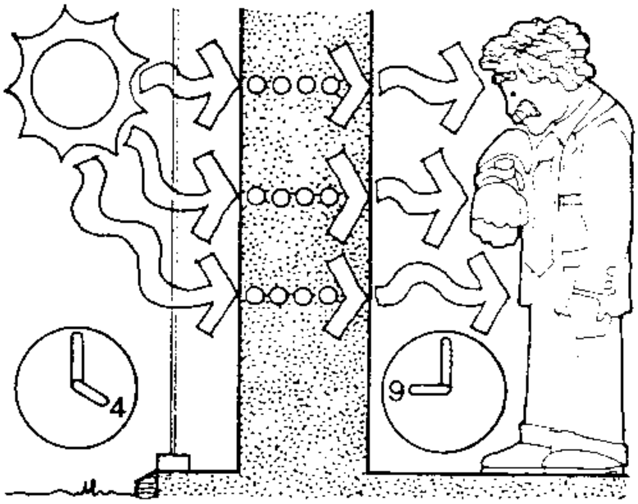
Many kinds of materials can serve as thermal mass and they can be arranged in myriad ways (FIG 2.6-4).



2.6-1 POSSIBLE MASS LOCATIONS

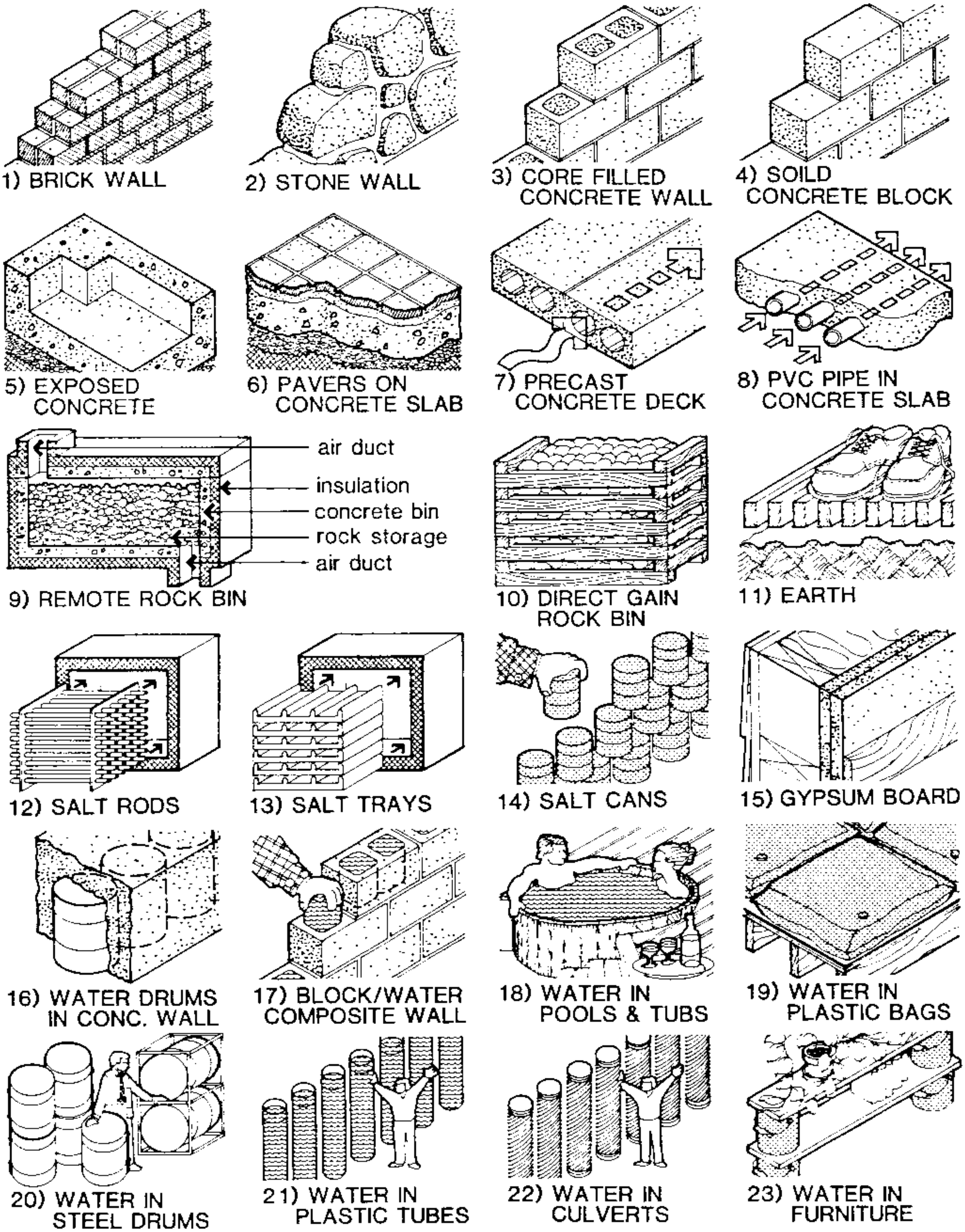


2.6-2 HOW SOLAR HEAT MOVES TO MASS



2.6-3 TIME LAG THROUGH STORAGE

MASS



1) BRICK WALL

2) STONE WALL

3) CORE FILLED CONCRETE WALL

4) SOILD CONCRETE BLOCK

5) EXPOSED CONCRETE

6) PAVERS ON CONCRETE SLAB

7) PRECAST CONCRETE DECK

8) PVC PIPE IN CONCRETE SLAB

9) REMOTE ROCK BIN

10) DIRECT GAIN ROCK BIN

11) EARTH

12) SALT RODS

13) SALT TRAYS

14) SALT CANS

15) GYPSUM BOARD

16) WATER DRUMS IN CONC. WALL

17) BLOCK/WATER COMPOSITE WALL

18) WATER IN POOLS & TUBS

19) WATER IN PLASTIC BAGS

20) WATER IN STEEL DRUMS

21) WATER IN PLASTIC TUBES

22) WATER IN CULVERTS

23) WATER IN FURNITURE

2.6-4 TYPES OF MASS STORAGE

VENTILATION

Thus far, the discussion of energy efficiency has been concentrated primarily on the heating season. Nebraska has approximately 6000 heating degree-days of heating requirement, and accordingly, the emphasis has been on heating season energy efficiency; Nebraska's 1000 cooling degree-days should not be ignored, however, because substantial summer energy savings can be realized by intelligent planning to maximize comfort and minimize the use of conventional air conditioners -- another expensive energy user.

One of the most important contributors to summer comfort is proper ventilation. Moving air, which enhances evaporative cooling of the skin, carries away body heat by convection and prevents humidity buildup in a structure. Proper site planning -- including proper shading and channeling of summer breezes -- aids all of the general natural home ventilation schemes discussed following.

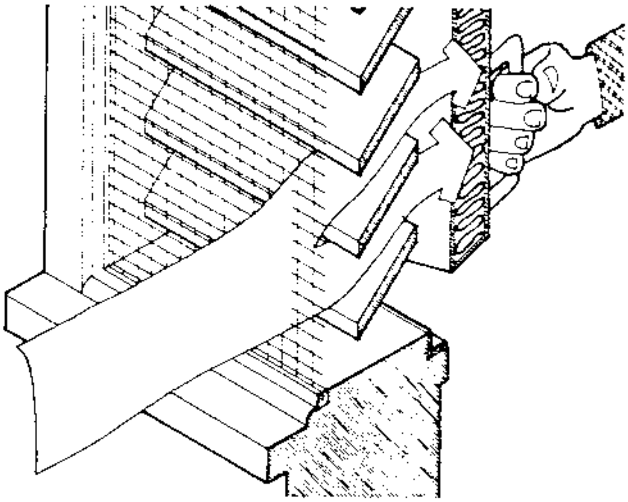
NIGHT COOLING

In those parts of Nebraska blessed with cool summer nights, a house can be opened and cooled at night, often through the use of special louvered panels. These panels are designed with fixed windows or windows that do not need to be opened (FIG 2.7-1). With the first morning heat, the panels are closed and the house otherwise sealed against hot outside air. In comparison to a conventionally-built home, a passive solar home is better suited to take advantage of night cooling since the mass can store more "coolness" than ordinary lightweight building materials. It has been known for many years that this is why some ancient stone temples and other buildings seldom need air conditioning.

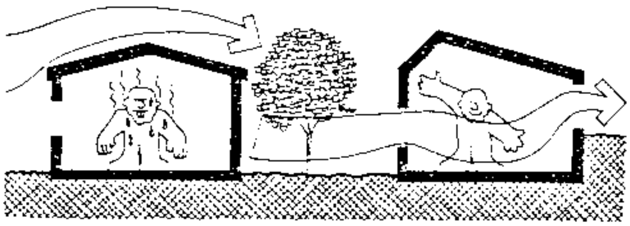
CROSS VENTILATION

Natural air flow through a house in the summer months aids in cooling for the following reasons: 1) moving air feels cooler than still air, and 2) without some airflow through a house, internally generated heat will build up to make the inside of the house significantly warmer than the outside.

Prevailing summer breezes can provide this natural air flow, if they are impeded as little as possible. An air exit as well as an entrance must be provided, preferably such that the breeze is forced to change direction as little as possible (FIG 2.7-2).

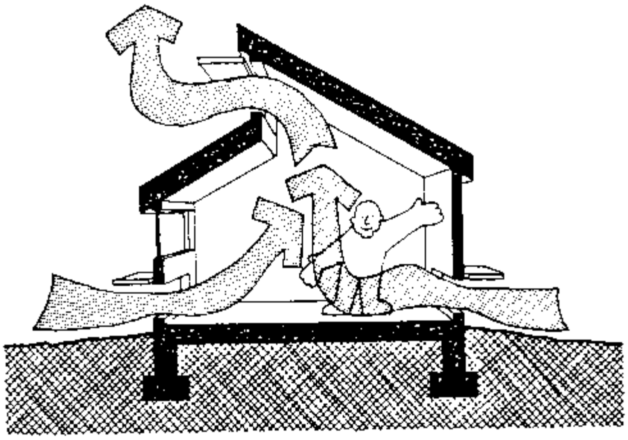


2.7-1 LOUVERED VENTS WITH INSULATED SHUTTER

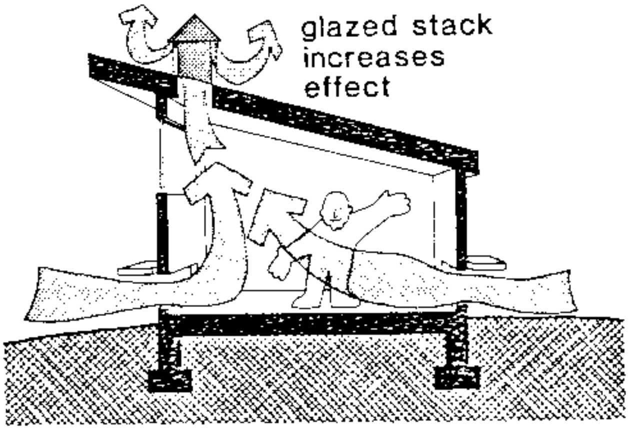


2.7-2 CROSS VENTILATION

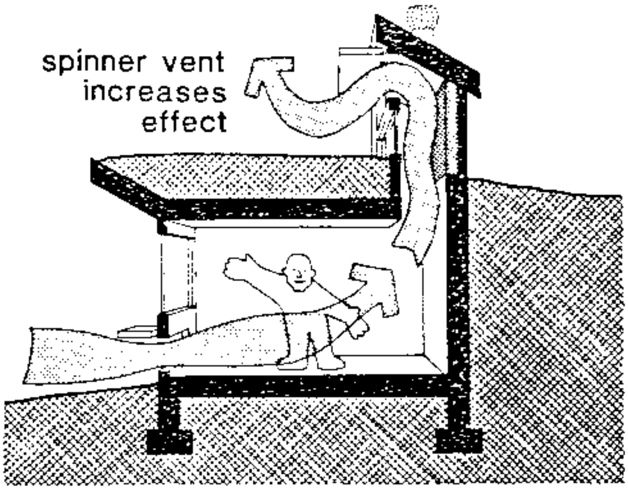
VENTILATION



2.7-3 CONVECTIVE VENTILATION



2.7-4 HEAT STACK VENTILATION



2.7-5 SOLAR CHIMNEY VENTILATION

The effect of natural cross ventilation can be enhanced by placing air exits high on the wall (since the warmest air will be near the ceiling), and entrances near ground level, where there can be some cooling of the air by ground and foliage.

CONVECTIVE VENTILATION

Convective effects can be used to drive air through a house even when there is little or no natural breeze. Inside air, heated by internal gains and the sun, rises to the top of the structure. If a vent is provided at a high point of the indoor space, the warm air will rise out of the building and fresh, cooler air will be drawn in at a lower level (FIG 2.7-3). This technique works best in homes with open, high interiors.

HEAT STACK

The convective ventilation technique can be enhanced by reinforcing the natural tendency for heated air to rise. A stack, painted black or other dark color, is mounted at the high point of a house (FIG 2.7-4) and the air within is heated to a relatively high temperature by the sun. The air rises, pulling air from the house. The effect is identical to that in convective ventilation, except that the driving force is much greater.

The effectiveness of the stack can be increased by surrounding it at a distance of 1" to 2" with a clear cylinder to prevent air from circulating around the outside of the stack. The stack will reach a higher temperature, increasing the driving force of the system.

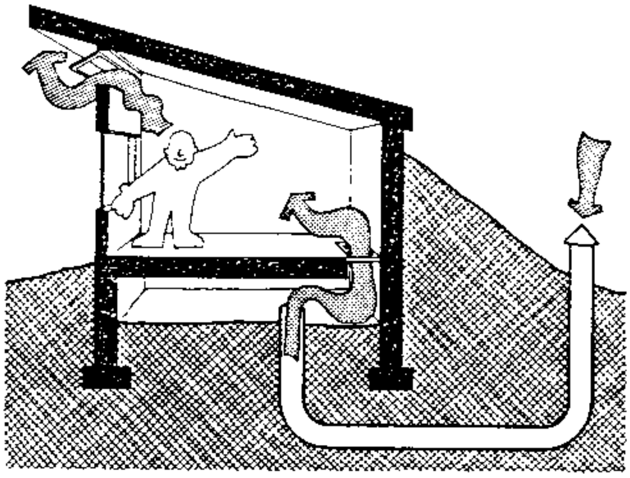
SOLAR CHIMNEY

The solar chimney is similar to the heat stack, except that the air is heated in a cavity built into the structure, rather than in a stack added to it (FIG 2.7-5). Thermal mass added to the solar chimney system will continue to vent the structure after the sun sets.

EARTH TUBES

These ventilation techniques can be augmented by the use of earth tubes. Air from a remote location is drawn through buried tubes into the building. The tubes are placed at a depth where the earth temperature is relatively cool all summer and are made long enough to reasonably cool the air before it enters the house (FIG 2.7-6).

All natural ventilation techniques discussed above can be aided further by strategically-placed fans or blowers.



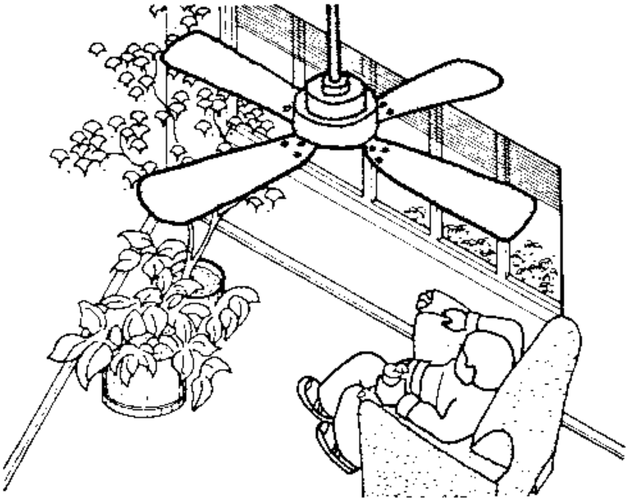
2.7-6 EARTH COOLING TUBE

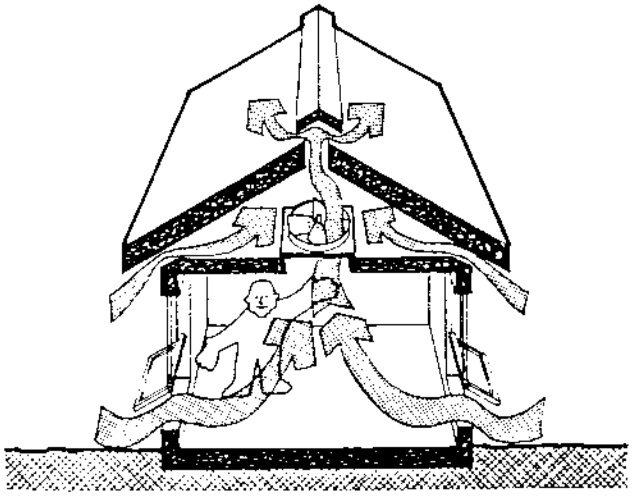
MISCELLANEOUS

MISCELLANEOUS ENERGY RELATED TECHNIQUES

FANS

Although primary emphasis has been placed on air circulation during the cooling season, air movement is also important during the heating season, although for slightly different reasons. Because warm air rises, the warmest air in a room is normally near the ceiling. Since thermostats are located below the ceiling level, air temperatures are comfortable at thermostat level and overheated near the ceiling. This results in higher than necessary heat losses and higher than necessary furnace use.


2.8-1 OVERHEAD FAN


2.8-2 WHOLE HOUSE FAN

To maximize efficiency, it is advantageous to break up this air stratification. Properly designed forced-air furnace systems can help, but only if the fan is allowed to run constantly. Even then, however, there is often little effect in some areas of a room because of the placement of vents. High or cathedral ceilings further exacerbate the stratification problem. Radiant heating systems provide no circulation benefit.

Ceiling fans provide a solution to the stratification problem (FIG 2.8-1). While the use of a fan may not appear to be energy efficient, a typical ceiling fan consumes less than 75 watts of electricity on its high speed setting, and as little as 20 watts on slow speed, as compared to 200 to 300 watts for a furnace blower. The fan forces the warm ceiling air to circulate and mix with room air, maintaining a more even temperature.

In warm weather, ceiling fans operated at high speeds can produce pleasant breezes, thereby reducing cooling requirements. An alternate warm weather approach is to provide air circulation for the entire structure through the use of a whole house fan (FIG 2.8-2). These fans, typically mounted at a point high in the attic or roof, draw air from the house and exhaust it to the outside. Fresh air inlets must be provided in each room that is to be ventilated, and a clear path for air movement must exist to the fan and then to the outside.

UNCONVENTIONAL FAN USE

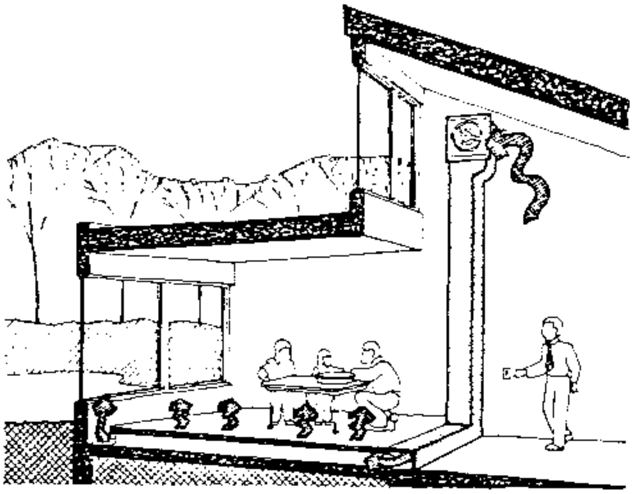
In structures with very high ceilings, a fan and duct system can be utilized to pull warm air from the top of the space and direct it through pipes set in the concrete mass floor. The air then exits through vents near the windows. In this system, some of the heat from the high warm air is stored in the mass for later use and the remainder is recirculated near the window area, which otherwise may tend to be cool (FIG 2.8-3).

Another unconventional fan approach is a system called a "volume collector". A remote direct gain type space, possibly an attic, is heated by the sun to relatively high temperatures, and a fan circulates this warm air through ducts into the living space (FIG 2.8-4). Although thermal mass is not necessary for daytime-only heating, thermal mass can be added to allow some nighttime storage.

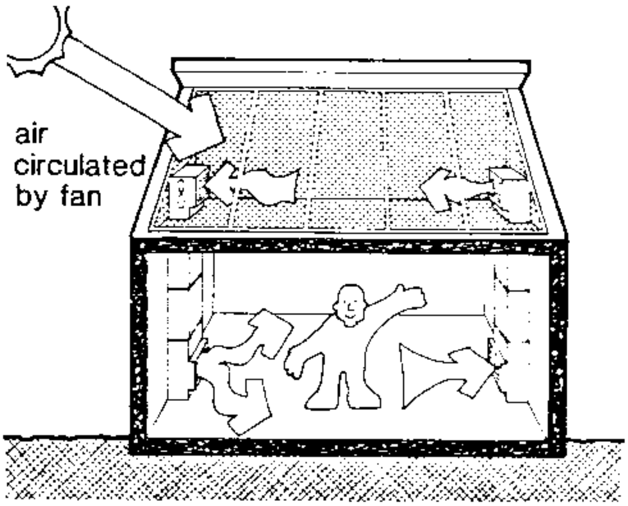
DOMESTIC HOT WATER (DHW)

A significant non-space-heating use of energy is the heating of domestic hot water. In a conventional system, water at 55-65°F is drawn into a tank where it is heated to a preselected hot water temperature (100-140°F) and stored in the tank for use. Ignoring heat losses from the tank, the amount of energy required in this process is a function of the number of degrees to which the water must be heated, i.e., it takes only half as much energy to heat a quantity of water from 80 to 100°F than to heat it from 60 to 100°F.

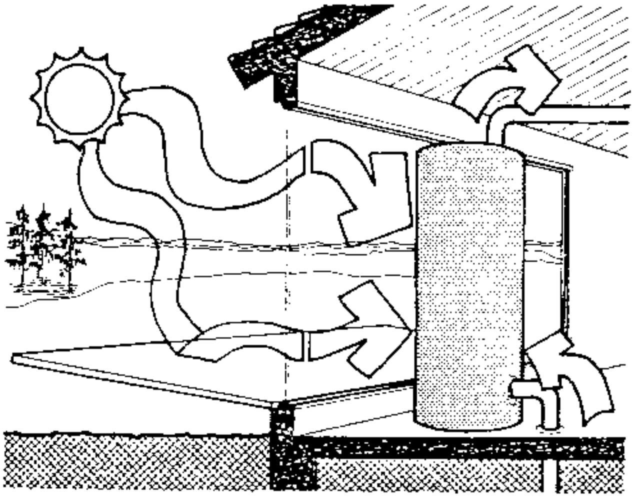
This energy usage can be reduced by utilizing a hot water preheat system. In a simple preheat system, water in a tank heated directly by the sun passes to the conventional hot water heater as it is needed (FIG 2.8-5).



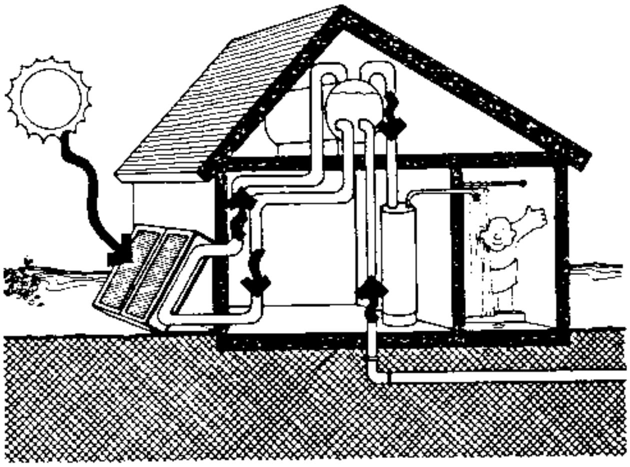
2.8-3 HIGH AIR HEAT RECOVERY



2.8-4 VOLUME COLLECTOR



2.8-5 HOT WATER PREHEAT



2.8-6 HOT WATER THERMOSIPHON

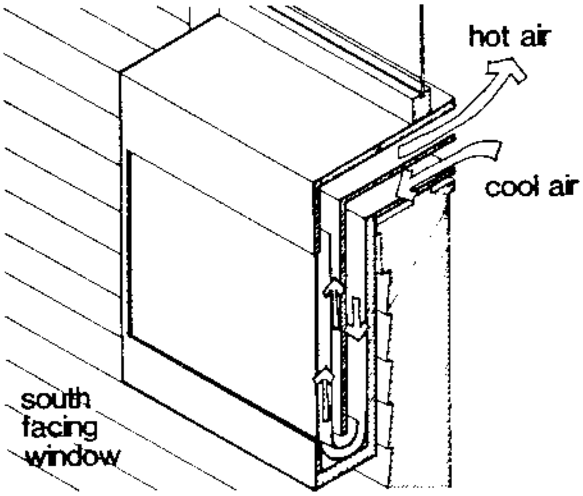
In a slightly more ambitious system, active-type solar collectors heat a water/antifreeze mixture, which rises naturally to pass through coils inside a water preheat tank (FIG 2.8-6). Heat is transferred to the water in the tank, and the antifreeze mixture returns to the collectors. This naturally-circulating closed loop is called a thermosiphon system. The warmed water in the preheat tank goes to the conventional water heater on demand and is replaced with fresh main water. One strength of a thermosiphon system is that it is normally self-terminating during periods of no sun. At night, for example, the thermosiphion loop simply stratifies, with cold liquid at the bottom and warm water at the top. This explains the need for a separate liquid loop for the collectors, which must be freeze protected. Systems without a separate collector loop require either a mild climate or drainage on cold nights.

RETROFITTING

Retrofitting is the application of passive solar techniques to existing homes.

THERMOSIPHON WINDOWBOX

A thermosiphon windowbox consists of an insulated cavity with a south-facing glass aperture (FIG 2.8-7) hung below a south window. Sunlight passing through the aperture falls on a dark-colored baffle which divides the cavity in half except for an air passage at the bottom. The baffle is warmed by the absorbed energy and heats the air in the outer portion of the cavity. This warm air rises and passes into the house. Replacement air is drawn from the house, and the cycle is repeated. At night, the unit shuts down because it is a thermosiphon system -- cold air stagnates at the bottom. Although commercially built units are available, a thermosiphon windowbox is a good do-it-yourself project.



2.8-7 RETROFIT: AIR THERMOSIPHON

GREENHOUSE RETROFIT

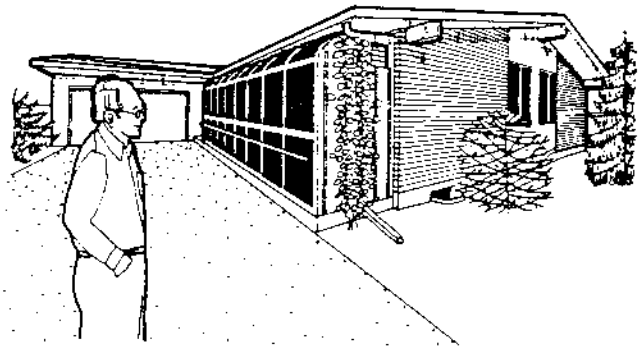
A greenhouse is a light construction addition to the south-facing side of a house. It includes a relatively large glass area, which is well-insulated, and thermal mass for storage. A means of drawing heated air into the home is also needed. Retrofit greenhouses vary from permanent frame or brick home additions to temporary "lean-to" structures with thin plastic film glazing supported by light metal conduit (FIG 2.8-8).

APERTURE ENHANCEMENT

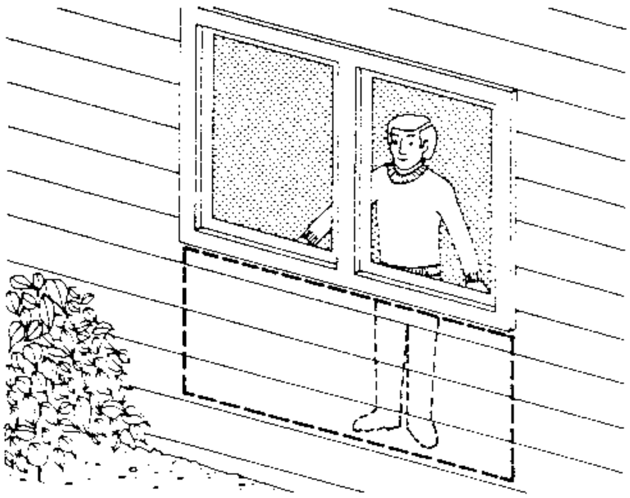
Another way to maximize solar benefit in an existing house is to increase direct solar gain through the south-facing window area. Of course, not all houses will lend themselves to this kind of modification. The effects of extra glazing can be enhanced by including a system of thermal mass to store increased thermal gains. (FIG 2.8-9).

RETROFIT TROMBE WALL

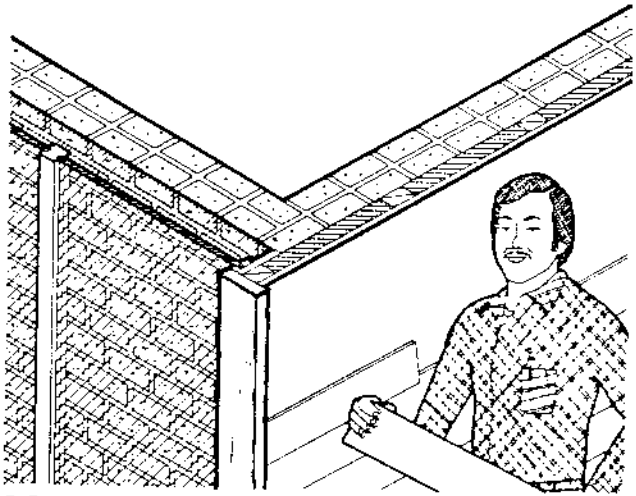
A brick, stone, or masonry home has considerable thermal mass. Unfortunately, this mass is on the outside of the structure where it does little good in stabilizing indoor temperatures. This situation can be rectified by applying insulation to the outside of the mass and removing any insulation barriers on the inside. For example, the south side of a building can be converted to an indirect gain system by applying a double layer of glass on the outside and removing the insulation on the inside (FIG 2.8-10).



2.8-8 RETROFIT: GREENHOUSE



2.8-9 RETROFIT: INCREASED GLAZING



2.8-10 RETROFIT: MASONRY BUILDING

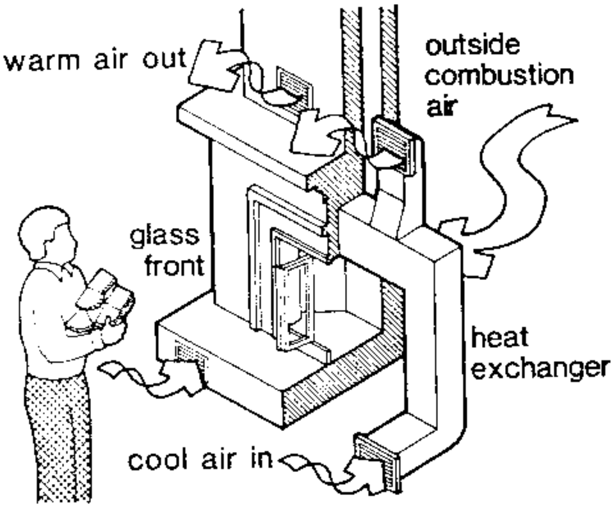
MISCELLANEOUS

AUXILIARY HEAT ALTERNATIVES

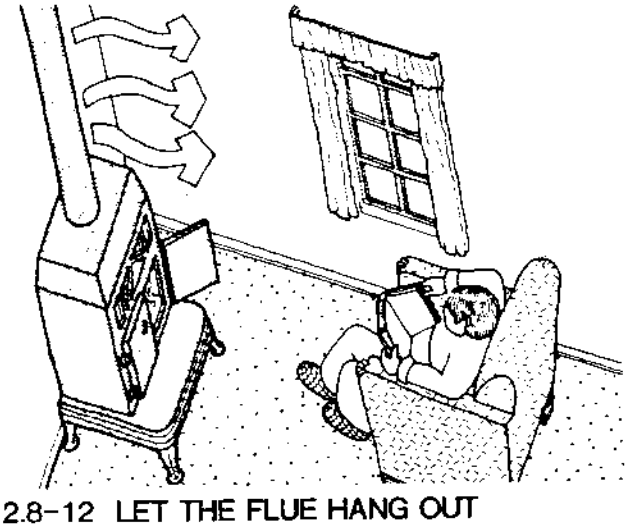
Very few solar designs provide 100% of the required heating energy over an entire season and backup (auxiliary) heating units are a necessity.

FIREPLACES

The energy performance of fireplaces varies widely. The use of most fireplaces results in a sizeable net energy loss from the house because the draft created by the fire draws heated air from the living space and sends it up the chimney. The area directly around the fireplace seems warm because the heated house air is funneled toward it and because of the radiant heating effects of the fire itself; the rest of the house becomes cooler, forcing increased output from the furnace.



2.8-11 ENERGY EFFICIENT FIREPLACE



2.8-12 LET THE FLUE HANG OUT

There are a number of solutions to this problem, and many are incorporated in modern energy-conserving fireplace designs.

Because a fireplace offers primarily radiant heat, it is not necessary that the firebox be open to the living space. A fireplace with a sealed front allows heat to radiate into the living space without any air flow, eliminating the air loss problem. This technique necessitates drawing combustion air from the outside.

Efficiency of the fireplace can be further improved by reclaiming some of the heat that is otherwise lost in the chimney gasses. This is done by drawing room air, either by natural or forced convection, into channels surrounding the firebox and flue where it is heated and then released to the living space (FIG 2.8-11).

Many of the concerns that apply to built-in fireplaces also apply to free-standing fireplaces and stoves. For these free-standing devices, additional heat can be gained by exposing the flue to room air for the maximum length possible, rather than running it directly through the nearest wall (FIG 2.8-12).

Capturing flue gas heat is accomplished in a slightly different way in what is called a "Russian stove", or "Russian fireplace", a type of stove that has been used in Eastern Europe for centuries and, in fact, appears in the history of the Nebraska settlers in the 1800's. In the Russian fireplace, the hot flue gasses are led through a long, zig-zag path before being allowed to escape. The chamber material, usually brick or a type of masonry, absorbs much of the heat from the gasses (FIG 2.8-13). The fireplace has a relatively large thermal mass itself, so that it can stay warm for long periods of time between uses.

WOOD STOVES

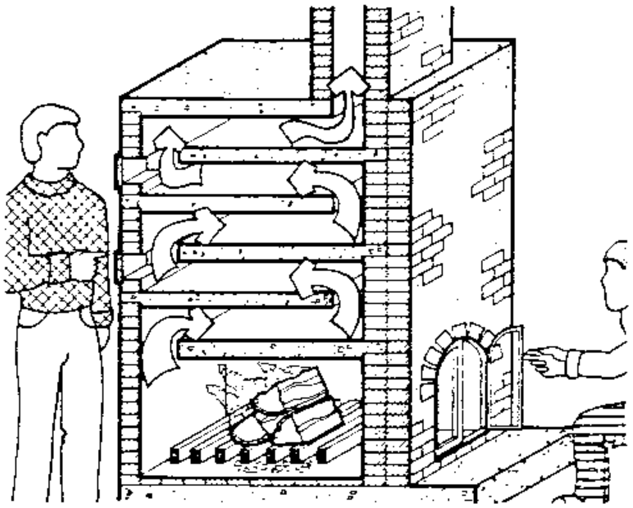
The wood stove is becoming a popular alternative for providing auxiliary heat (FIG 2.8-14). Like fireplaces, wood stoves vary greatly in their efficiency.

Wood stoves are of two basic types -- airtight and non-airtight. Airtight stoves have carefully sealed joints so that the amount of air admitted for combustion is easily controlled by adjustable vents. By restricting the entry of air into the stove, room air losses are cut substantially and the rate of combustion can be controlled to permit slower, longer burning.

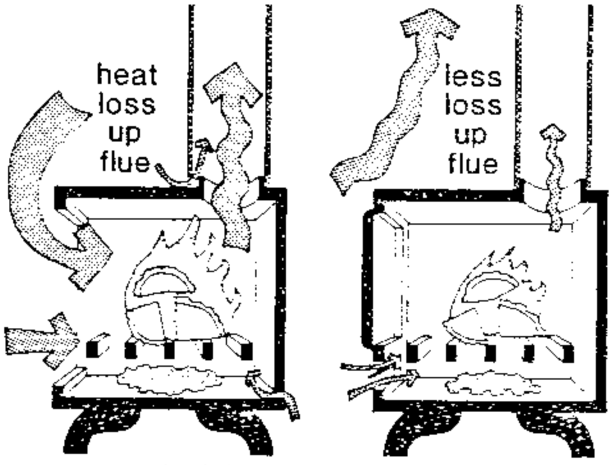
Non-airtight stoves can suffer from some of the same problems as open fireplaces. One advantage of stoves, however, is that heat is more easily transferred to the room air than with a conventional fireplace. This is because the metal body of the stove has good conductivity, the flue is exposed, and air surrounds the free-standing stove on all sides.

RADIANT PANELS

Radiant heating panels increase radiant temperature in a space while reducing air temperature requirements for the same comfort level. Radiant panels can reduce heating needs in selected parts of a home, especially in areas of sedentary activity. The panels are most commonly electric, although natural gas or propane models may be found. They are easy to install and provide good intermittent spot or zone heating (FIG 2.8-15).

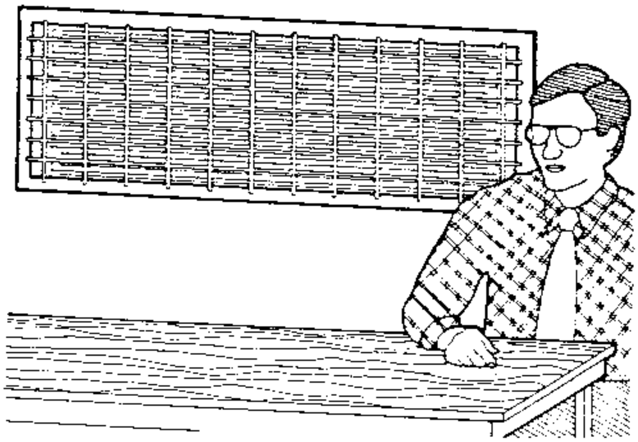


2.8-13 RUSSIAN STOVE



non air tight air tight

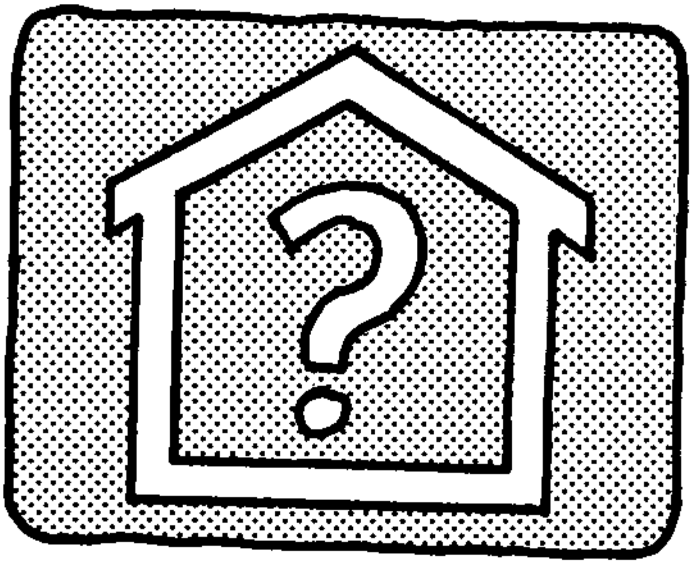
2.8-14 WOOD STOVE



2.8-15 RADIANT HEATING PANELS

CHAPTER 3
SYSTEMS

This chapter identifies six different passive solar heating techniques. The characteristics, advantages and disadvantages, rules of thumb, and considerations of each passive solar heating system are discussed in detail.



DEFINITION

A passive solar energy system is one in which heat is distributed by natural means of conduction, radiation, and convection. The building itself acts as the collector and its structure may contribute mass. In a pure sense, passive solar energy systems do not use fans, pumps, or separate collectors.

INTRODUCTION

The six passive solar energy techniques discussed in this chapter are DIRECT GAIN, TROMBE WALL, SOLAR GREENHOUSE, CONTINUOUS THERMAL ENVELOPE, THERMOSIPHON, and ROOF POND.

The direct gain is the simplest to understand, most widely employed, and least expensive passive solar heating technique. Its principal drawback is the tendency for wide temperature fluctuations where there is insufficient thermal mass.

The Trombe wall has high temperature stability and, except for occasional cleaning, is virtually maintenance free. Construction costs for a Trombe wall will usually be more than for a direct gain system.

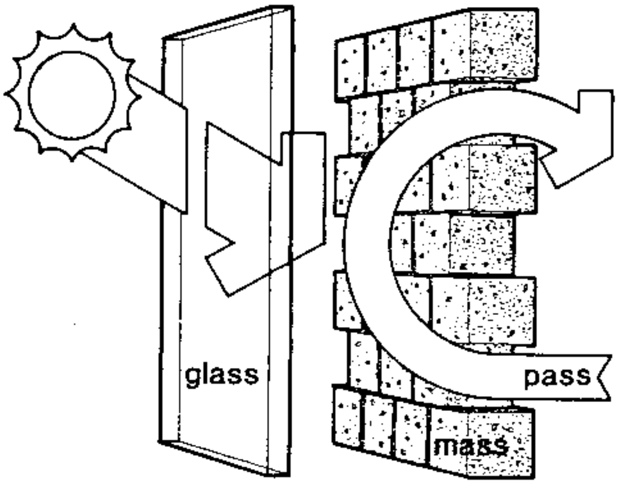
The solar greenhouse (sunspace) is a popular technique for both new home construction and retrofit applications. Potential problems can arise in matching the heating requirements of the home to the desired use of the greenhouse space, as the space will tend to overheat.

The continuous thermal envelope (double shell) is the most recently developed passive solar heating technique. A greenhouse provides a tempered layer of warm air which bathes the ceiling and north wall. At night, the earth beneath the home releases heat to the envelope, thereby eliminating the need for night shutters and thermal mass.

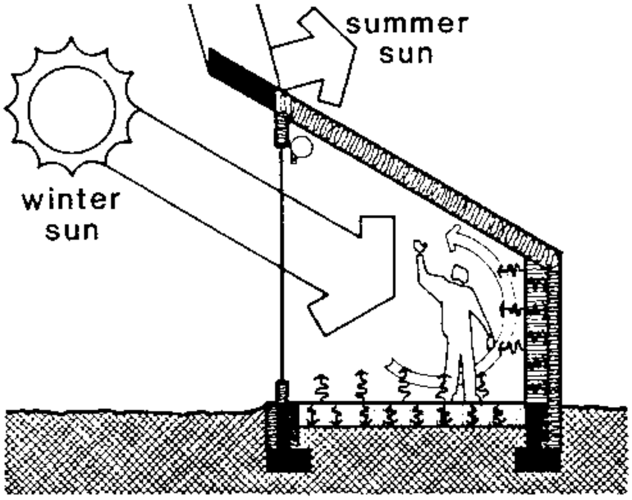
The last two techniques -- thermosiphon and roof pond -- have not been as widely utilized as the other four techniques. The thermosiphon, however, is used extensively in other regions for domestic hot water production.

GPM

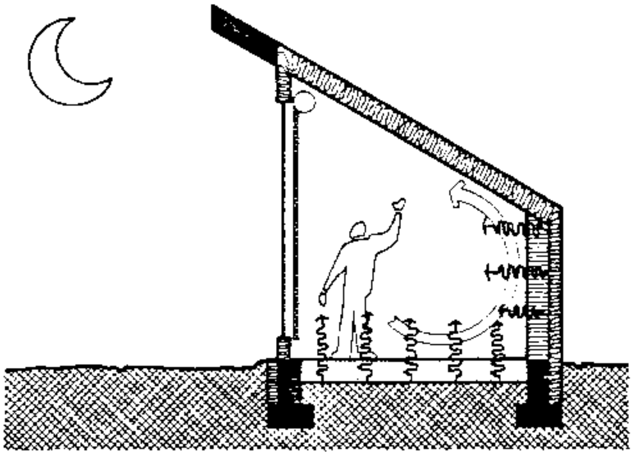
GPM is the foundation of all passive solar energy heating systems (FIG 3-1). The letters G, P, and M refer to GLASS, PASS, and MASS. Heat energy from sunlight gathered through south- facing GLASS must PASS into the living space by direct gain or indirect means. The Trombe wall, solar greenhouse, double shell, thermosiphon, and roof pond are indirect methods of passing solar energy into a home since they intercept the sun's rays prior to entering the living space. MASS absorbs excess energy and prevents the space from overheating. In sunless periods, thermal mass can release stored energy back to the living space.



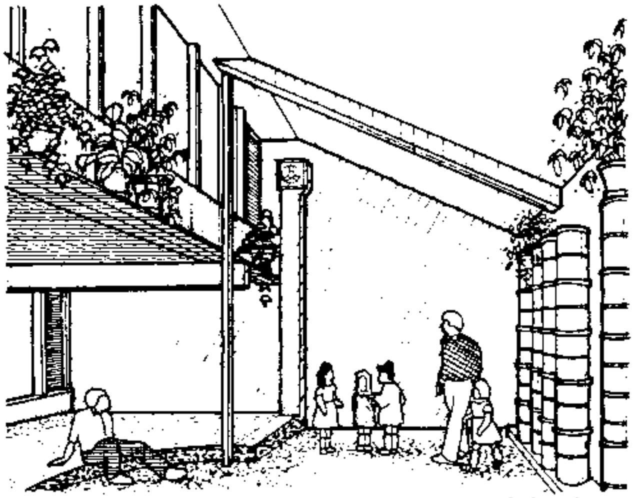
3-1 GLASS MASS PASS (GPM)



3-2 DIRECT GAIN: DAYTIME OPERATION



3-3 DIRECT GAIN: NIGHTTIME OPERATION



3-4 DIRECT GAIN MONTESSORI SCHOOL OMAHA, NEBRASKA

DIRECT GAIN

The most simple of the passive solar energy concepts is the direct gain system (FIG 3-2); most homes have some direct gain if they have any south-facing windows. In a direct gain system, sun shines directly into the occupied space which functions as a collector. The room air is heated first. Exposed walls, floors, and other thermal mass are then heated by the sun and the warmed air. Without sufficient mass, living spaces tend to overheat and undergo significant temperature fluctuations. Double or triple glazed windows with nighttime insulating shutters are strongly recommended, particularly for Nebraska and the upper midwest (FIG 3-3).

DIRECT GAIN CHARACTERISTICS

ADVANTAGES

1. Direct gain is the lowest-cost passive solar energy system to build.

2. Direct gain is the easiest passive solar energy technique to comprehend and to incorporate within a structure (FIG 3-4).

3. The south glazing admits solar radiation and provides a view of the surrounding environment.

4. When small solar savings fractions are needed, direct gain systems may not require much thermal mass.

DISADVANTAGES

1. There is a possibility of unacceptable glare during sunlit periods.

2. Unless shutters are employed, there may be a problem of privacy.

3. Direct sunlight may cause ultraviolet degradation of materials, fabrics, and artwork.

4. Relatively large temperature fluctuations may occur over a daily cycle.

5. There may be unacceptable nighttime losses through the south glazing. Double glazing with night insulation or triple and quadruple glazing without night insulation is required in a northern climate.

RULES OF THUMB

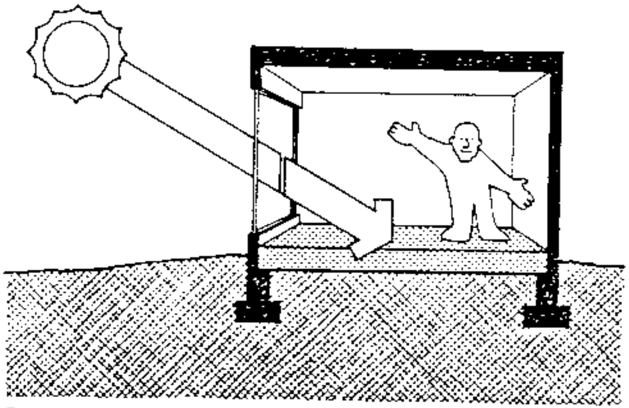
1. The ratio of window area to floor area should range from 0.21 to 0.33. Thus for a 1000 sq ft home the amount of south glazing should be between 210 to 330 sq ft. For super insulated structures (minimum R 35 walls and R 50 roofs) the ratio should be from 0.08 to 0.12.

2. Because direct gain systems tend to overheat, the placement and sizing of thermal mass is critical to optimizing performance. Sunlight may shine directly upon the thermal mass, it may be reflected onto the mass, or the thermal mass itself may be removed from both direct or reflected light and must be heated by warmed air. The ability of various thermal mass materials to absorb heat is dependent on the material's thermal conductivity and specific heat.

The following tables present a general set of quidelines for determining the surface area of thermal mass required for each square foot of window area. The values listed are for specific thicknesses of material used and for lighting patterns upon the mass.

DIRECT SUN ON WALL OR FLOOR (TABLE 3-1)

TABLE 3-1 is used to determine the sizinq of mass exposed to direct sunlight in situations where sunlight strikes a wall or floor directly for at least six hours of the day (FIG 3-5). Read down the column of thermal mass material and across from the material thickness column. This number

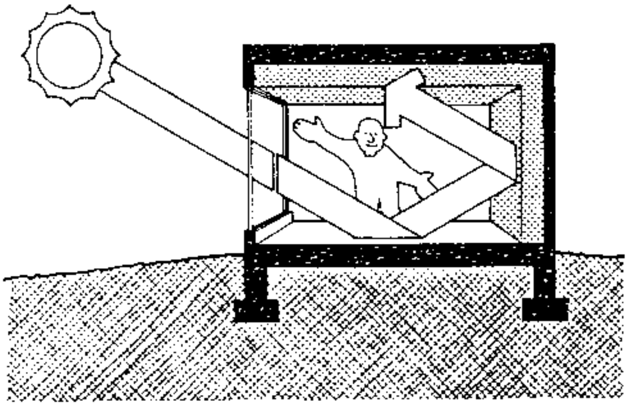


3-5 DIRECT SUN ON WALL OR FLOOR MASS

TABLE 3-1 MASS SIZING (DIRECT SUN)

MATERIAL THICKNESS	THERMAL MASS AREA TO GLAZING AREA RATIO					
	Concrete	Brick	Water	Gypsum	Pine	Slate
0.5"	28	36	13	63	78	16
1.0"	14	18	7	32	39	8
1.5"	9	12	5	22	27	5
2.0"	7	8	4	17	21	4
3.0"	5	6	3	14	18	3
4.0"	4	5	3	15	18	2
6.0"	3	5	4	16	20	2
8.0"	3	5	4	16	20	3

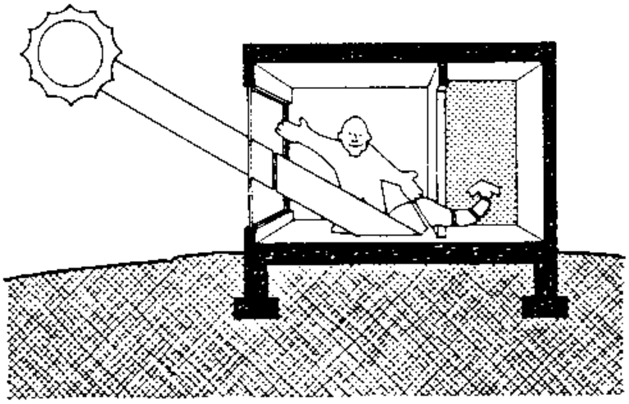
represents the square feet of thermal mass required for each square foot of south-facing window. For example, a 4" brick wall which receives direct sunlight for six hours per day requires 5 sq ft of brick surface for each square foot of window. A 10 sq ft window would require 50 sq ft of exposed wall.



3-6 INDIRECT SUN ON MASS

INDIRECT SUN ON FLOOR, WALL, OR CEILING (TABLE 3-2)

Where sunlight is reflected onto the thermal mass (FIG 3-6), more surface area is required for each square foot of glass in comparison with a system where sunlight shines directly on thermal mass. A 4" brick wall that does not receive direct sun will now require 9 sq ft of surface area for each square foot of glazing compared with the ratio of 5 for sunlight shining directly on the brick wall.



3-7 DIRECT GAIN TO REMOTE MASS

THERMAL MASS REMOTE FROM DIRECT OR REFLECTED SUNSHINE (TABLE 3-3)

Thermal mass which is located in a space which receives no direct or reflected sunlight is warmed by air that has been heated elsewhere (FIG 3-7). This configuration requires more thermal mass for each square foot of south window in comparison with the two previous methods.

TABLE 3-2 MASS SIZING (INDIRECT SUN)

MATERIAL THICKNESS	THERMAL MASS AREA TO GLAZING AREA RATIO					
	Concrete	Brick	Water	Gypsum	Pine	Slate
0.5"	49	63	23	111	136	28
1.0"	25	32	12	56	69	14
1.5"	16	21	8	38	47	9
2.0"	12	16	6	30	37	7
3.0"	8	11	6	25	31	5
4.0"	6	9	6	26	32	4
6.0"	5	9	7	28	35	4
8.0"	5	9	7	29	36	5

TABLE 3-3 MASS SIZING (REMOTE LOCATION)

MATERIAL THICKNESS	THERMAL MASS AREA TO GLAZING AREA					
	Concrete	Brick	Water	Gypsum	Pine	Slate
0.5"	50	64	26	112	137	30
1.0"	27	34	16	58	70	18
1.5"	20	24	15	41	50	15
2.0"	17	20	14	35	42	13
3.0"	14	17	15	32	38	13
4.0"	14	17	15	34	40	13
6.0"	14	18	16	36	44	14
8.0"	14	19	16	37	44	14

OTHER CONSIDERATIONS

1. Night shutters or movable insulation of at least R 9 are strongly recommended to improve thermal performance.

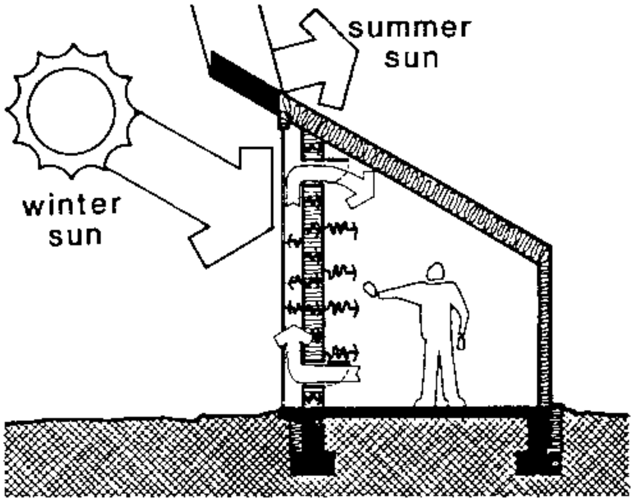
2. For northern climates like Nebraska's, triple or quadruple glazings with airgaps between glazings should be used to reduce conductance losses.

3. Carpets and wall hangings that cover thermal mass should be kept to a minimum. Otherwise unacceptable temperature swings may result.

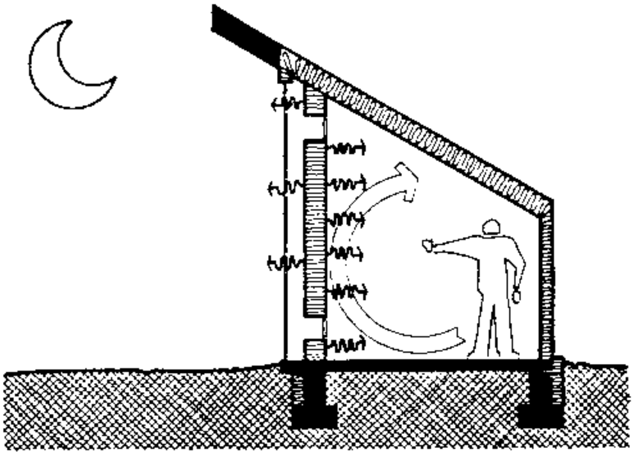
4. Although some reflection may be desirable for better heat distribution, the average of the solar absorptance for the total sunlit area should not fall below 0.5. Table 3 contains typical values of solar absorptance for different colors.

TABLE 3-4 SOLAR ABSORPTANCE

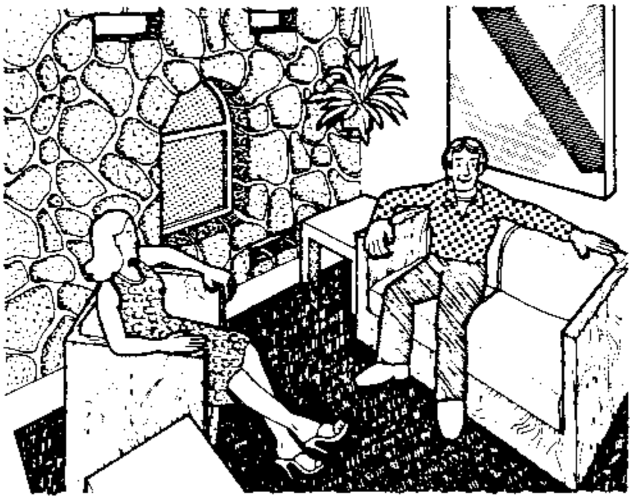
Flat black paint	0.98
Black concrete	0.91
Dark brown paint	0.88
Brown concrete	0.84
Red bricks	0.70
Uncolored concrete	0.65
Medium yellow paint	0.57
Light green paint	0.47
White semi-gloss	0.30
White gloss paint	0.25
Polished aluminum	0.15
Reflector sheet	0.12



3-8 MASS WALL: DAYTIME OPERATION



3-9 MASS WALL: NIGHTTIME OPERATION



3-10 MASS WALL INTERIOR VIEW

TROMBE WALL (THERMAL STORAGE WALL)

The Trombe wall, named for Felix Trombe, is also referred to as a thermal storage wall. Instead of placing thermal mass inside the building, as in a direct gain system, the thermal mass is located directly behind the south glazing (FIG 3-8, FIG 3-9). Sunlight passing through the glazing strikes the thermal mass wall and most of the solar energy is absorbed by the mass. This energy migrates through the mass wall via conduction and radiates into the living space.

The energy transfer through the thermal mass may take a number of hours. This delay may be offset in two ways: 1) vent openings placed at the top and bottom of the mass wall provide a natural convection path which permits warmed air to enter the living space when the sun comes up, and 2) placing a window in the mass wall allows sunlight to heat the space directly (FIG 3-10).

TROMBE WALL CHARACTERISTICS

ADVANTAGES

1. Ventless thermal mass walls tend to have the most temperature-stable living spaces in comparison with other passive heating systems.

2. The mass wall can serve as a structural element of the building.

3. Depending on the type and thickness of the wall material, a thermal lag of several hours may occur. This may be desirable if the space is used most often during the evening hours.

4. Fabric degradation and glare problems caused by ultraviolet light are reduced or eliminated.

5. A variety of different materials such as brick, stone, concrete, block, water, and phase change salts can be used as thermal mass.

6. Commercially built thermal mass walls are available as modular construction components.

DISADVANTAGES

1. Thermal mass walls can obstruct views to the outside.

2. Additional costs may be incurred with the construction and installation of thermal mass walls.

RULES OF THUMB

1. In Nebraska, the ratio of mass wall area to floor area is between 0.51 and 0.93 for a masonry wall and between 0.38 and 0.70 for a water wall.

2. During the process of preliminary design, the amount of thermal mass required to achieve a certain solar savings must be considered. TABLE 3-5 is intended to provide general sizing guidelines.

TABLE 3-5 SIZING OF THERMAL MASS

Expected Solar Savings	Recommended Thermal Mass Per Square Foot Of Glass	
(%)	Water (lbs)	Masonry (lbs)
10%	6	30
20%	12	60
30%	18	90
40%	24	120
50%	30	150
60%	36	180
70%	42	210
80%	48	240
90%	54	270

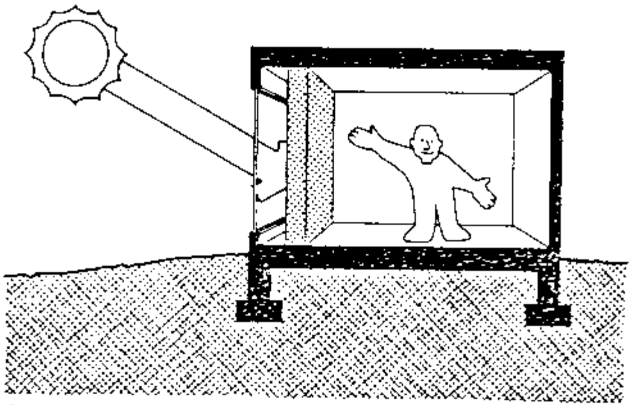
The density of water is 62.4 pounds per cubic foot in comparison with mortar-filled concrete block which is approximately 130 pounds per cubic foot.

PATTERNS OF DISTRIBUTING THERMAL MASS

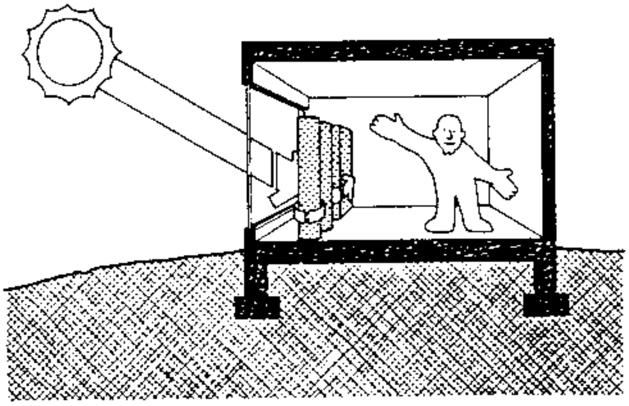
A Trombe wall is typically placed behind a window and the mass wall area equals the window area (FIG 3-11).

TABLE 3-6 MASS WALL IN DIRECT SUNLIGHT

MATERIAL	THERMAL MASS AREA TO GLAZING AREA RATIO
Brick 8"thick	1
Concrete 12"thick	1
Waterwall 8"thick	1



3-11 MASS WALL IN DIRECT SUNLIGHT



3-12 MASS WALL AND DIRECT GAIN

In many instances there may be a combination system of mass wall and direct gain (FIG 3-12). This is especially true when water is employed as the thermal mass.

TABLE 3-7 MASS WALL AND DIRECT GAIN

MATERIAL	THERMAL MASS AREA TO GLAZING AREA RATIO
Brick 8"thick	2
Concrete 6"thick	2
Drums or tubes of water	7 gallons or more of water per square foot of glazing

3.Vents in a Trombe wall provide a means for quick heat gain. This is especially important when the thermal mass wall is very thick (beyond 18") or has poor heat conductivity. Vents are also recommended when a solar savings fraction of 30% or less is to be obtained. At these lower solar savings fraction levels, it is advantageous to reduce the daytime heating load as much as possible; vents will provide heated air to the building to reduce daytime heating loads. As a percentage of the total wall area, the vents should not exceed the values shown in TABLE 3-8.

TABLE 3-8 SIZING VENT OPENINGS FOR MASS WALLS

Expected Solar Savings Fraction (%)	Vent Area (%)
25	1.5
50	0.5
75	0.25

Provisions must be made to prevent a backflow of warm air from the room to the window glazing area during sunless periods.

OTHER CONSIDERATIONS

1.Night shutters or movable insulation of R 9 or higher should be used.

2.Selective surface coatings should be applied to the exterior face of the Trombe wall. These coatings will reduce heat radiating from the wall back through the glass.

3.Conduction losses to the outside can be reduced through the use of triple glazing.

4.Reflectors can be used to increase the amount of solar energy striking the thermal mass.

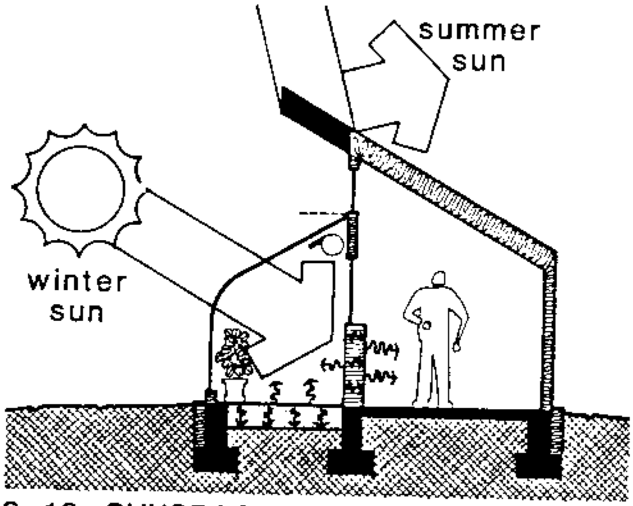
5.Overhangs or shading of the glazing surface should be provided during the summer months.

6.If vents are used, some means for venting hot air to the outside during the summer is desirable.

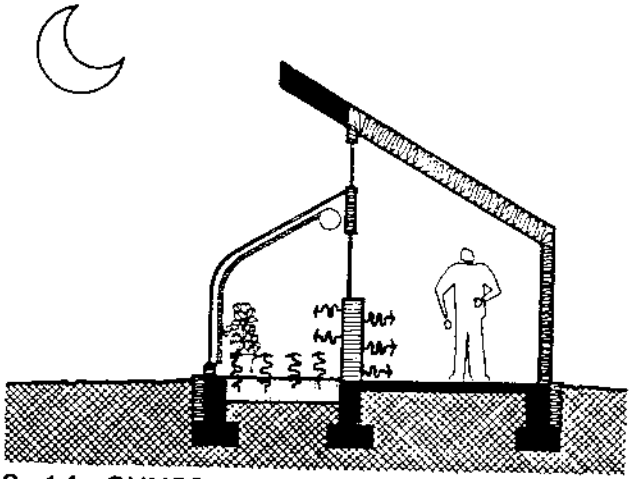
7.If the mass wall has vents, provisions must be made for cleaning the inside surface of the glazing.

SUNSPACES (ATTACHED SOLAR GREENHOUSES)

The sunspace is one of the most popular passive solar heating techniques. Winter sun shines through the south glazing of the greenhouse onto the common wall between the living space and sunspace (FIG 3-13). The heat migrates through the wall, as it does through a Trombe wall, and radiates into the living space. Vents, operable windows, and sliding glass doors located in the common wall between the sunspace and living space provide a means to heat the living space directly. Mass in the sunspace helps to reduce temperature fluctuations over a 24 hour period in the sunspace. The use of insulating curtains is recommended to retain energy captured during daylight hours. particularly if freezing temperatures are not desired in the sunspace during the night (FIG 3-14). Perimeter insulation should be placed down to the footings of the sunspace in order to reduce losses.



3-13 SUNSPACE: DAYTIME OPERATION

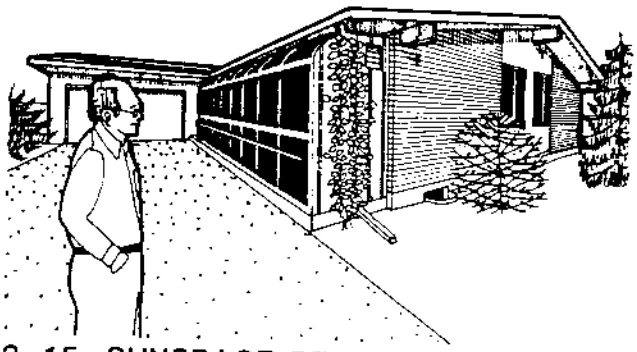


3-14 SUNSPACE: NIGHTTIME OPERATION

ATTACHED SOLAR GREENHOUSE CHARACTERISTICS

ADVANTAGES

1. The sunspace serves as a buffer between outdoor ambient conditions and interior living space.
2. Sunspaces designed as solar greenhouses can be used to grow flowers, plants, and vegetables.
3. Sunspaces serve as an aesthetic focal point when used as extensions of living spaces.
4. Existing buildings can be retrofitted with attached sunspaces (FIG 3-15).
5. Sunspaces can be utilized to provide preheated water by the use of an inline tank that has been painted black.



3-15 SUNSPACE RETROFIT:
THOMSEN HOUSE LINCOLN, NEBRASKA

DISADVANTAGES

1. Construction costs of a solar greenhouse may be significantly higher in comparison with other passive solar heating methods.

2. Thermal performance may be difficult to compute accurately due to the many variations in design.

3. Humidity (condensation), carbon dioxide levels, insect infestation, drainage, water supply, and temperature fluctuation must be considered when sunspaces are used as greenhouses.

4. Night shutters and/or movable insulation may be required to maintain nighttime temperatures above freezing to ensure plant survival. Auxiliary heating may also be required.

RULES OF THUMB

1. To keep the sunspace and adjoining area at an average temperature of 65 - 70°F, the ratio of floor area to double glazed window area can be determined by the following table:

TABLE 3-9 SIZING GLAZING AREA FOR ATTACHED SOLAR GREENHOUSES

Glazing area per sq ft of floor area	Building material between sunspace and living space
0.78 - 1.3 sq ft	masonry wall
0.57 - 1.05 sq ft	water wall

2. If a thermal wall is the chief heat transfer mechanism between the sunspace and the living space, the wall thickness is sized according to the following table:

TABLE 3-10 SUNSPACE WALL THICKNESS

MATERIAL	THICKNESS
Brick	10" - 14"
Concrete	12" - 18"
Water	8" or more or 0.67 cubic feet per sq ft of south glazing

OTHER CONSIDERATIONS

If the sunspace is to be used as an attached greenhouse for plants, the following suggestions should be considered:

1. As many surfaces as possible should be painted white in order to maximize light reflected onto plants. Any thermal walls may be painted red or blue.

2. As morning light is more beneficial to plants, east glazing is preferable to west glazing.

3. Ventilation will provide needed carbon dioxide to plants.

4. Proper ventilation can also control humidity levels. 60% relative humidity is ideal; insects and pests thrive in an environment with relative humidity above 75%.

5. Ventilating fans should be sized at 5 cfm per square foot of south glazing.

6. Plants usually cannot tolerate more than a 10 - 15°F fluctuation. Night shutters and auxiliary heat may be required.

7. Rockbed or water container storage will maximize solar heat gain and plant production.

CONTINUOUS THERMAL ENVELOPE

Also called the "double shell", the continuous thermal envelope (CTE) is the latest arrival on the passive solar energy scene. It was popularized by Tom Smith of Lake Tahoe, California, and has had a wide following among builders and the public, however, little actual testing of the system has been reported. The only known test room is located on the Omaha campus of the University of Nebraska whose Passive Solar Research Group has also monitored the Smith House and the Dennis Demmel double shell house in Hartington, Nebraska.

In a double shell system, sunlight enters the greenhouse and heats the air which rises to the cavity space in the roof area. As heat transfers to both the interior living space and the outside, the column of air begins to cool and slowly falls down the cavity on the north side of the structure. Any excess energy is transferred to the earth beneath the home. The cooled air re-enters the south-facing greenhouse to replace heated air and the process is repeated (FIG 3-16). In the evening, the reverse process occcurs as heat is lost through the south glazing causing the air in the greenhouse to cool and fall into the crawl space. Warm air from the roof cavity is drawn down into the greenhouse, which in turn pulls air up the cavity in the north wall. Some heat from the earth storage is transferred to the air column in the north wall. This causes a reverse siphoning effect to occur (FIG 3-17).

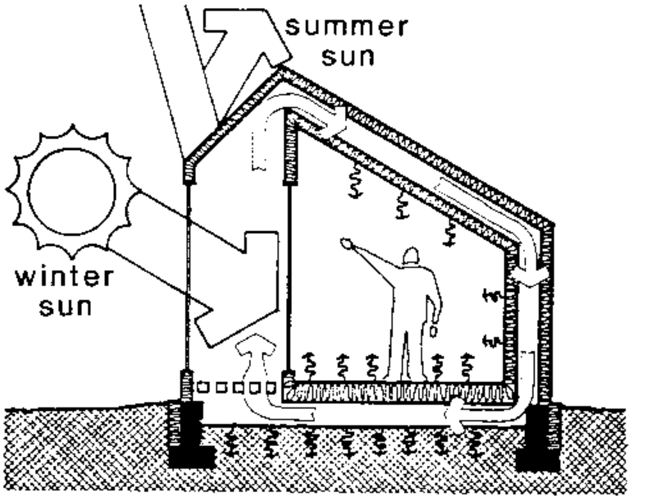
DOUBLE SHELL "CTE" CHARACTERISTICS

ADVANTAGES

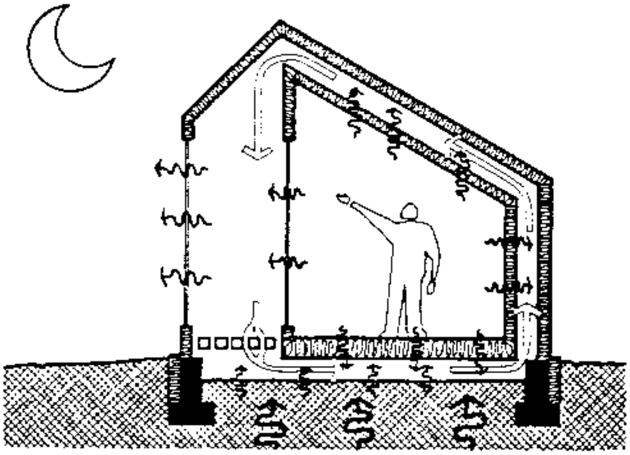
1. Though recommended, night shutters are not required.

2. Thermal mass is not required except in the crawl space.

3. The design is adaptable, and numerous variations can be made from the original plans (FIG 3-18).

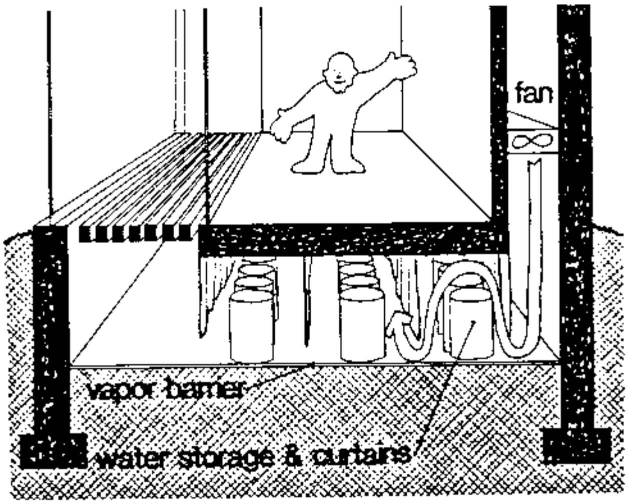


3-16 DOUBLE SHELL: DAYTIME OPERATION



3-17 DOUBLE SHELL: NIGHTTIME OPERATION

3-18 PAUL NYHOLM DOUBLE SHELL HOME OMAHA, NEBRASKA



3-19 DOUBLE SHELL: STORAGE DETAIL

4. Unlike a typical sunspace, the greenhouse in a double shell may not overheat because the heat is distributed during the warm air movement through the convective loop cycle.

5. Heat to each room can be regulated by windows or vents in the inner shell.

6. The greenhouse serves as a focal point for the home and provides a pleasant sunlit space. Flowers and other plants lend a cheerful touch to the space and their fragrance can permeate the entire home.

DISADVANTAGES

1. Temperature stratification in the greenhouse can make upper floors uncomfortable, particularly in the summer and possibly during late spring and early fall.

2. This system may cost more to construct than other passive solar heating techniques because building an inner and outer envelope requires additional materials.

3. In the winter, rooms on the the north side which are not in direct contact with the greenhouse are noticeably colder than other rooms.

4. Firestop dampers and/or fire-resistant sheetrock may be required in the north cavity.

5. Condensation may develop on glazing surfaces and cause rot damage to wood surfaces.

OTHER CONSIDERATIONS

1. Water storage can be located in the crawl space (FIG 3-19).

2. A fan or blower is recommended if temperature stratification is found to be a problem or if thermal storage (other than earth) is utilized in the crawl space.

3. A vapor barrier covering the earth in the crawl space will reduce moisture condensation significantly.

4. Flashing should be placed on the sills to collect condensation which may occur on the greenhouse glass. The flashing can be tilted so that water runs off. Flexible hose at the flashing depression has been successfully utilized in some double shell homes.

5. The sloped roof glazing common to many double shell designs is not recommended for several reasons: 1) it does not appreciably help the driving force of the convection loop, 2) shutters must be used during the cooling season to prevent overheating, and 3) it is more difficult to successfully shade a sloped roof than a vertical surface.

6. The R value of the outer wall should be much higher than that of the inner wall. When additional thermal storage is placed in the crawl space and a fan is used, the ratio of insulation in the outside wall to inside wall should be 3 to 1 or greater.

THERMOSIPHON (NATURAL CONVECTION)

The thermosiphon operates on the same principle as the continuous thermal envelope: warmed air rises and cold air falls. In a U tube collector with thermal storage (FIG 3-20, 3-21), an angled U tube collector is placed below the storage. Sun shining through the glazing causes the absorber plate, consisting of several layers of metal lath, to heat rapidly. This raises the temperature of the air coming in contact with the metal lath causing the air to expand and rise. This rising column of warm air enters the building where, depending on the damper setting, it can either heat thermal storage or enter the living space directly. Cold replacement air is drawn from the rear channel of the collector. When properly designed, the process does not reverse at night, as cold air pools at the bottom of the collector, eliminating the flow until the sun rises the next day (FIG 3-22).

THERMOSIPHON (NATURAL CONVECTION) CHARACTERISTICS

ADVANTAGES

1. Thermosiphon systems can have thermal efficiencies equaling those of active flat plate collectors.

2. The principle can be used in retrofitting an existing home. Systems can range from simple window boxes to entire wall systems.

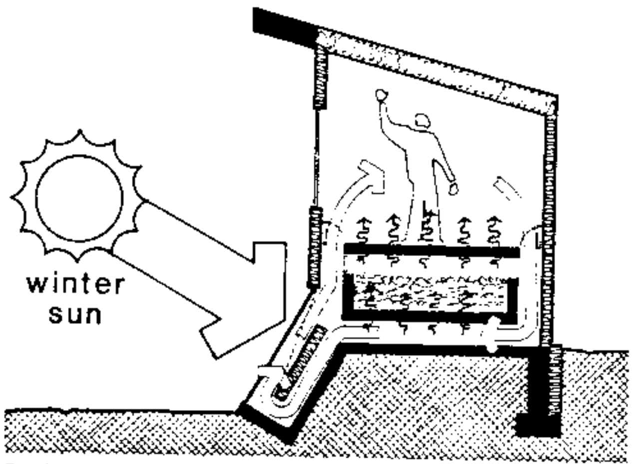
3. Unlike active systems, fans are not required for operation.

4. The cost of construction can be modest.

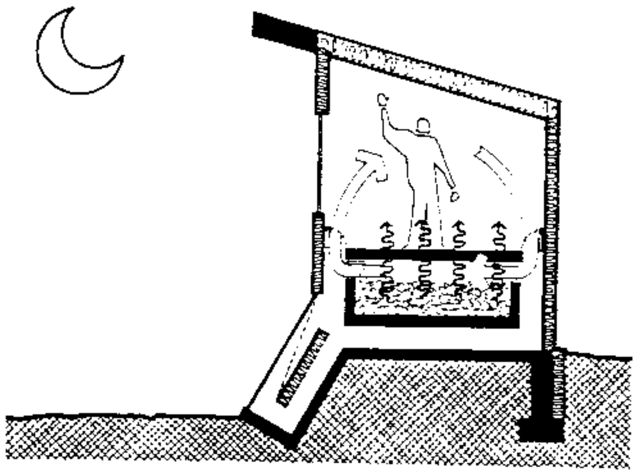
DISADVANTAGES

1. Natural convection systems will reverse siphon if not properly designed.

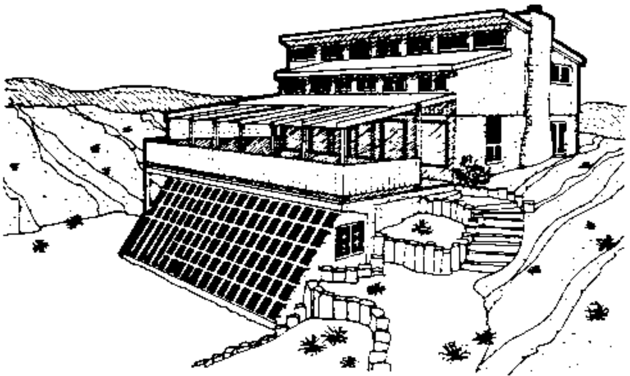
2. Vents and dampers may be required, particularly if the angled U collector is not used.



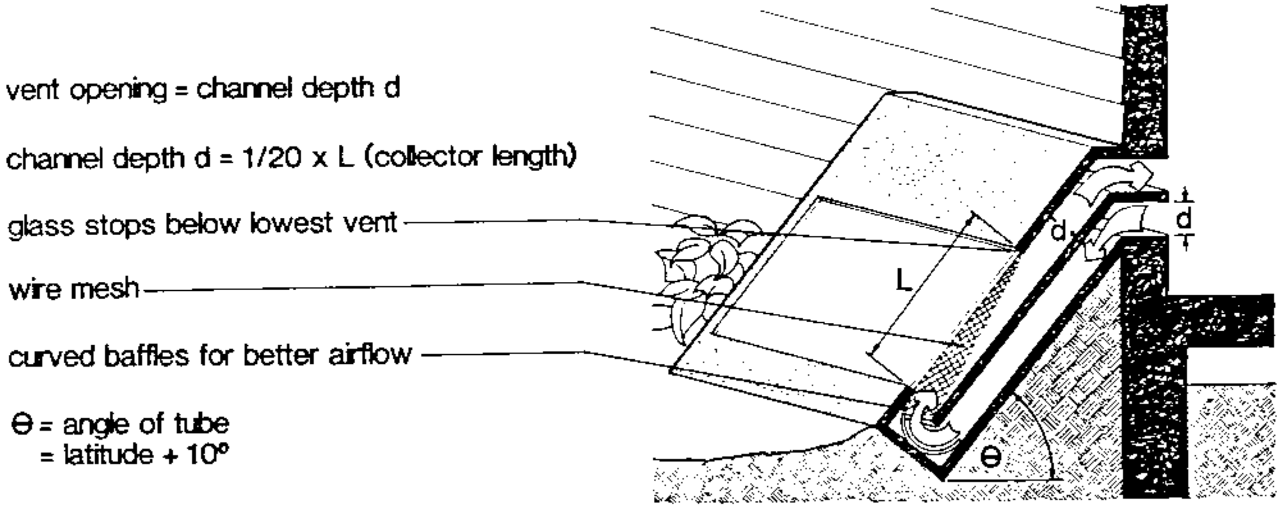
3-20 THERMOSIPHON: DAYTIME OPERATION



3-21 THERMOSIPHON: NIGHTTIME OPERATION



3-22 PAUL DAVIS THERMOSIPHON HOME: ALBUQUERQUE, NEW MEXICO



3-23 THERMOSIPHON U TUBE DETAIL

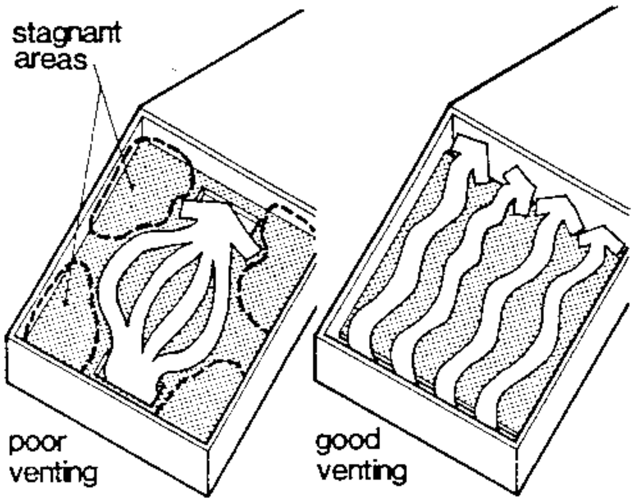
3. Site considerations may not permit incorporating storage with the angled U collector.

RULES OF THUMB

1. The ratio of glass area to floor area is 0.2 to 0.4. For a well-insulated home, this ratio should not be less than 0.08. If there is thermal storage as well, the ratio can be much higher.

2. Other sizing parameters:

Collector Tilt: the angle from the horizontal should be latitude +10 degrees.



3-24 VENTING STRATEGY FOR THERMOSIPHONS

Channel Depth: the depth of the air flow channels should be 1/20 of the collector length. Thus, a 6' long collector should have channels which are 3"-4" deep (FIG 3-23).

Vertical U Tube Length: if the collector is placed vertically, the tube should be at least 4' long.

OTHER CONSIDERATIONS

1. The glazing must not be placed above the level of the lowest vent. If it is, an extra head of cold air will exist at night to push the cold air back through the system, thus cooling the house.

2. All natural convection systems must be designed with easy air movement in mind. Any impediment to flow will hamper overall thermal performance. To facilitate air movement, the following suggestions should be observed:

   A. Curved baffles should be used in place of square corners (FIG 3-23).

   B. The width of the vent opening should be equal to the width of the collector (Fig 3-24).

C. Vents must be as deep as those in the flow channels of the collector.

3. As air is not a good conductor of heat, it is desirable to maximize the heated surface area exposed to flowing air.

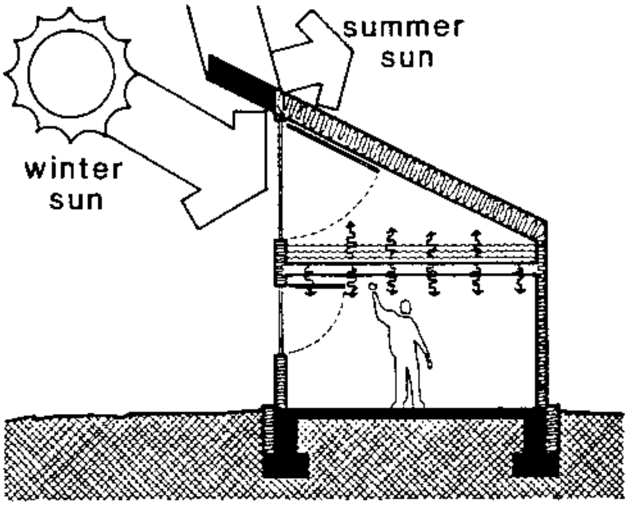
4. Aluminum or steel absorbers should be covered with high temperature black paint (or a selective surfacecoating) in order to survive in a higher temperature environment.

5. Glass should be used for glazing. Fiberglass and plastic glazing materials should be avoided.

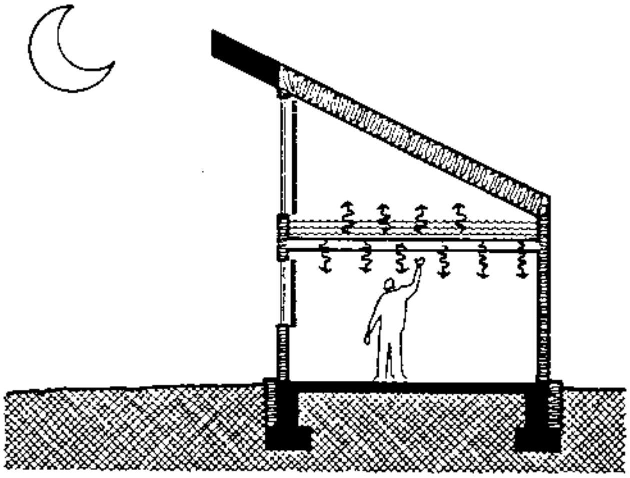
6. The thermal performance of a natural convection system is based on two measures: 1) the temperature difference between inlet and outlet of the collector, and 2) the flowrate. A high outlet temperature indicates the collector is too hot and is losing much of its gain back to the outside. During the noon hours on a sunny day a U tube collector can have a flowrate of 4 to 5 cubic feet per square foot of collector per minute.

TABLE 3-9 THERMOSIPHON PERFORMANCE CRITERIA

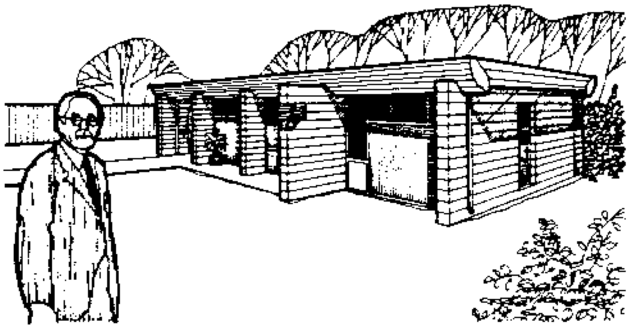
Inlet/outlet temperature difference °F	Comments
20 - 40	high efficiency and very good air flowrate
40 - 55	good efficiency and good air flowrate
55 - 70	reasonable efficiency and acceptable air flowrate
70 - 85	slow flow and collector temperatures are too high
85 or more	mistakes in design and/or construction



3-25 ROOF POND: DAYTIME OPERATION



3-26 ROOF POND: NIGHTTIME OPERATION



3-27 HAROLD HAY DESIGNED ROOF POND HOUSE

ROOF PONDS

In a roof pond system, water is stored in a membrane liner located in the structure's roof. During the day, the shutters are opened to permit sunlight to penetrate the roof space and heat the water (FIG 3-25). At night, the shutters are closed,and heat from the roof pond transfers into the home (FIG 3-26). During the summer, the process is reversed: the shutters are closed during the day, and the water absorbs heat from the house; at night, the shutters are opened to allow heat to be radiated to the night sky. The roof pond concept has not been tested in Nebraska.

ADVANTAGES

1. Roof ponds have been demonstrated to provide high solar heating fractions in the southwestern United States (FIG 3-27).

2. Roof ponds can provide passive cooling via night sky radiation in summer.

DISADVANTAGES

1. As additional loads must be supported by the building, it is recommended that the services of a structural engineer be obtained.

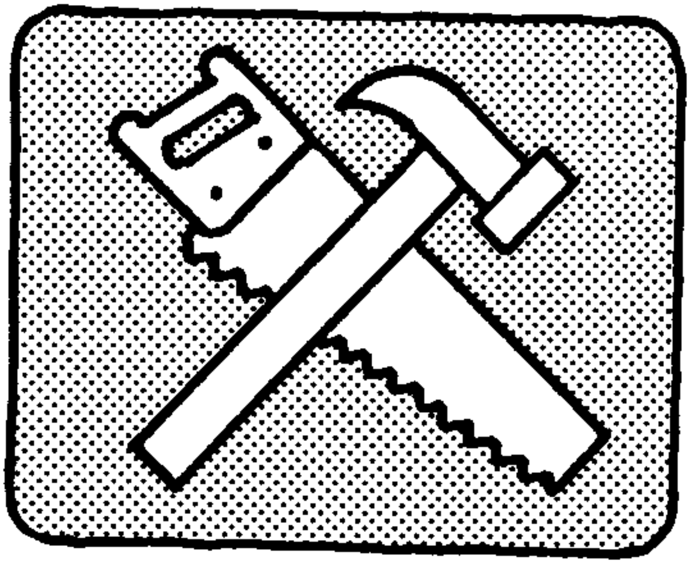
2. The roof pond has only been tested in warm climates. Due to problems caused by freezing, extensive modifications in the design may be required in the midwest.

RULE OF THUMB

1. For a south sloping collector with night shutter, the ratio of roof pond area to floor space area should be 0.40 to 0.60.

CHAPTER 4
CONSTRUCTION DETAILS

This chapter focuses on specific construction details for solar buildings. Included are recommendations for different passive solar systems, wall, roof and floor sections, and grade and subgrade wall details. By selecting the appropriate details, the desired solar and structural systems can be assembled.



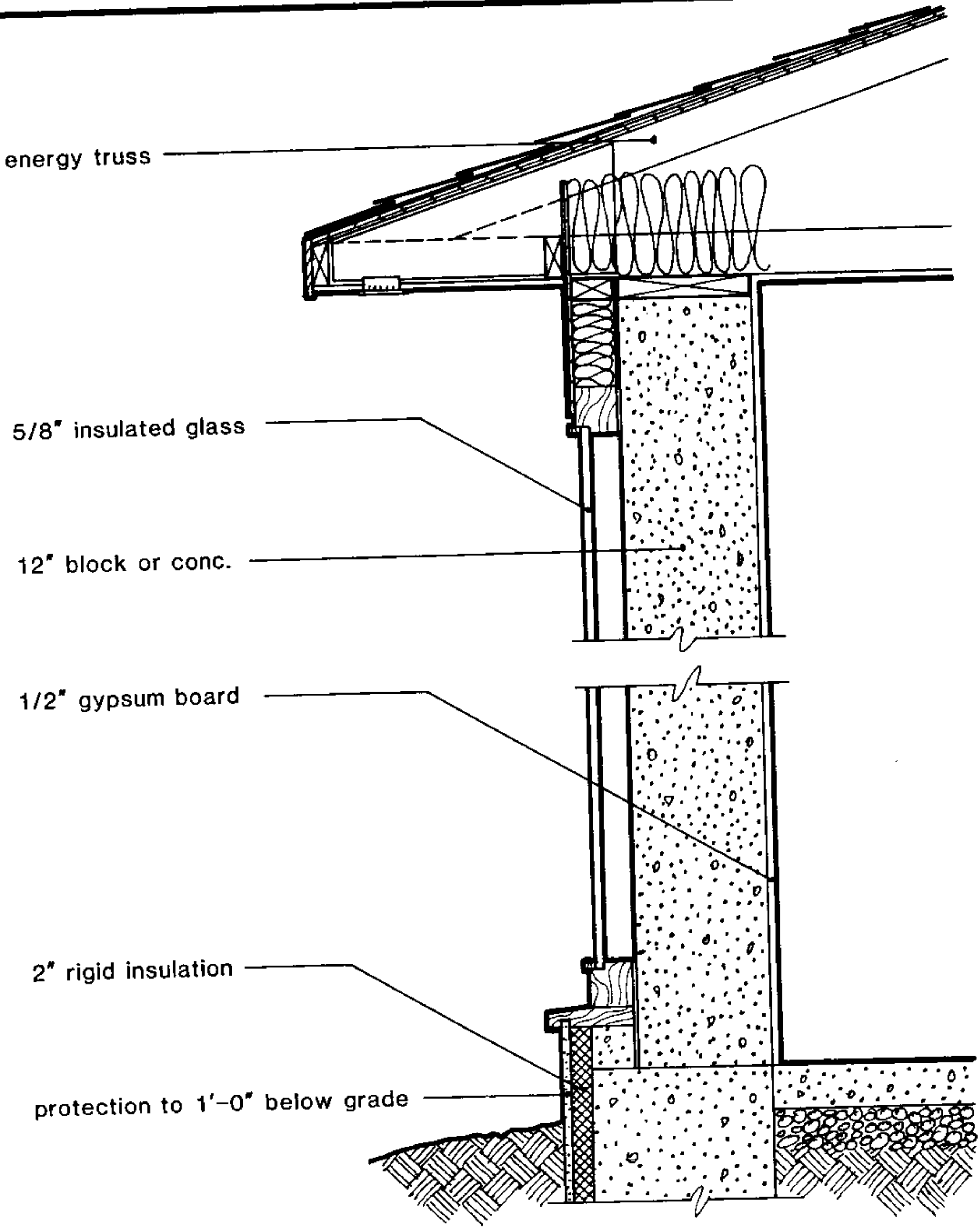
SOLAR SYSTEMS

TROMBE WALL

The ventless trombe wall (FIG 4-1) can be constructed from solid poured concrete, brick, stone, or concrete block with filled cores. The advantages in not venting this wall to the interior space are: 1) no insects or dirt will collect, and 2) little maintenance will be needed. Provisions for removing the glass to repaint the dark trombe wall surface should be made.

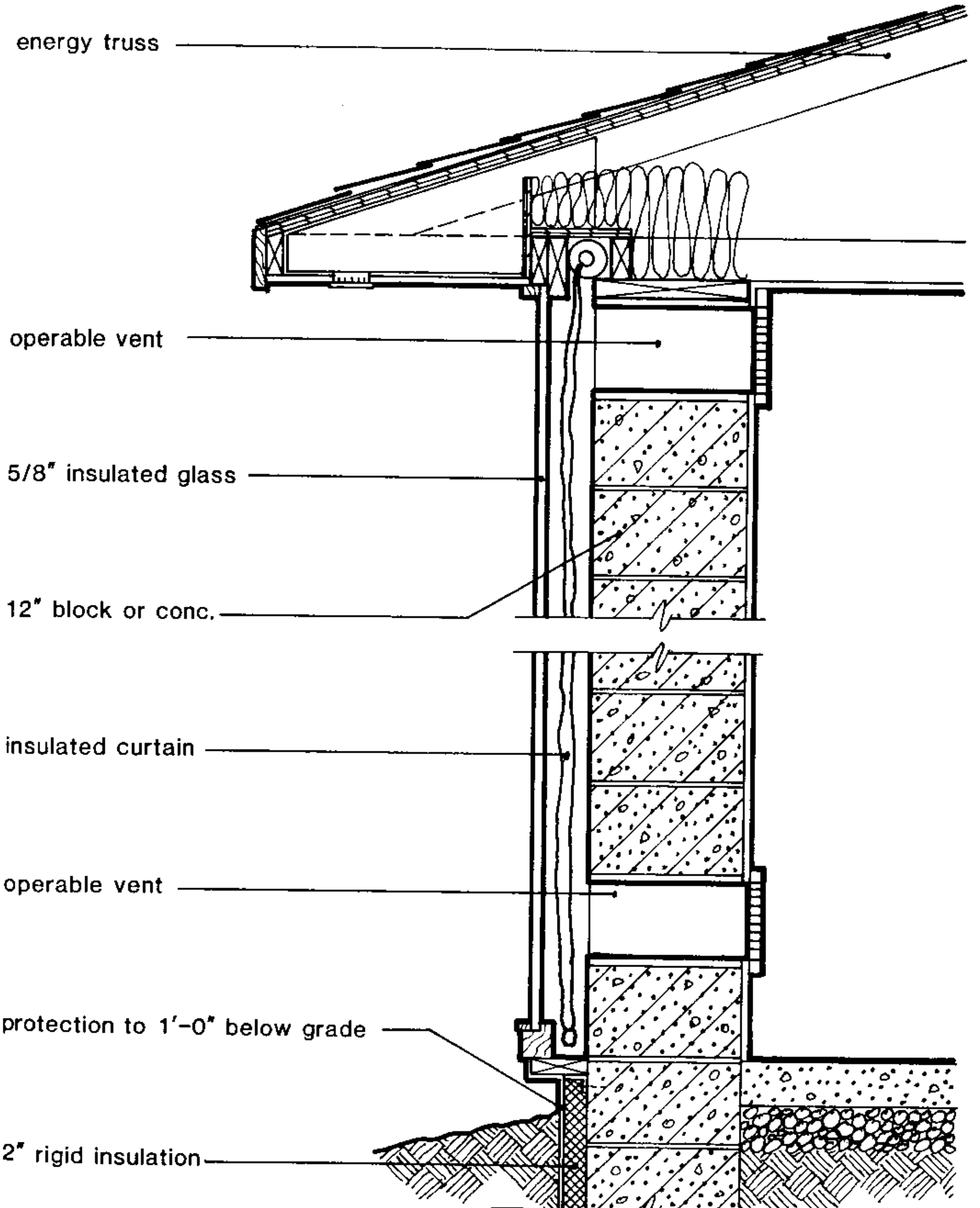
The vented trombe wall (FIG 4-2) begins transferring heated air directly to the living space as soon as the sun rises. The operable vent should have either manual or automatic controls to stop the flow of hot air to the space as well as to prevent warm house air from flowing back through the collection area and losing heat to the cold night glass. This detail includes a movable insulation system to reduce nighttime losses from the wall surface. Access to the movable insulation system through the attic space, operable vents, or by removing glazing is recommended.

CONSTRUCTION DETAILS



4-1 VENTLESS TROMBE WALL

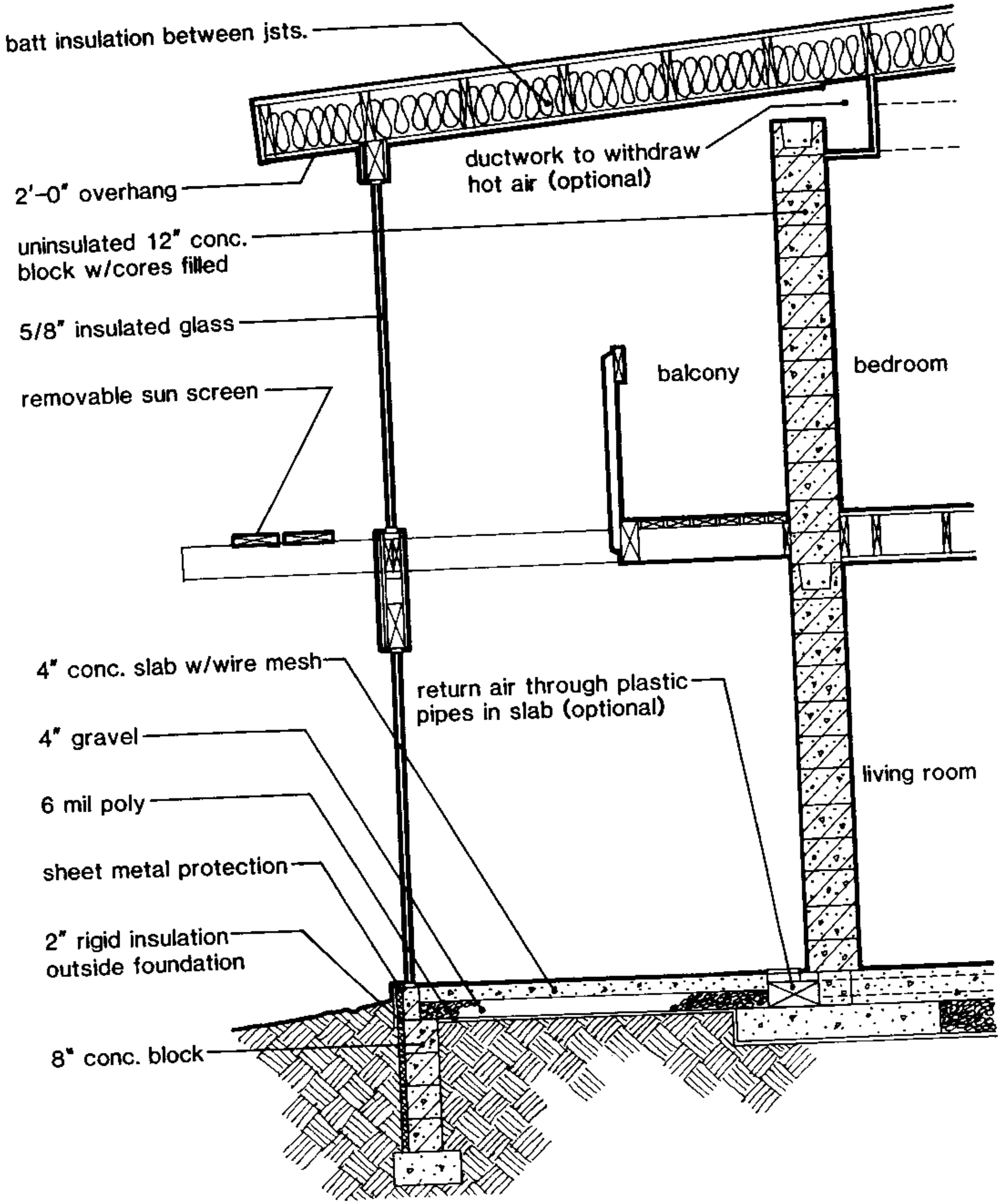
scale: 1"=1'-0"



4-2 VENTED TROMBE WALL

scale 1"= 1'-0"

CONSTRUCTION DETAILS



4–3 GREENHOUSE

scale 3/8" = 1'-0"

GREENHOUSE

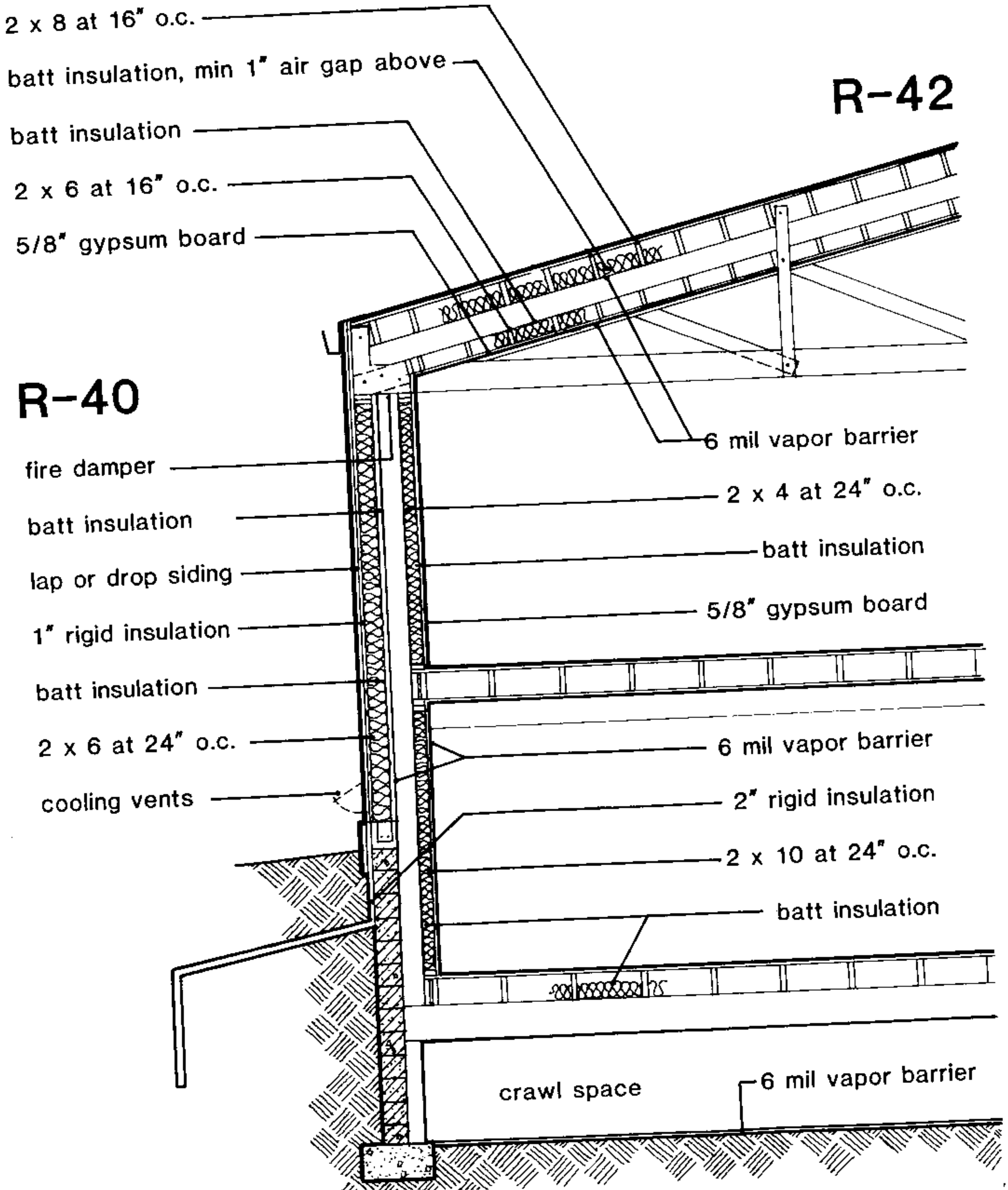
The greenhouse section (FIG 4-3) is a typical two-story passive solar greenhouse layout utilizing vertical glazing to reduce summer heat gain. Solar energy passes through the glass and is stored in the 12" concrete block wall between the greenhouse and living area. The cores of the concrete block should be filled with a sand and concrete grout to allow for better heat conduction to the interior of the house. With the aid of a fan, heated air can be moved from the top of the greenhouse through ductwork to the floor slab. Heat is transferred to the floor slab as it passes through PVC pipe embedded in the concrete. Cooled air is drawn into the greenhouse at the floor. The fan system is controlled by a thermostat located at the top of the greenhouse space. The greenhouse space is kept warm by solar heat stored in the mass wall and concrete floor slab. The slab has 2" of rigid insulation at the perimeter to control heat loss.

DOUBLE SHELL

In a double shell design, increased insulation is placed in the outer roof and wall (FIG 4-4). This allows the energy from the heated air in the cavity to transfer more readily to the inside than to the outdoors. By extending the perimeter insulation away from the wall below grade, the lower wall and soil area can be used as additional thermal mass for heat storage. A cooling vent has been added to the wall above grade to reduce heat build up during the summer. A 6 mil vapor barrier has been added to the floor of the crawl space to reduce the moisture build up along greenhouse windows. Another 6 mil vapor barrier is located on the warm side of both the inner and outer walls to keep insulation dry and to reduce infiltration. Local codes may require fire dampers to keep a possible wall fire from spreading into the roof cavity.

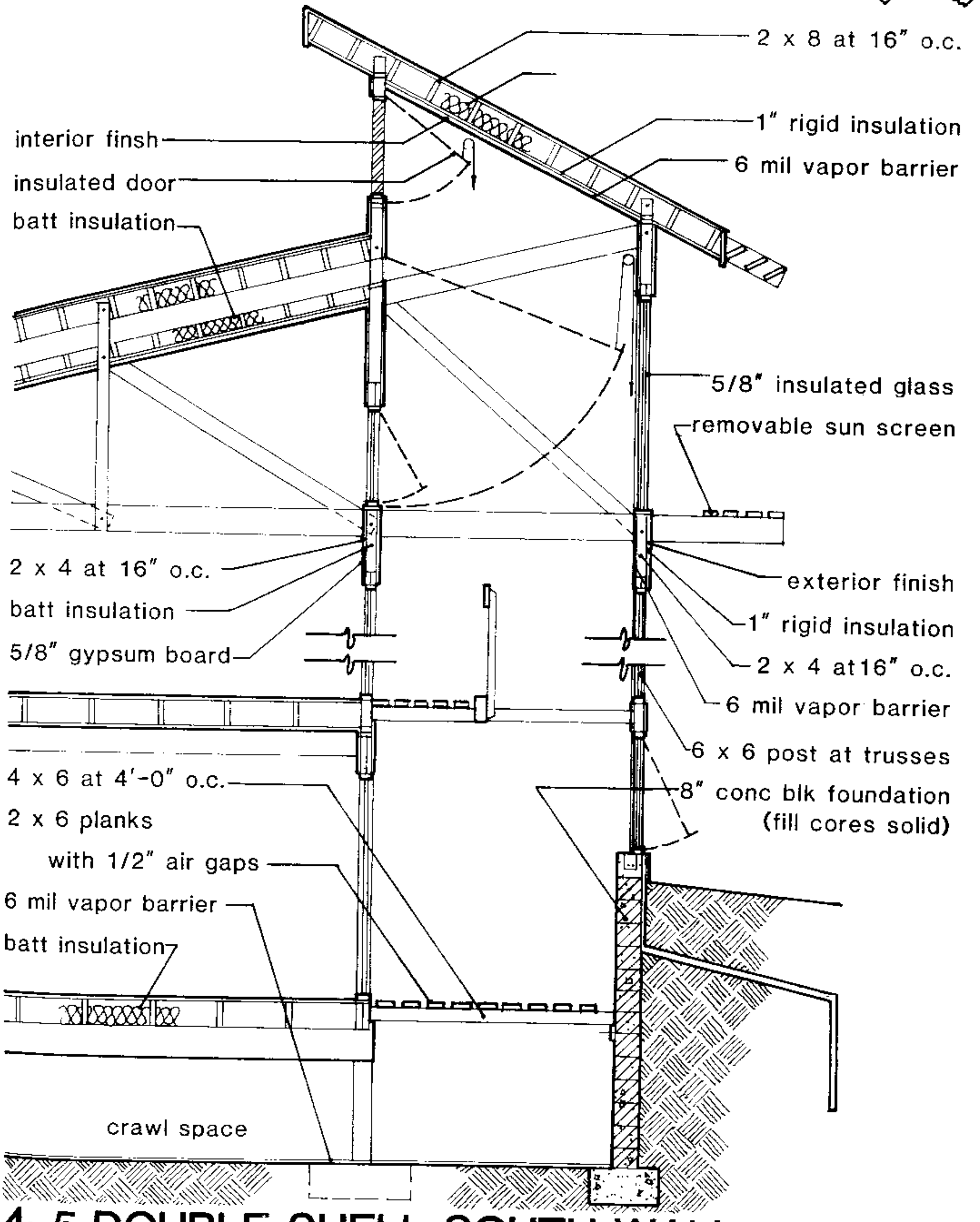
The south side of a double shell contains the greenhouse space (FIG 4-5). Note that there is only vertical glazing, unlike many double shell buildings which have sloped glazing. With Nebraska's hot summer climate, this vertical-glazing-only scheme is much easier to shade with overhangs to keep the greenhouse space and house cool. A hinged insulated door behind the louvers at the top of the greenhouse will exhaust superheated air. The awning window at the bottom of the south glazing will allow cool air into the space.

CONSTRUCTION DETAILS



4-4 DOUBLE SHELL NORTH WALL

scale: 1/4"=1'-0"



4–5 DOUBLE SHELL SOUTH WALL

scale 1/4" 1'-0"

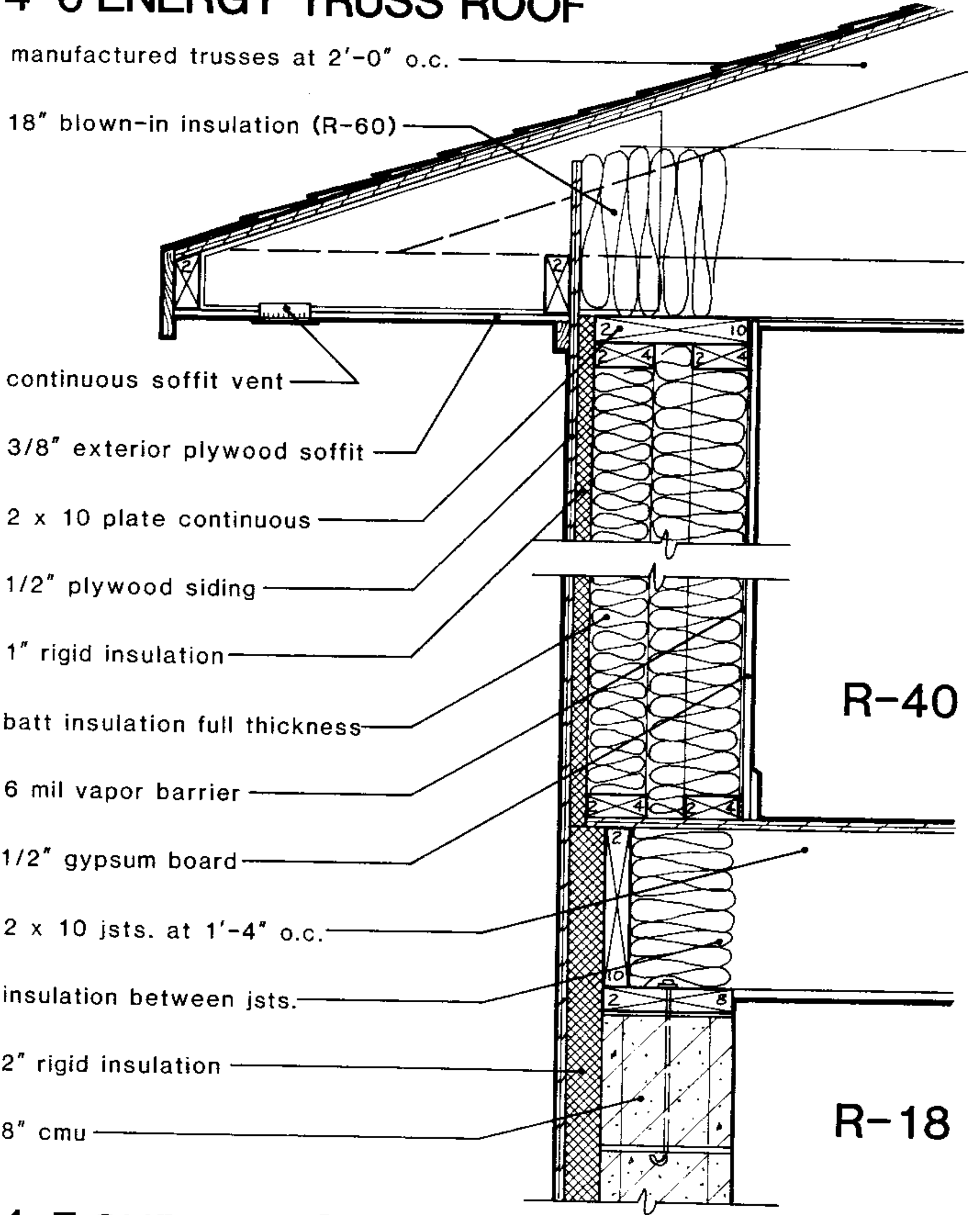
ENERGY TRUSS

The energy truss roof (FIG 4-6) is a modified wood truss which bears upon the lower cord or ceiling joist. This departure from the standard practice of bearing on the upper cord gives the energy truss greater depth for insulation, while allowing free air passage from the soffit vent to the attic space.

SUPER INSULATED

The super insulated wall system (FIG 4-6, 4-7) is one of several methods of using large amounts of insulation in a frame wall. The framing system consists of staggered 2x4 framing stud walls 2' on center. One 2x4 wall supports exterior siding while the other 2x4 wall supports the gypsum board on the inside. The 2x4 stud walls are separated by a 2-1/4" center space. By separating the stud walls in this manner, the transfer of heat directly through the studs to the outside is eliminated. Also, because the net wall width is greater than customary, the batt insulation throughout most of the wall is a full 11 1/4" and the minimum is 7 3/4". Combined with 1" of thermax insulation, the wall has a total R value of 40. The wall is extended over the joist to allow for the use of increased insulation around the foundation while maintaining a flush appearance. By placing rigid insulation on the exterior of the foundation, the block wall can be exposed to the interior; this adds thermal mass to the building.

4-6 ENERGY TRUSS ROOF



4-7 SUPER INSULATED WALL

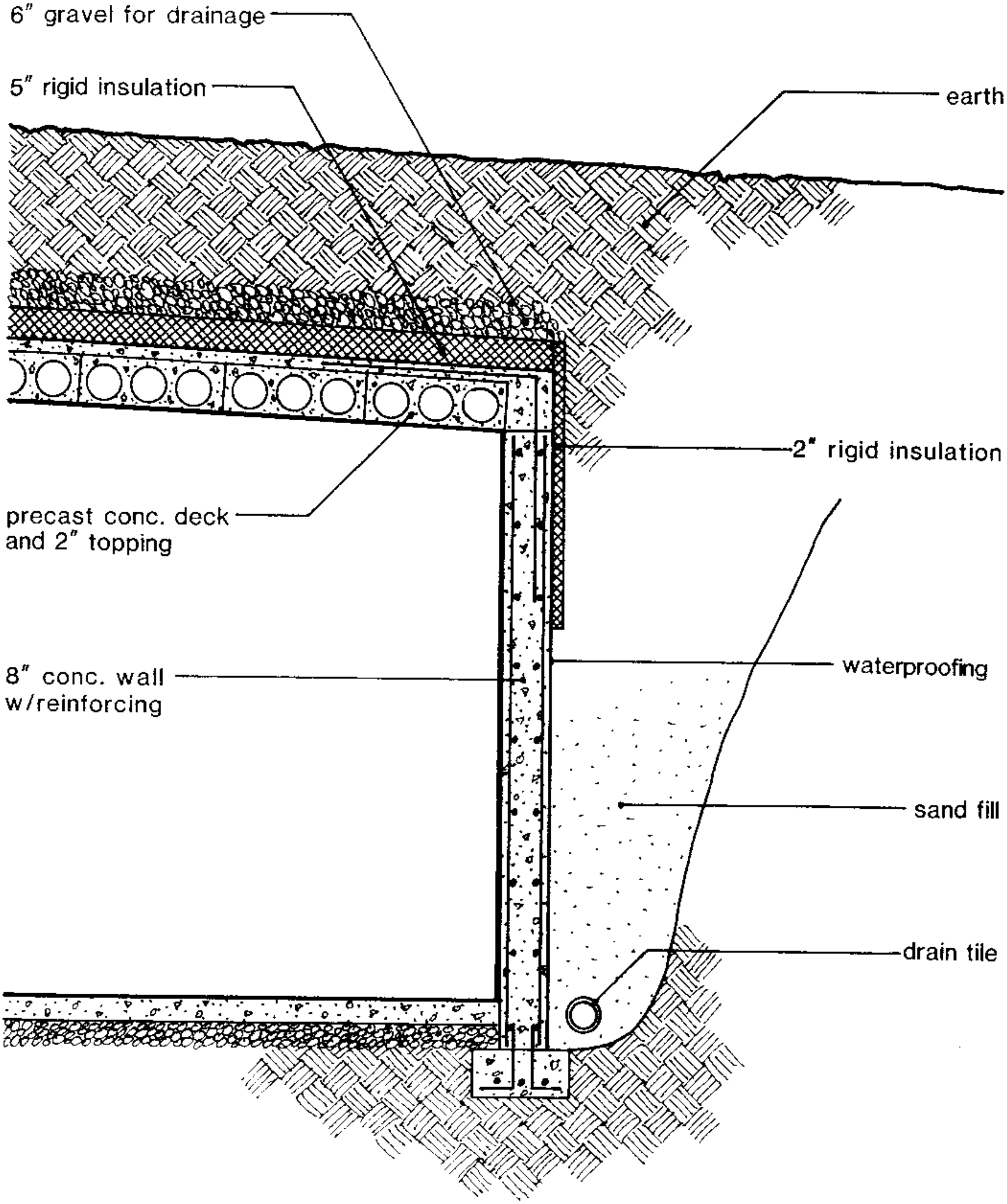
scale: 1 1/2" = 1'-0"

CONSTRUCTION DETAILS

EARTH SHELTERED

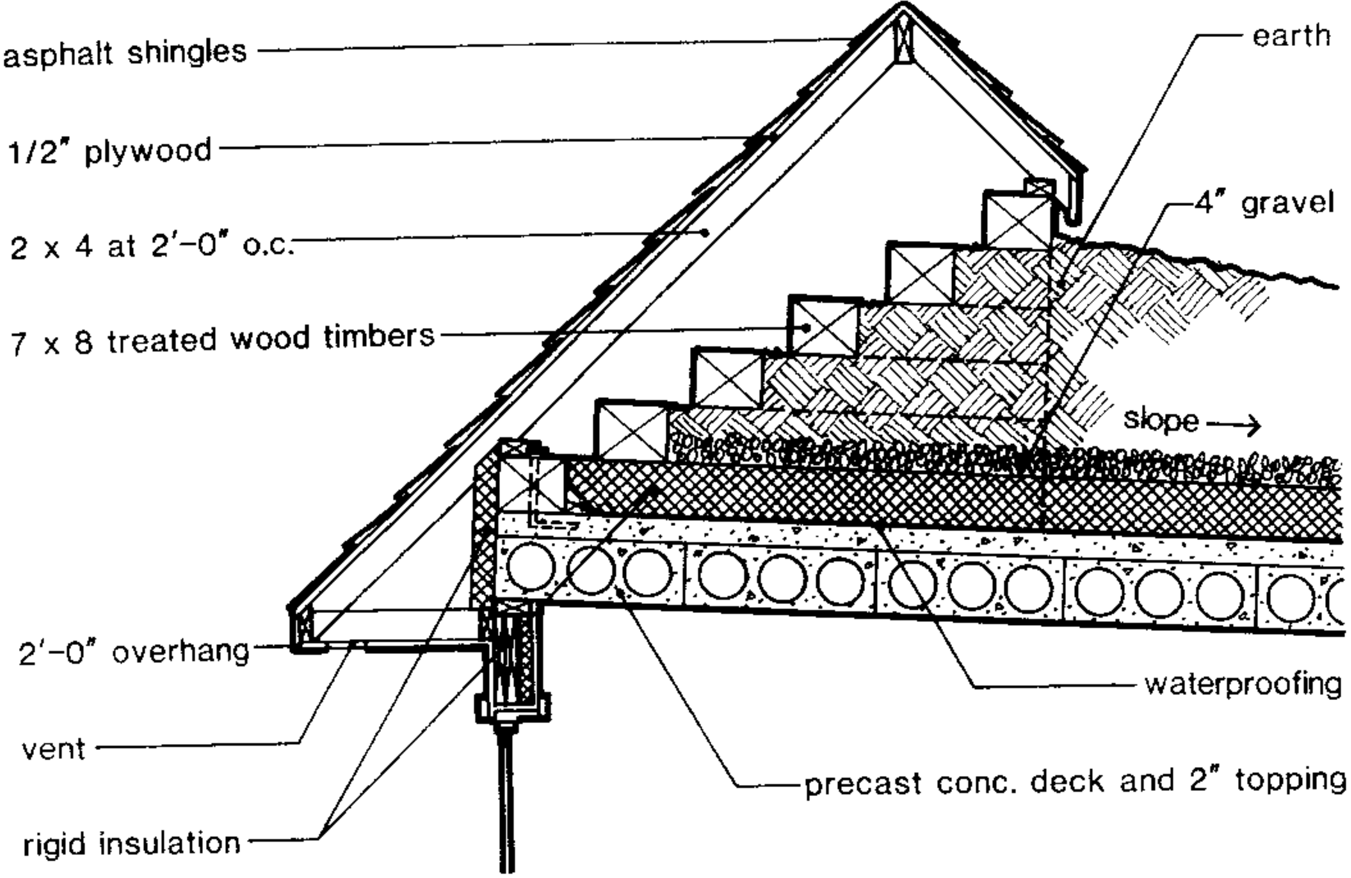
The earth sheltered wall section (FIG 4-8) is a reinforced poured concrete wall with a precast concrete roof deck. The roof deck should be sloped to provide positive drainage and prevent water from ponding in the middle of spans. The wall and roof should be waterproofed before the insulation is installed. Gravel backfill is placed over the insulation to provide drainage away from the insulation and the building. A drain tile at the bottom of the footing is used to carry water away from the building. In Nebraska, 12" to 24" of earth should maintain vegetation growth over the roof. Greater earth cover does little but add to the structural problems encountered in placing soil on a roof deck.

Two methods of retaining earth at the roof edge of an earth sheltered building are the mansard and canted parapets (FIG 4-9). The mansard parapet uses treated wood timbers that are stacked with each timber placed 1' behind the one below. This system prevents frozen ground from pushing against the parapet. The mansard roof can also prevent accidental falls from the roof, keep moisture away from the roof edge, and give a more conventional look to the structure. The canted parapet performs substantially the same function as the mansard but can be cheaper to build.

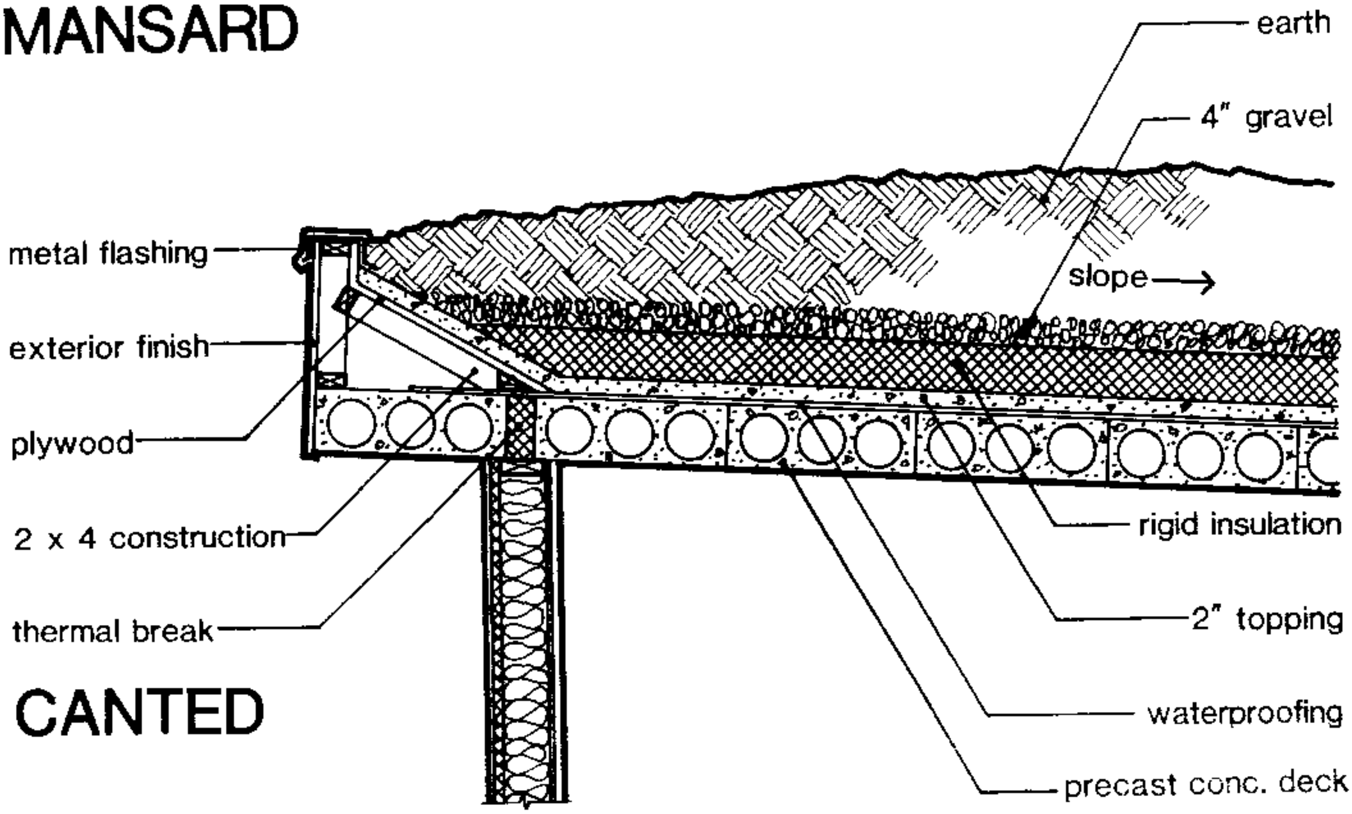


4–8 EARTH SHELTERED WALL

scale: 1/2 = 1'–0"



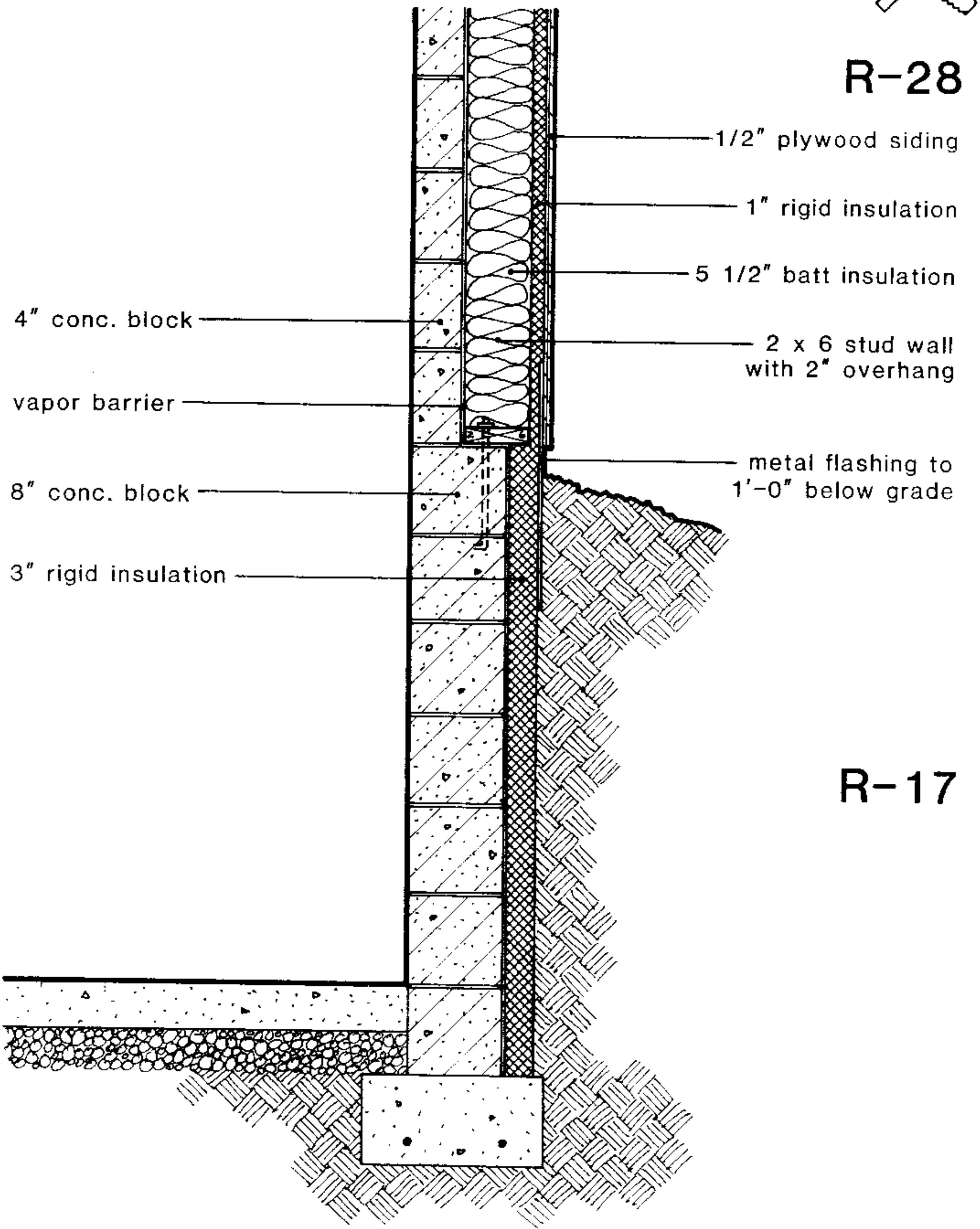
MANSARD



CANTED

4-9 EARTH SHELTERED PARAPETS

scale: 1/2" = 1'-0"



4-10 EARTH BERM

scale: 1" = 1'-0"

AT GRADE AND BELOW GRADE DETAILS

The earth berm detail (FIG 4-10) is typical of those used in many passive solar homes. The concrete block wall exposed to the interior acts as solar storage mass. The 2x6 stud wall insulates the mass from the cold outside and is extended over the foundation edge 2" to allow for increased insulation below grade.

There are a number of options in placing rigid insulation below grade. Insulation of uniform thickness down to the footing is easy to install but it is not the most effective use of the material (FIG 4-11). Insulating part-way down the wall provides greater insulation where it is needed most, near cold frozen ground. The lower portion of the wall is exposed to the ground which increases the potential for ground cooling during the summer (FIG 4-12). Overlapping insulation places the most insulation at the top while providing decreasing amounts of insulation to the bottom of the footing (FIG 4-13). This system can provide the greatest heat loss protection per square foot of insulation material available.

Another technique places insulation next to the wall for the first few feet below grade (FIG 4-14). Below the frost line, the insulation is extended at an angle down to a point level with the footing. This adds earth mass to the building mass without increasing material costs. One problem with this approach, however, is the extra cost involved in placing the backfill under and over the insulation. Settlement in the soil backfill can also create gaps in the insulation, resulting in a lower R value.

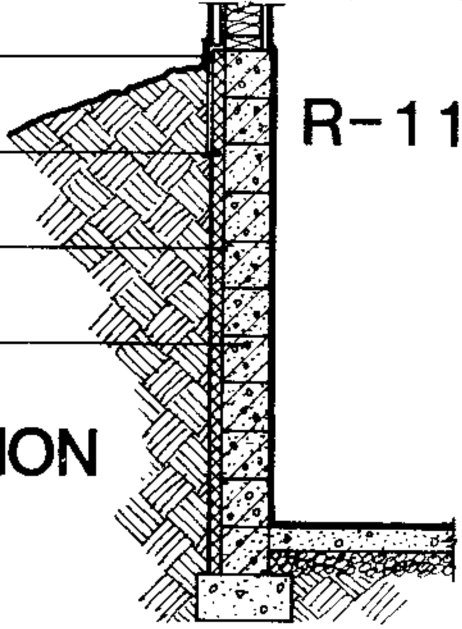
Cheaper batt insulation can also be used below grade on the exterior of the masonry foundation (FIG 4-15). To be successful, high grade waterproofing and drainage away from the foundation are needed to keep treated foundation-grade plywood from leaking.

All the preceding exterior insulation techniques require protection from damage during backfill as well as protection from deterioration due to exposure to sunlight. The method of protection may be dependent on the placement of the frame wall on the foundation.

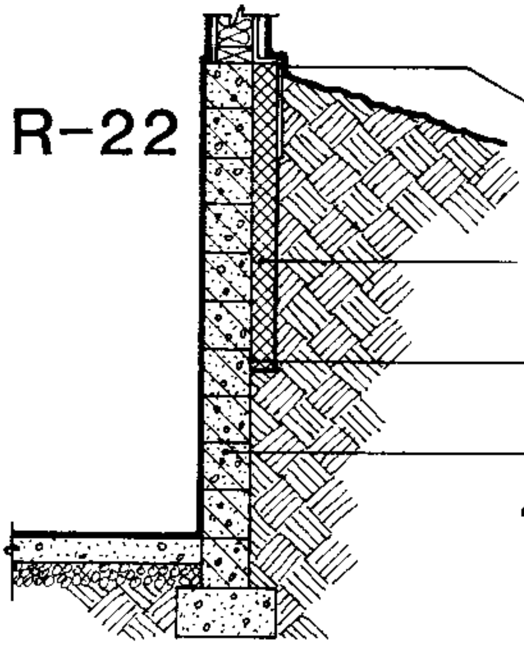
Flush insulation is very simple to install and protect with a band of flashing which extends 1' below grade and behind exterior siding material (FIG 4-16). Cantilevering the frame wall over the foundation increases insulation thickness levels at the foundation but requires metal flashing bent to seal the top of the foundation. If cantilevered placement is not used, the increased insulation can be extended and covered by bent metal flashing. Metal flashing can be galvanized metal (to prevent rusting), painted or anodized aluminum to match window and door trim.

Cement asbestos board or shingles can be nailed to the sill plate to mimic the look of concrete while protecting the rigid insulation (FIG 4-17).

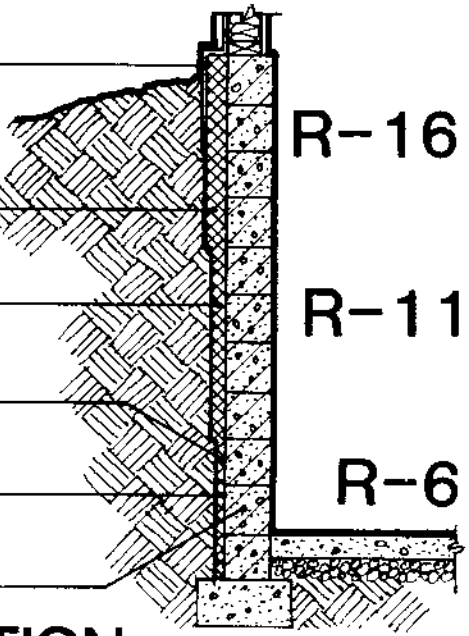
There are several products which can be used to coat rigid insulation, and those which are waterproof are ideal for exterior use (FIG 4-18). Most have fiberglass reinforcing mesh for strength.



4-11 CONTINUOUS INSULATION

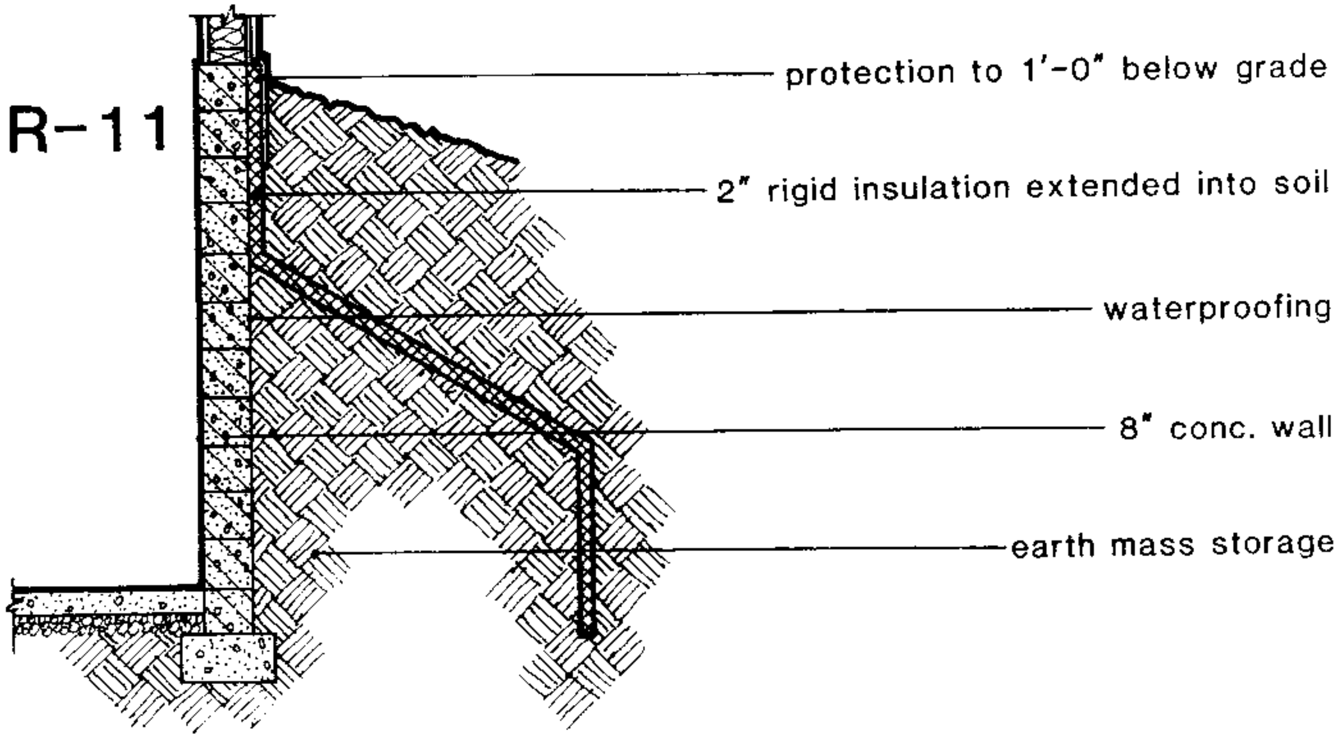


4-12 PARTIAL INSULATION



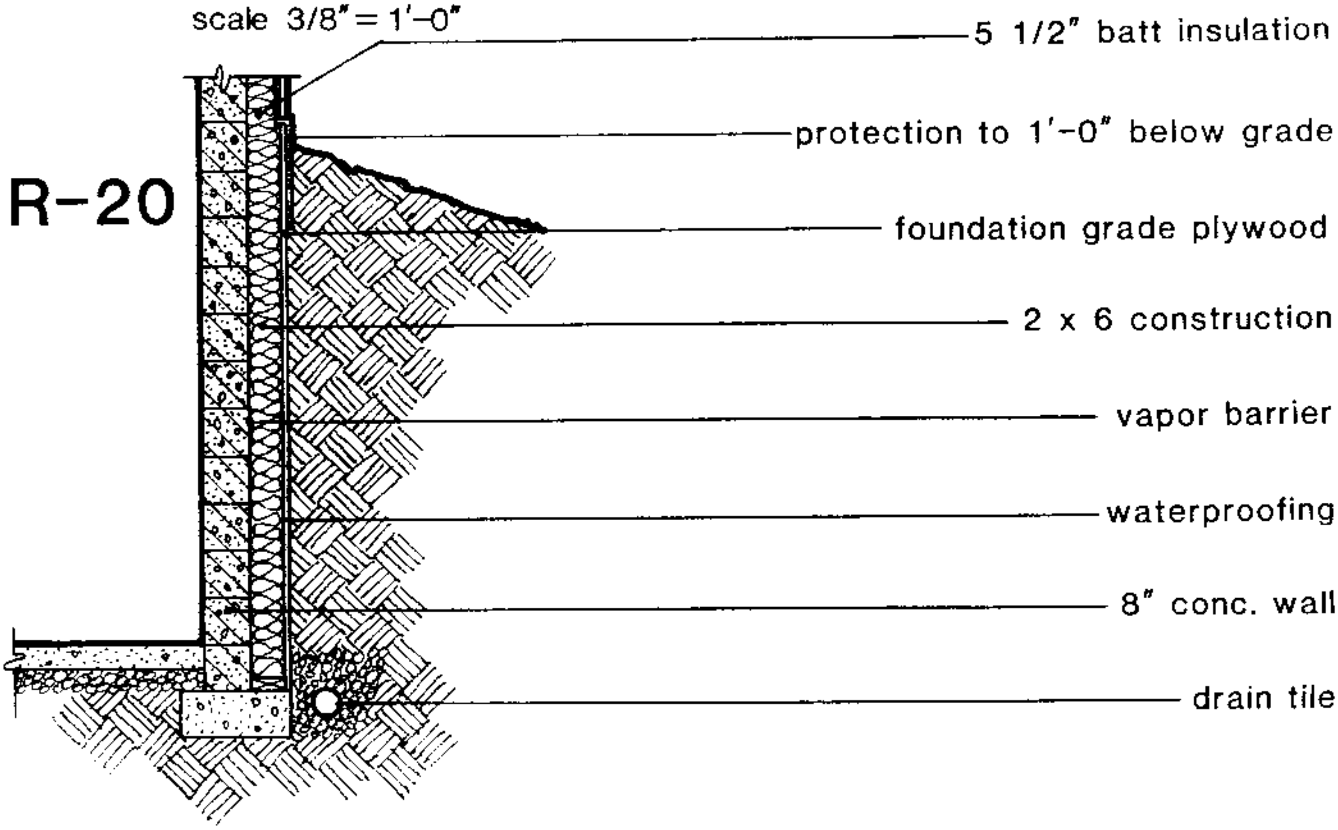
4-13 OVERLAPPING INSULATION

scale: 3/8" = 1'-0"



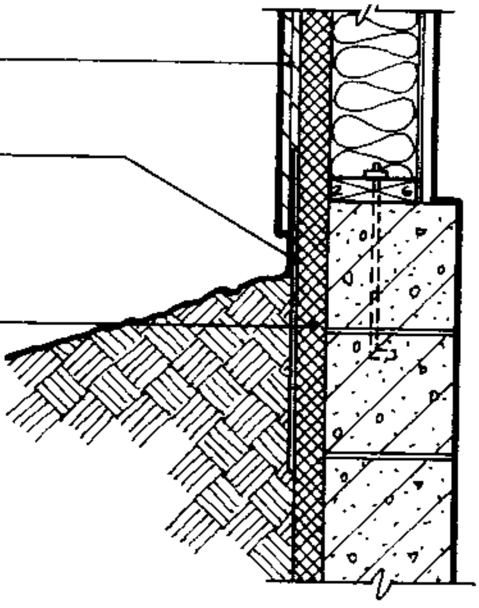
4-14 INSULATION EXTENDED INTO SOIL

scale 3/8"=1'-0"

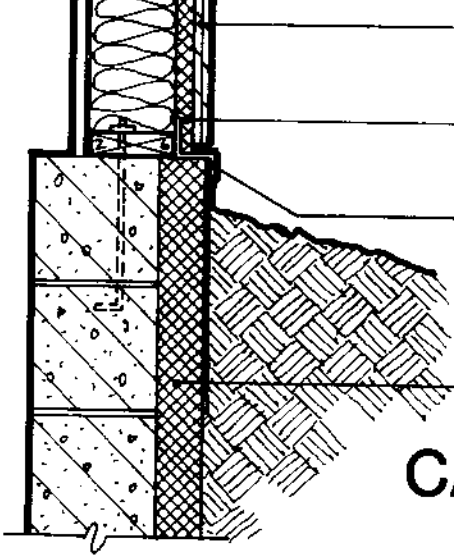


4-15 CONTINUOUS BATT INSULATION

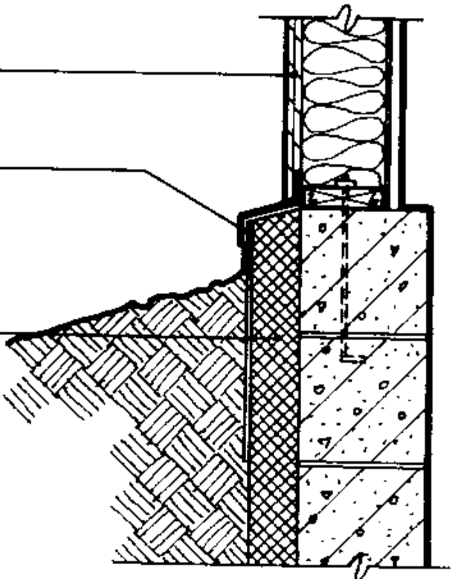
scale 3/8"=1'-0"



FLUSH



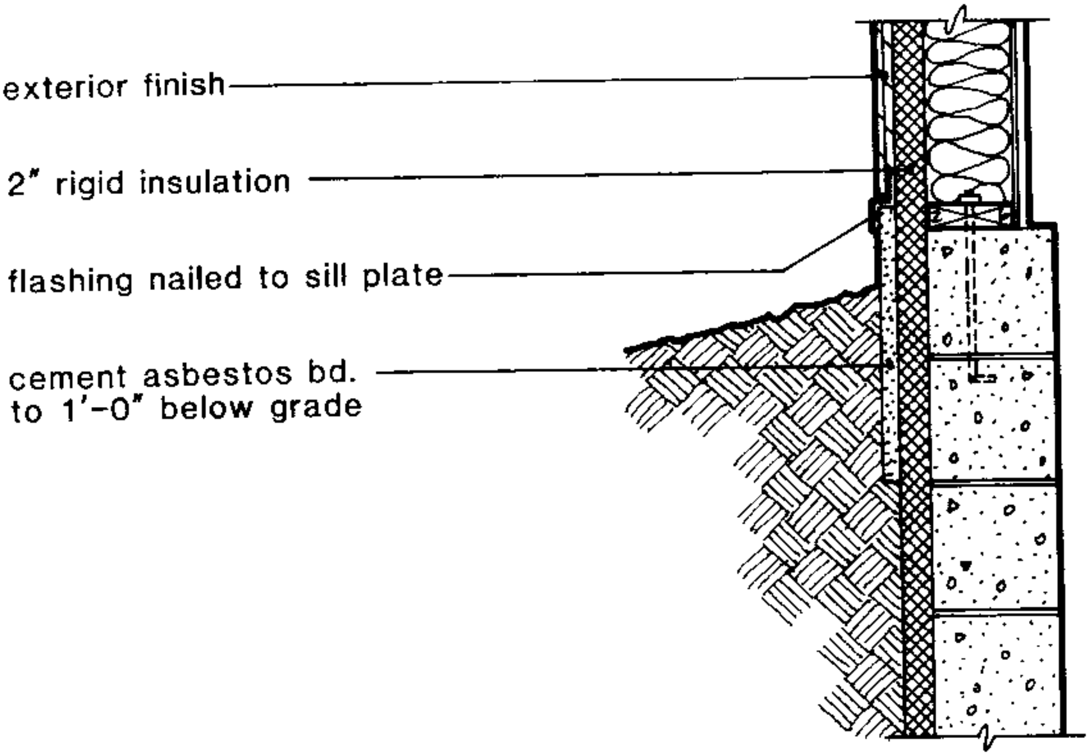
CANTILEVERED PLATE



EXTENDED

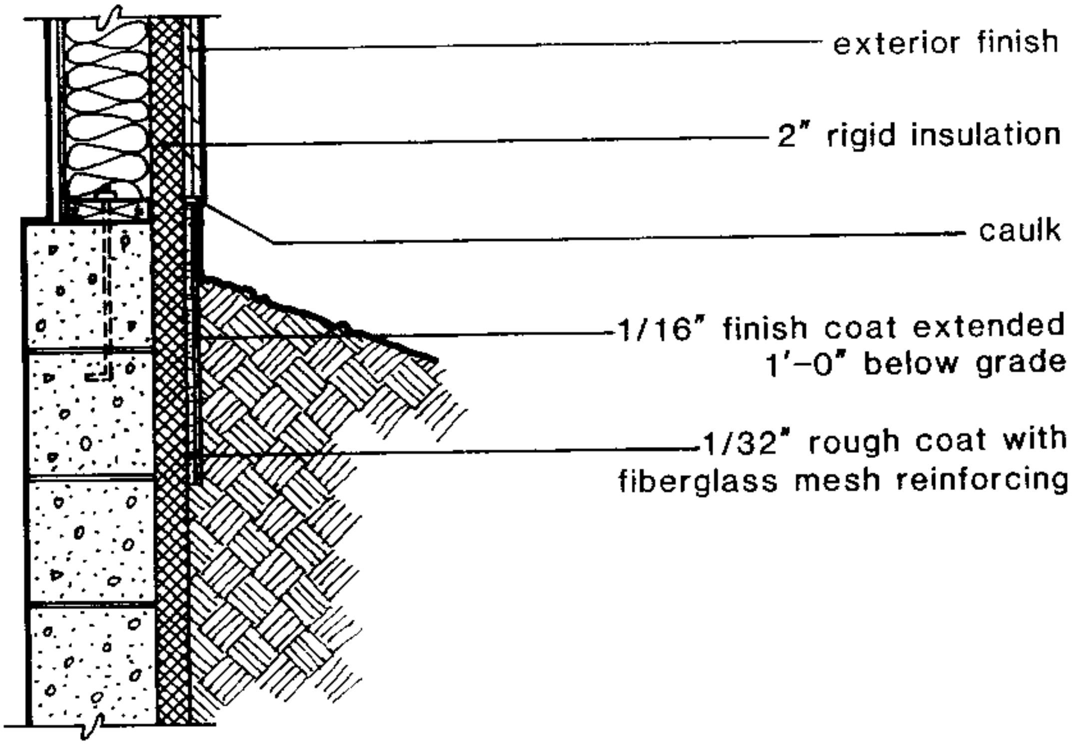
4–16 METAL FLASHING AT GRADE

scale 1"= 1'-0"



4-17 CEMENT ASBESTOS BD. AT GRADE

scale: 1"= 1'-0"



4-18 SKIM COAT AT GRADE

scale: 1"= 1'-0"

WALL SECTIONS

Rigid insulation is frequently used to insulate a masonry storage wall. A thin fiberglass reinforced coating gives the appearance of concrete or stucco and comes in several colors (FIG 4-19). This system works well on existing masonry structures.

For thicker rigid insulation installations, two furring strips can be attached to masonry (FIG 4-20). A lath system spans the rigid insulation and serves as a base for the stucco coating. Stucco on lath can also be held in place with wire ties inserted into masonry joints (FIG 4-21).

Wood furring strips placed vertically and horizontally can be used effectively in providing a well-insulated wall of minimal thickness which will receive conventional siding (FIG 4-22). A more typical approach to wall construction places rigid insulation between brick and concrete block (FIG 4-23). Another alternative uses a masonry storage wall as a structural wall. A wood stud wall provides insulation space and a nailing surface for siding (FIG 4-24).

Multi-layered gypsum board storage walls can be used to provide solar storage where heavier mass storage materials, such as concrete, masonry, and water, cannot be used (FIG 4-25). Although lighter in weight than most storage wall materials, gypsum board can be distributed over wall surfaces to provide necessary storage. The wall should be multi-layered if it will receive direct sunlight during a portion of the day, and the gypsum boards should be bonded together to eliminate airspaces.

A possible detail for super insulating a commercial building wall uses precast concrete double tees placed vertically (FIG 4-26). A new exterior finish leaves a 10" cavity for insulation, and the concrete facing the interior can be used as mass.

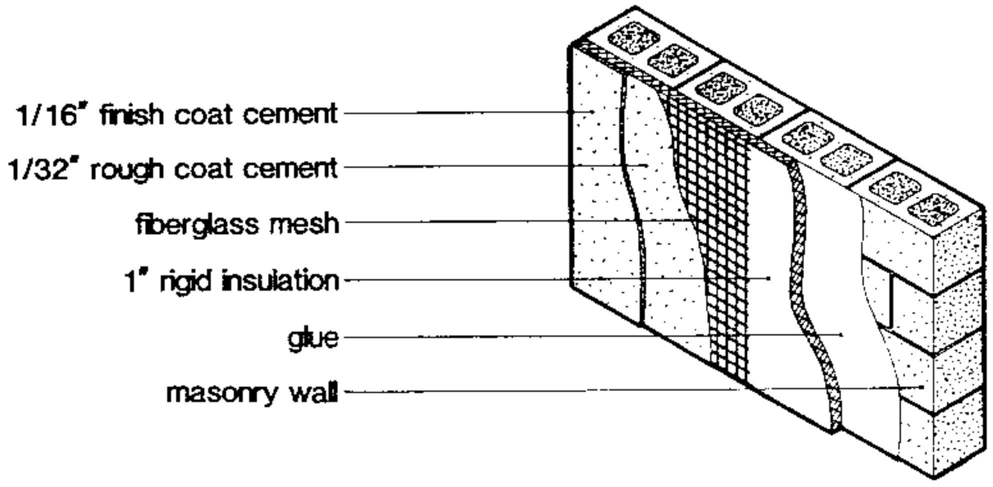
Where the exterior siding used does not permit the use of rigid insulation as sheathing, the rigid insulation should be placed on the interior between the stud wall and the gypsum wall (FIG 4-27). This application can be used in retrofit situations where interior finish material is removed; the exposed frame cavity makes the addition of batt insulation relatively easy.

Rigid insulation can replace sheathing on the exterior of a frame wall to isolate the stud from cold outside temperatures and retard the flow of heat through this insulation weakspot (FIG 4-28). Where rigid insulation is used in place of sheathing, care must be taken to ensure the structural stability which wall sheathing normally provides.

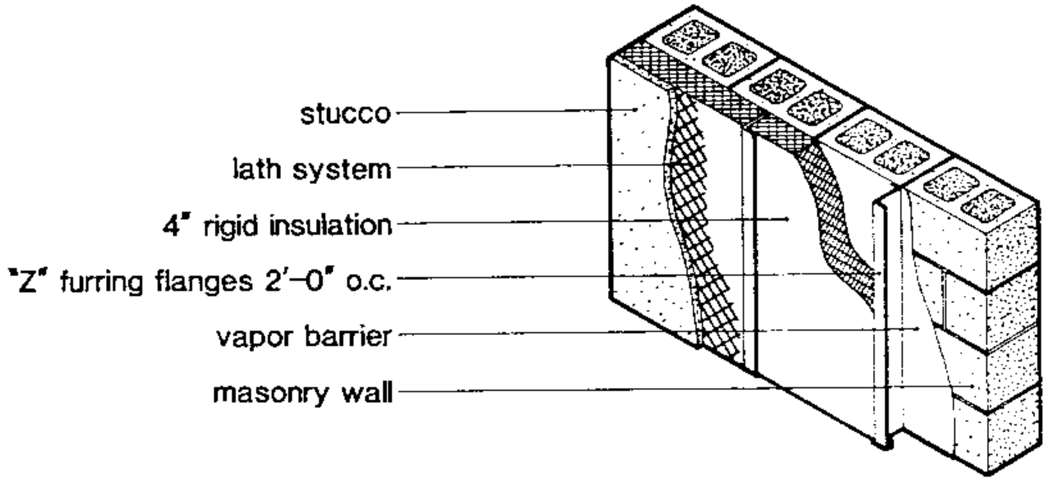
Rigid insulation placed on both the exterior and interior walls gives superior insulation with minumum stud width (FIG 4-29).

A super insulation scheme for walls uses a system of two 2x4 stud walls placed on a 2x10 sole plate creating an 11 1/4" insulation cavity (FIG 4-30). The double stud wall stops heat transfer from the inner wall to the outer wall. The exterior wall may be covered with a thin sheet of rigid insulation before siding is installed.

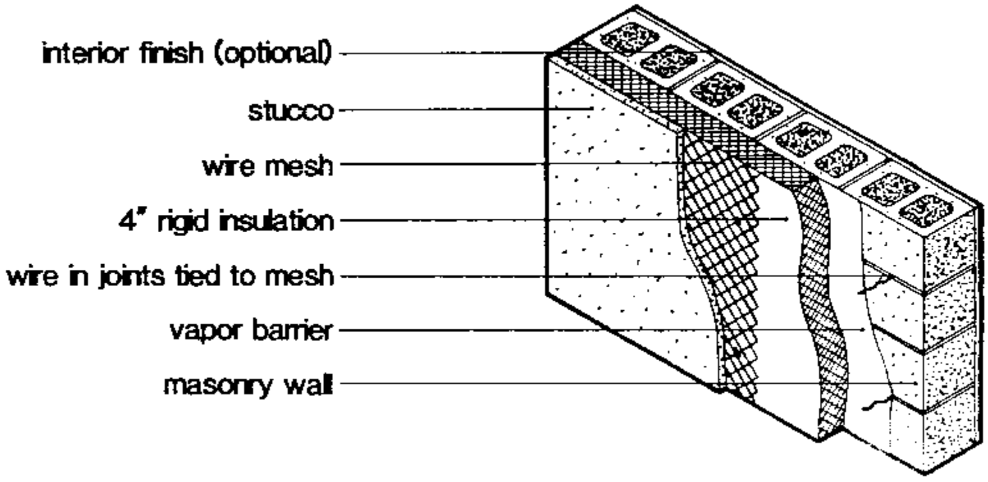
CONSTRUCTION DETAILS



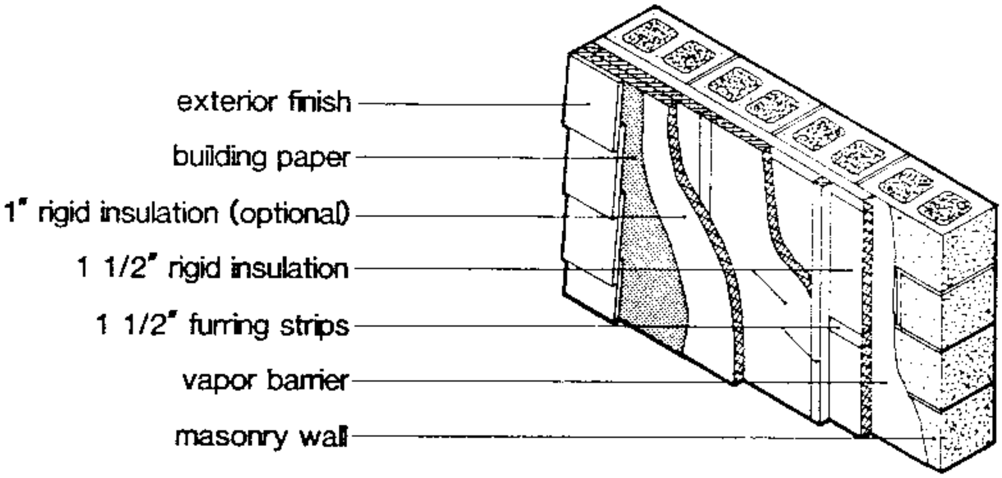
4-19 STORAGE WALL: SKIM COAT OVER FIBERGLASS MESH R-10



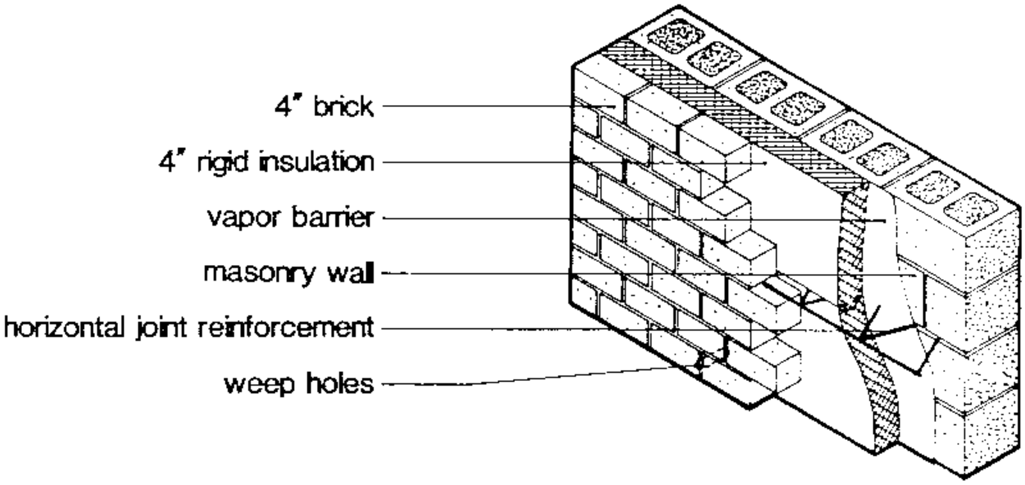
4-20 STORAGE WALL: STUCCO ON LATH WITH METAL FURRING STRIPS R-25



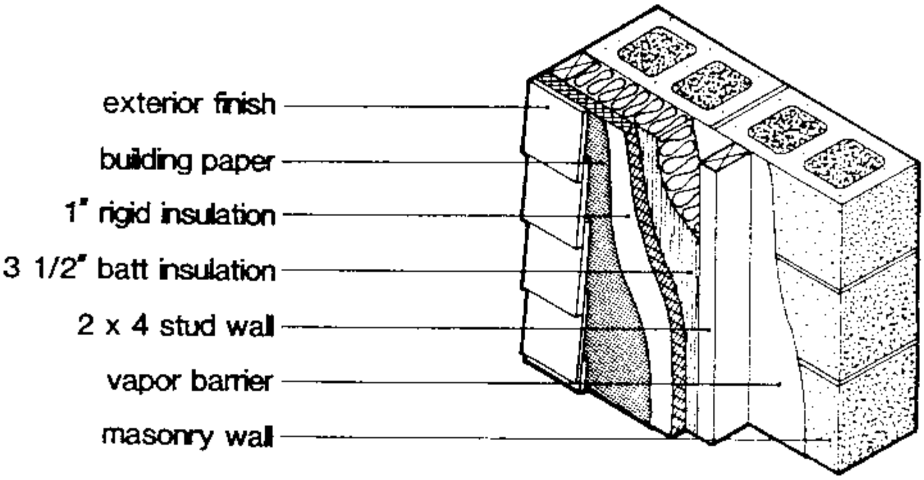
4-21 STORAGE WALL: STUCCO ON LATH WITH WIRE TIES R-25



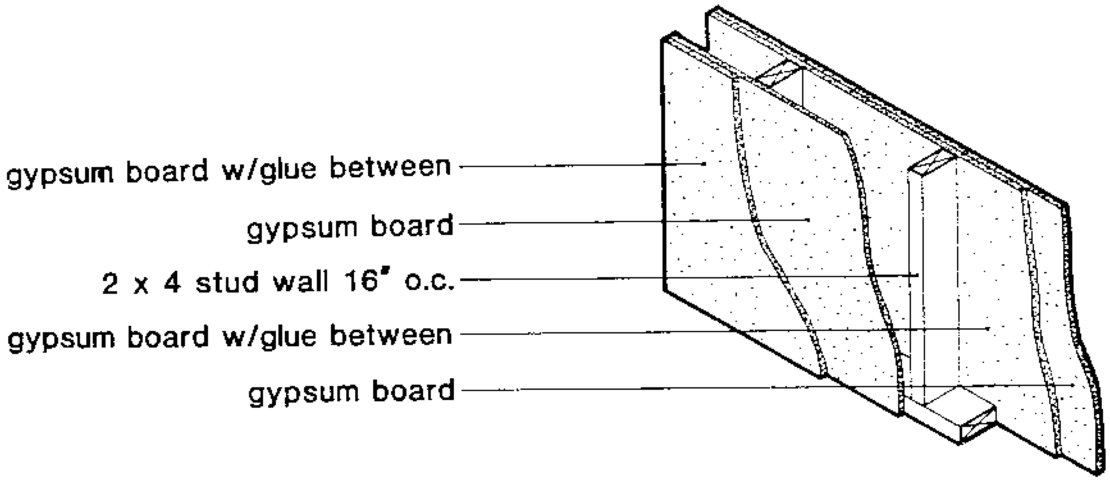
4-22 STORAGE WALL: SIDING ON WOOD FURRING STRIPS R-26



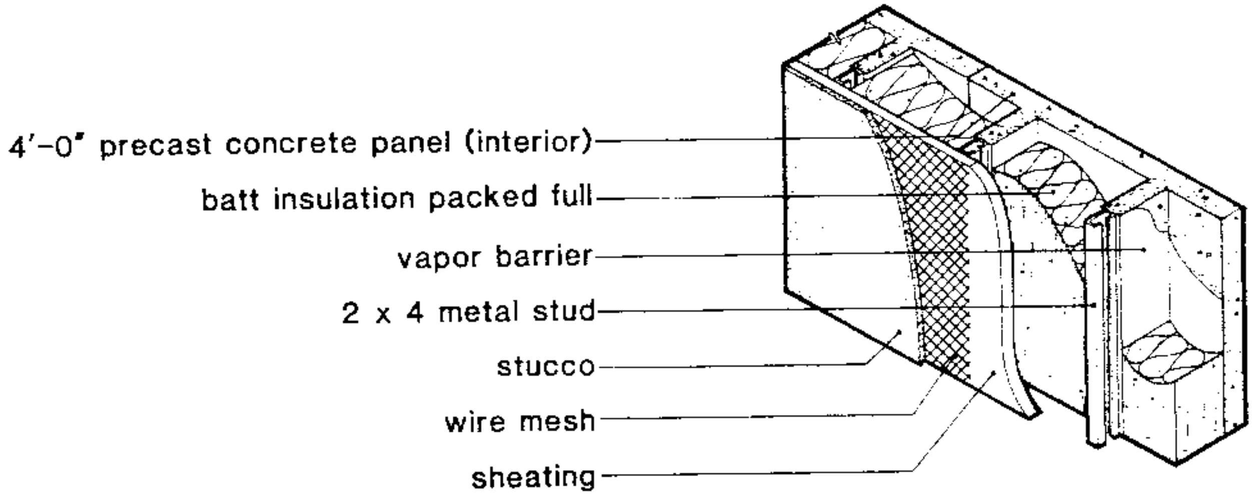
4-23 STORAGE WALL: INSULATED MASONRY CAVITY WALL R-26



4-24 STORAGE WALL: INSULATED STUDS & SIDING R-22

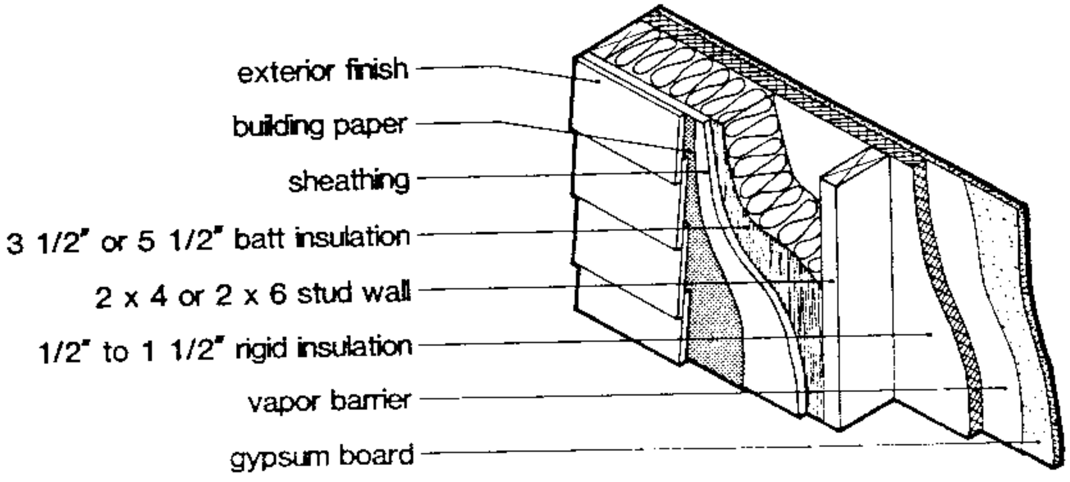


4-25 INTERIOR STORAGE WALL: MULTILAYERED GYPSUM



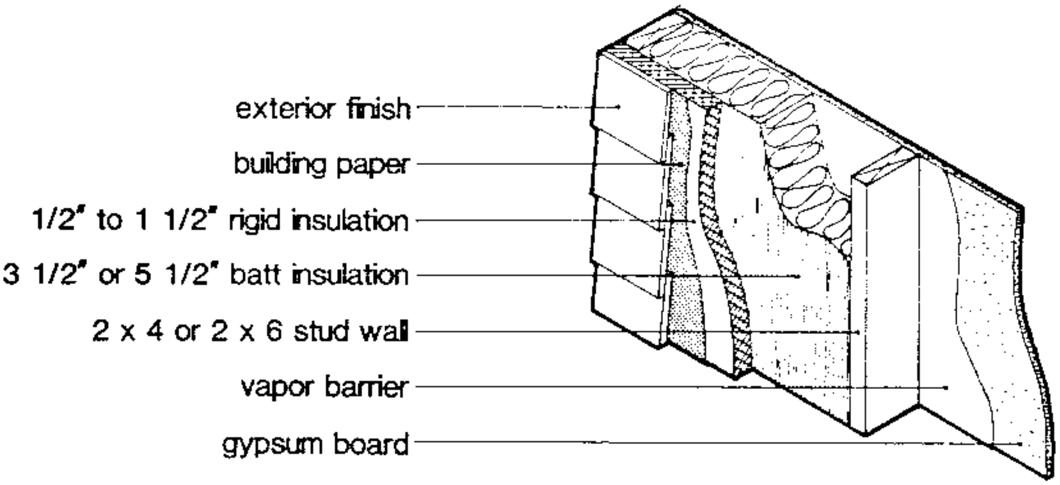
4-26 WALL: COMMERCIAL BUILDING

R-32

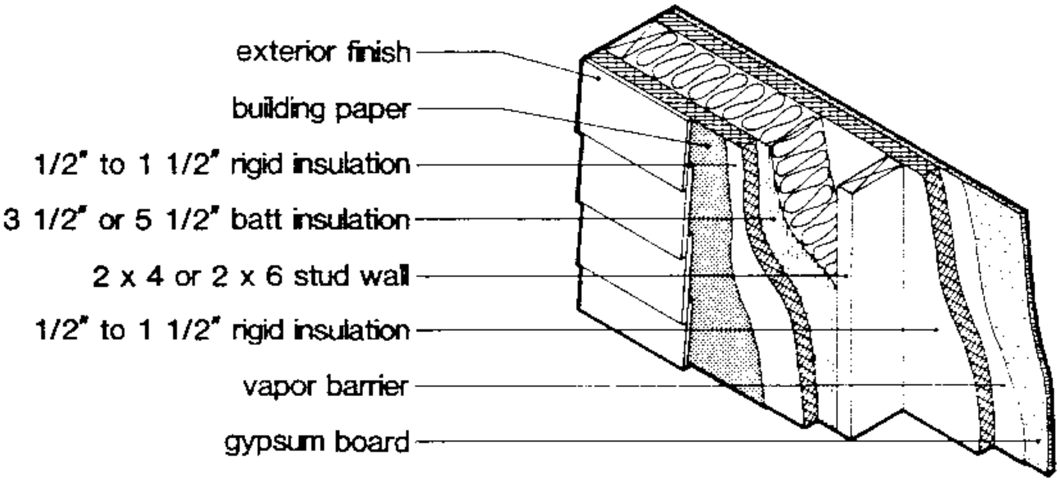


R-28

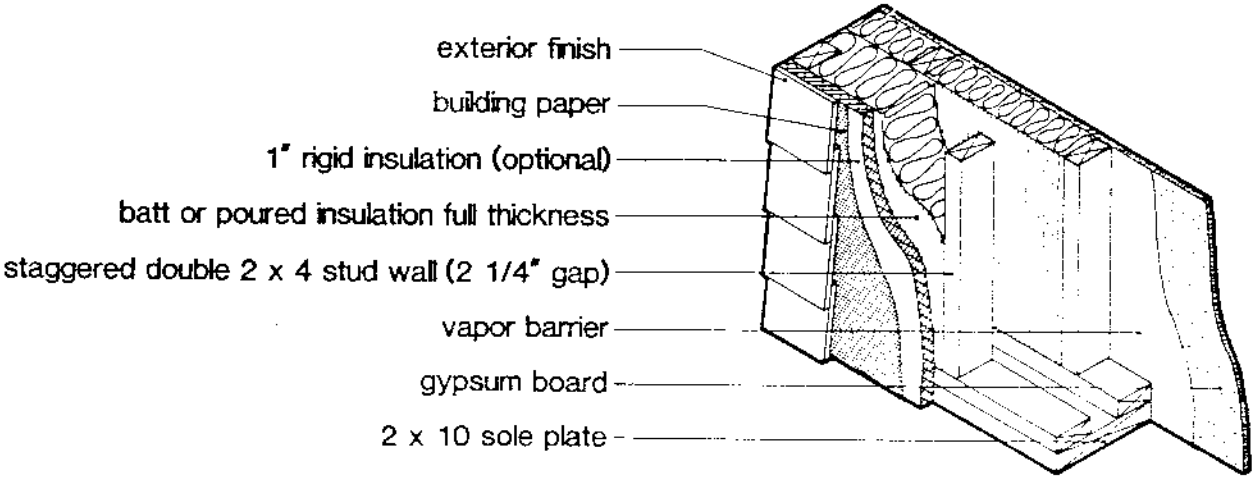
4-27 WALL: RIGID INSULATION INSIDE



4-28 WALL: RIGID INSULATION OUTSIDE R-28



4-29 WALL: RIGID INSULATION INSIDE & OUTSIDE R-35



4-30 WALL: SUPER INSULATED R-40

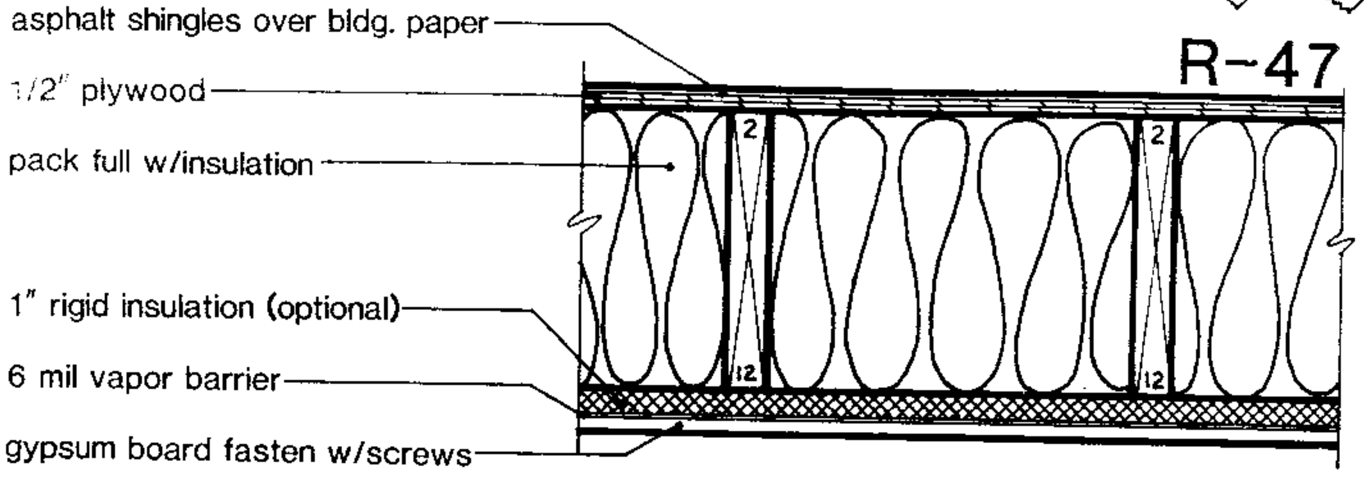
ROOFS

The cathedral ceiling shown has insulation completely filling the cavity space with neither ridge nor eave vents being used (FIG 4-31). When using this option, the insulation must be protected by a tight fitting vapor barrier to stop moisture generated in the house. Air spaces left in the ceiling will trap heat which radiates into the space. This system gives maximum insulation values within the framing depth, and rigid insulation placed between the bottom of the rafters and the gypsum board can further raise these values. The use of rigid insulation requires longer nails or long screws to hold it in place.

An alternative cathedral roof scheme is not filled completely with batt insulation (FIG 4-32), instead a 2" air space is left to vent moisture and, in summer, excess heat. Additional rigid insulation may be required to equal the R value of the preceding cathedral roof detail.

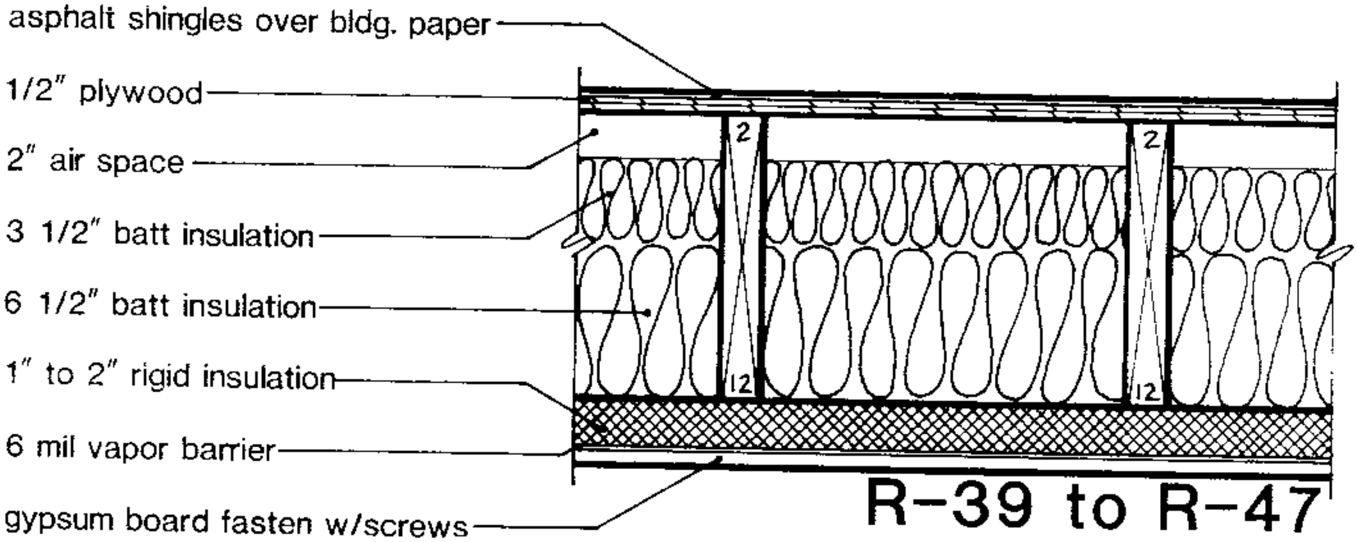
The double shell roof (FIG 4-33) has a greater amount of insulation in the roof and a lesser amount over the interior ceiling joists. The cavity should be free from obstructions for unrestricted airflow and be protected from moisture by a vapor barrier on the warm side of the roof and ceiling frames.

The wood truss roof (FIG 4-34) effectively controls framing costs while providing a deep cavity for insulation placement as well as a few inches of venting space.



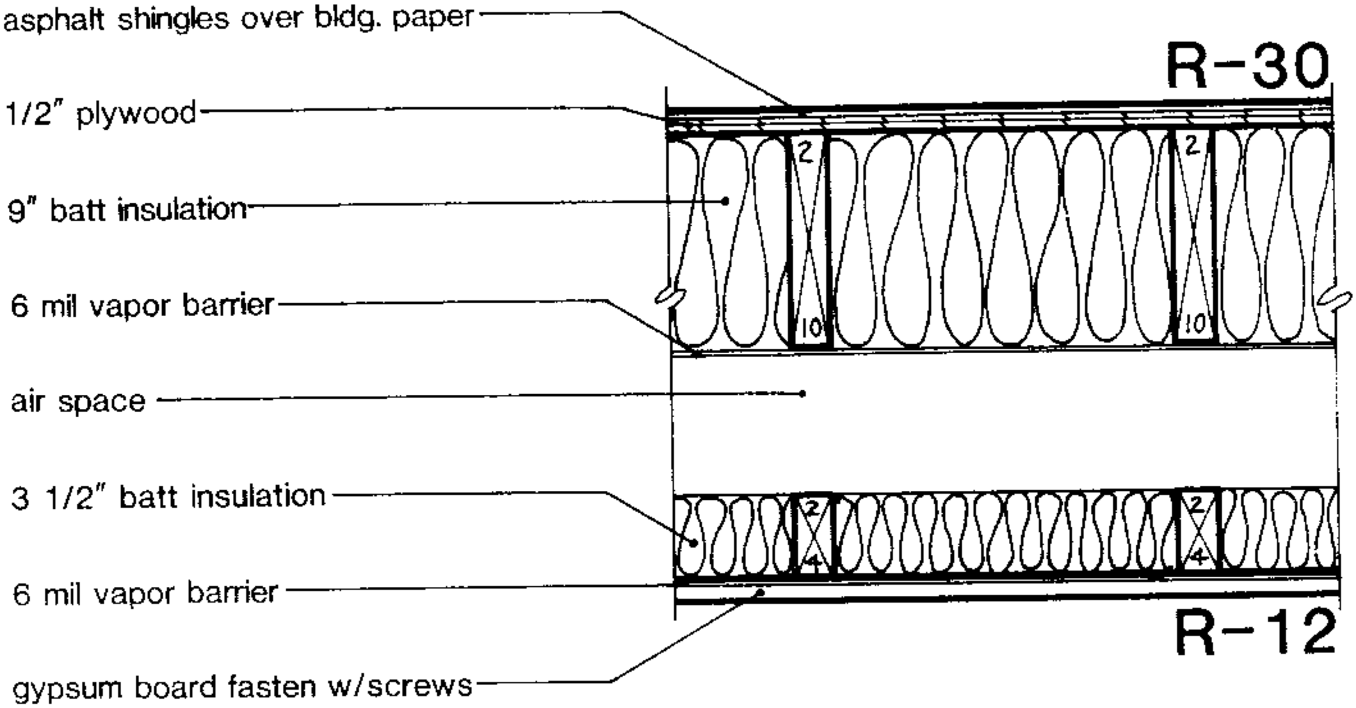
4-31 ROOF: CATHEDRAL PACKED FULL

scale: 1 1/2" = 1'-0"



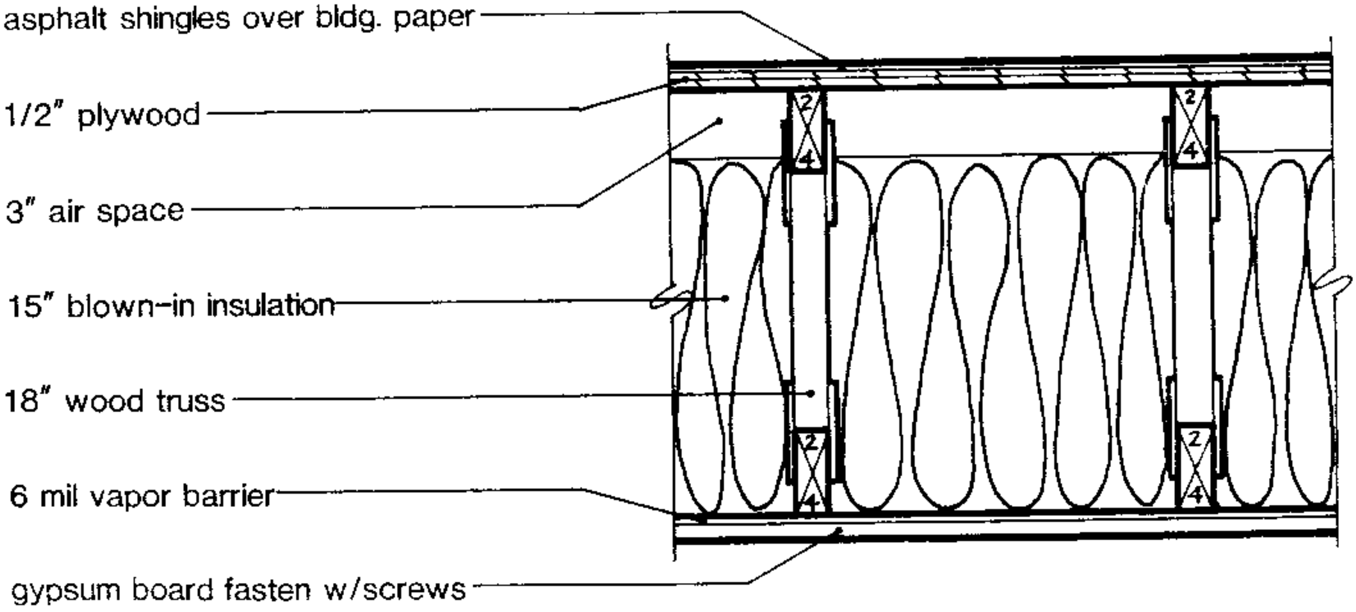
4-32 ROOF: CATHEDRAL WITH AIR SPACE

scale: 1 1/2" = 1'-0"



4-33 ROOF: DOUBLE SHELL R-42

scale: 1 1/2" = 1'-0"



4-34 ROOF: WOOD TRUSS R-50

scale: 1 1/2" = 1'-0"

FLOORS

The concrete storage floor (FIG 4-35), a standard commercial construction technique, is very effective when placed in direct sunlight. The slab can be thickest where the sunlight strikes, tapering to a standard depth in shaded areas. The floor can be painted a dark color to increase absorption and should not be carpeted, although small rugs can be used sparingly.

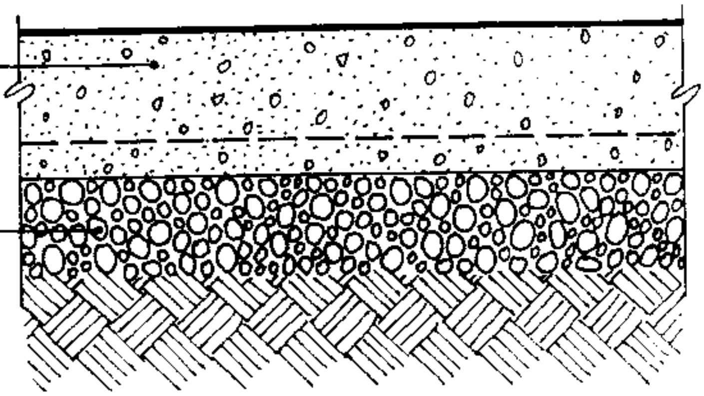
Brick pavers can cover the concrete slab for a more attractive appearance (FIG 4-36). Dark colors and non-reflective surfaces should be selected to aid in energy absorption.

PVC pipes imbedded in a concrete slab can increase the heat transfer to the concrete mass (FIG 4-37). Solar heated room air can be moved by fans from the warmest areas of the building through air ducts to a manifold which directs air to the individual pipes in the concrete.

Quarry tile can be added to a wood joist floor by placing the tile in a 1 1/2" concrete bed or adhering it directly to the plywood deck (FIG 4-38). When sizing wood floor joists, consideration must be given to the extra deadweight of the concrete or tile. Quarry tile should be dark in color and non-reflective in finish.

Concrete slabs on a steel deck and joist system are commonly used in commercial construction (FIG 4-39). This method of solar storage works well because it transfers heat to two levels of a building at the same time. Heat radiates from the slab to the upper level as well as to the lower level (provided the deck is not covered by carpet and the underside of the joist is not covered by a finished ceiling).

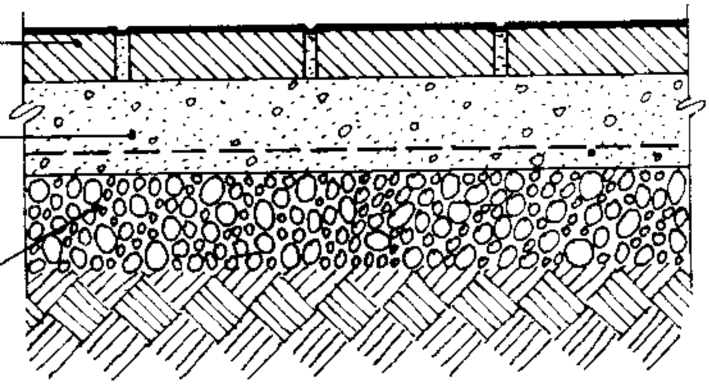
Precast concrete planks can function much like PVC pipe buried in a concrete slab in transferring heat to the deck (FIG 4-40). The planks have the advantage of being a radiant surface to two levels of a structure, like the concrete on a steel deck and joist system, and give the added benefit of a finished ceiling to the space below.



4" to 6" conc. slab
w/wire mesh reinforcing

4" granular fill

4–35 CONC. STORAGE FLOOR
scale: 1"=1'-0"

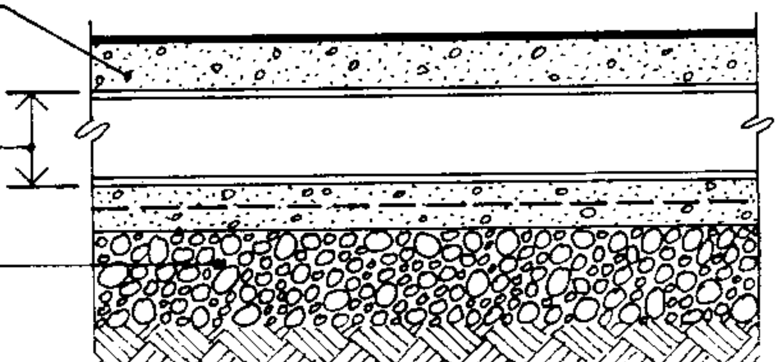


2" brick pavers

3" to 4" conc. slab
w/wire mesh reinforcing

4" granular fill

4–36 BRICK STORAGE FLOOR
scale 1 1/2"= 1'-0"

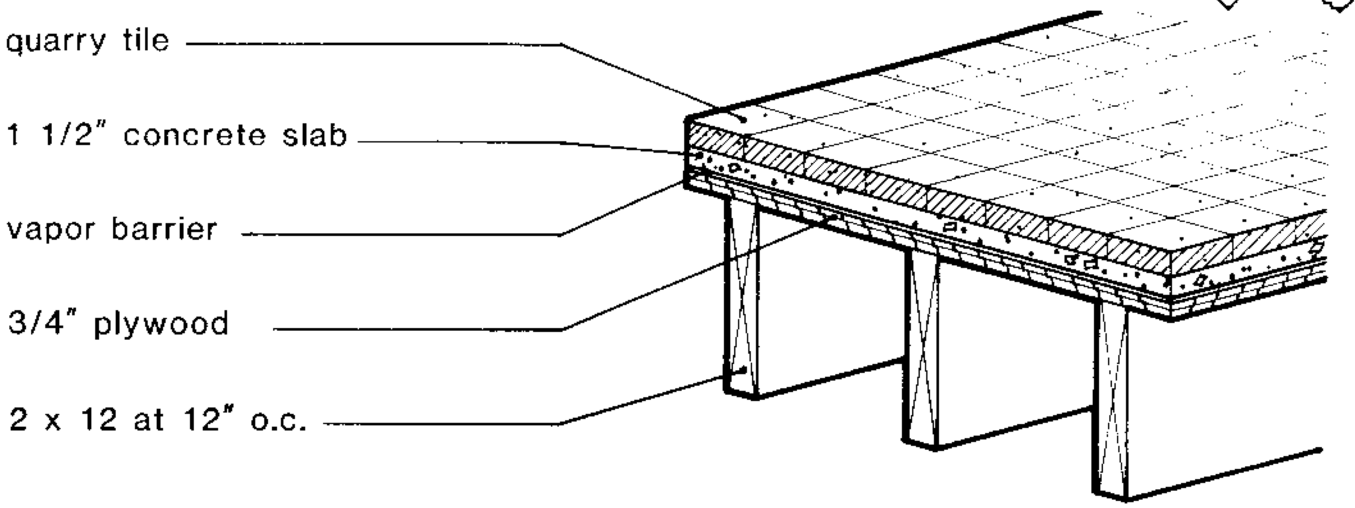


6" to 8" conc. slab
w/wire mesh reinforcing

3" or 4" pvc pipe in slab

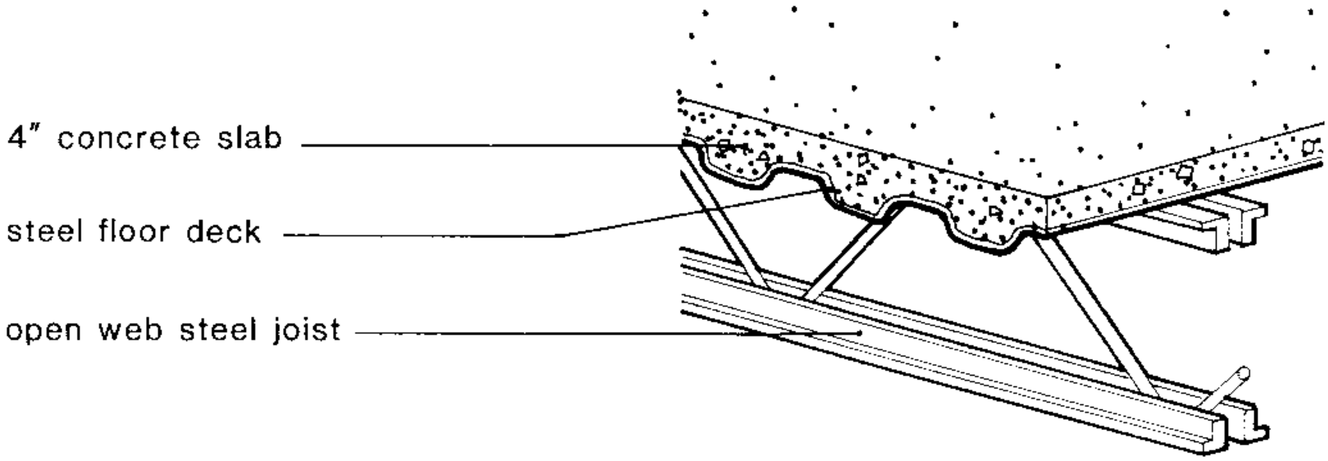
4" granular fill

4–37 PVC IN CONC. SLAB
scale 1 1/2" = 1'-0"



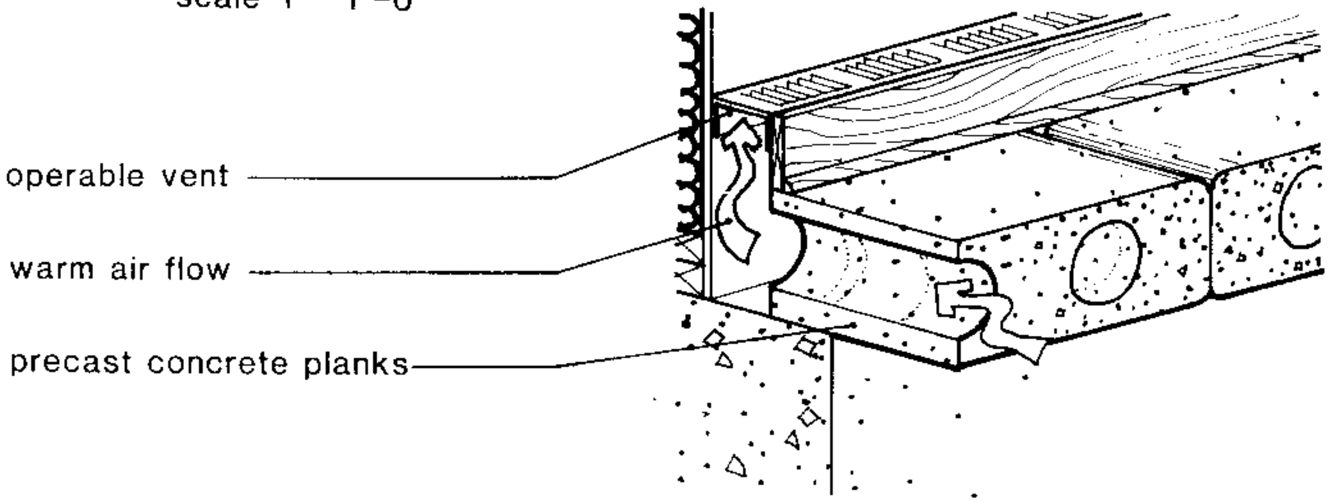
4–38 FLOOR: QUARRY TILE ON JOISTS

scale:1"= 1'–0"



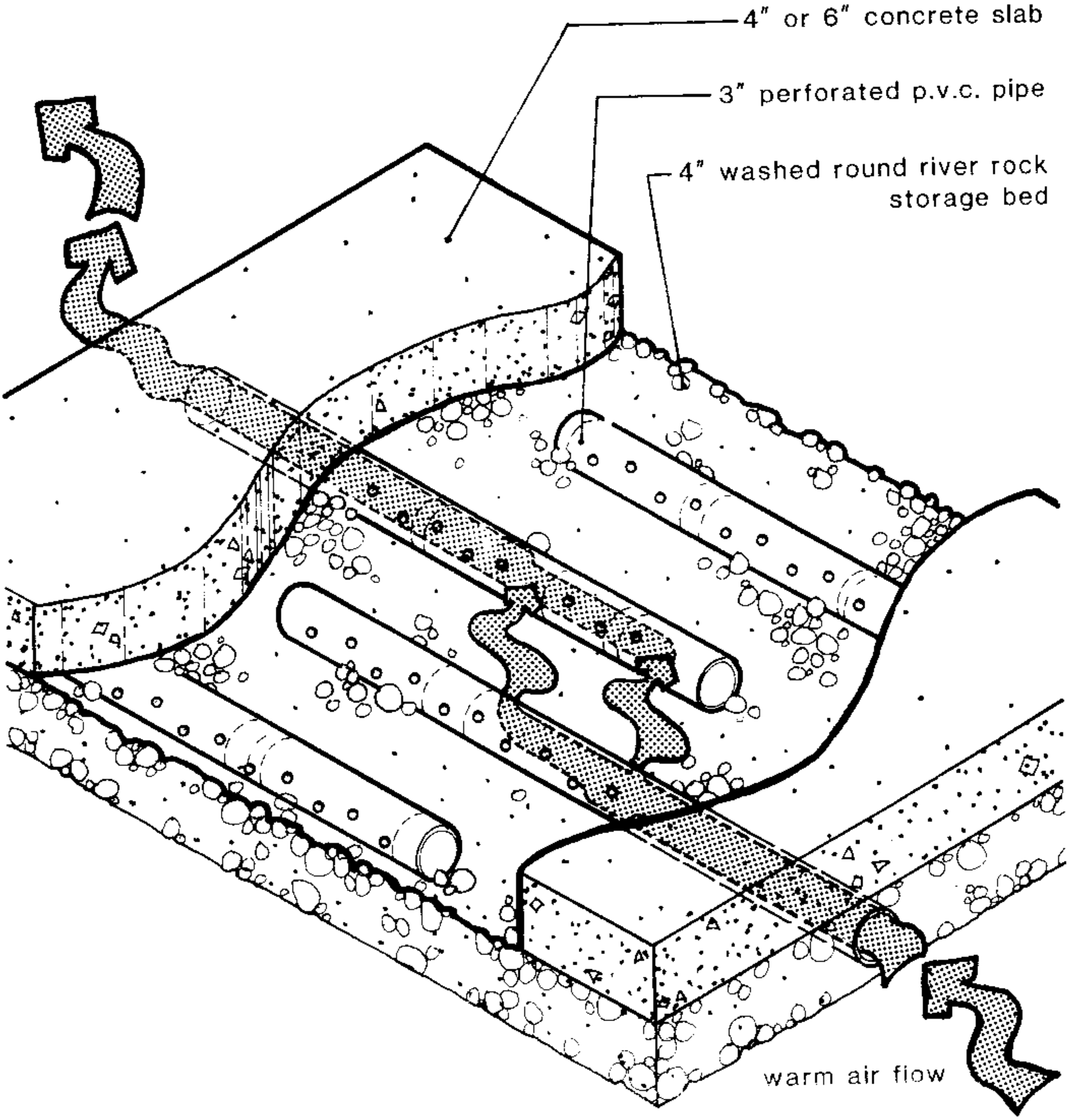
4–39 FLOOR: CONC. ON JOISTS

scale 1" 1'–0"



4–40 FLOOR: PRECAST CONC. PLANKS

scale 1" 1'–0"



4–41 FLOOR: FINGER SYSTEM

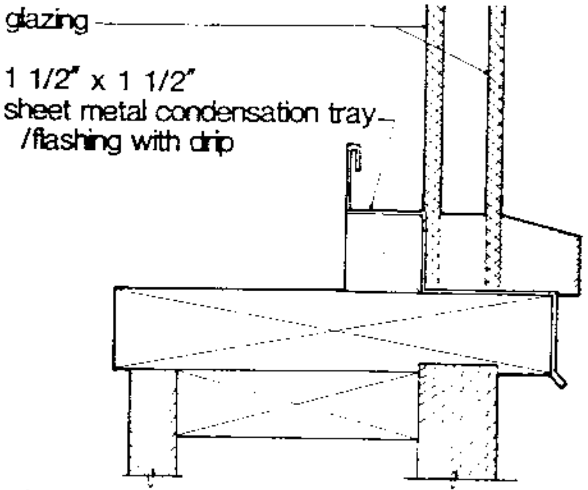
MISCELLANEOUS DETAILS

The finger floor slab system (FIG 4-41) is a conventional concrete slab over a 4" round river rockbed through which air can be moved in a horizontal charge configuration. This system provides the benefits of a rockbed system without the expensive, time- and space-consuming drawbacks of traditional rockbed systems.

Early morning condensation on glass in damp spaces such as greeenhouses and bathrooms can be a problem. A condensation tray gives the water condensate a place to collect and evaporate from while protecting wood windows from rotting (FIG 4-42).

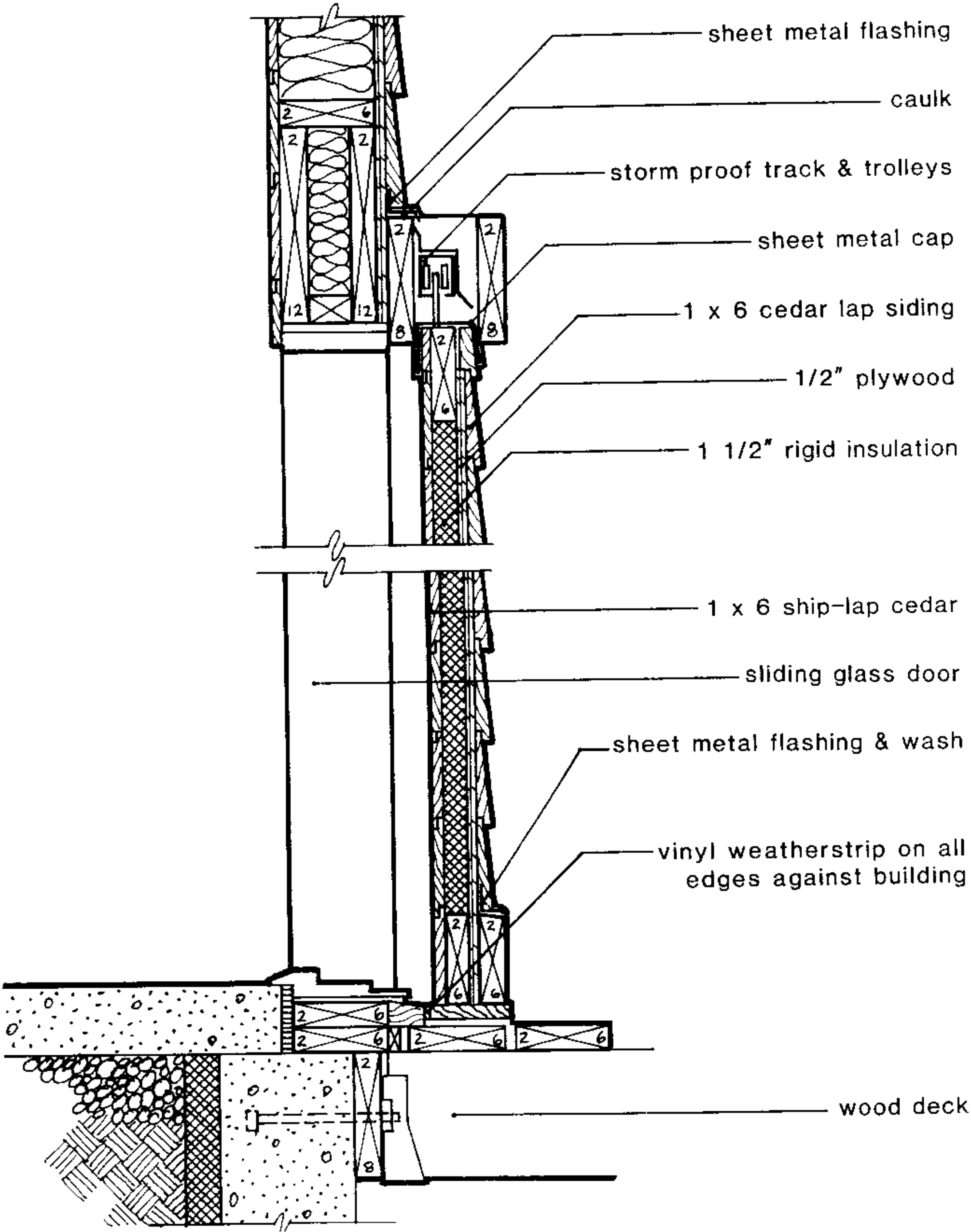
Exterior movable insulation prevents heat loss and solves window condensation problems by keeping the glass surface warm. In a storm-proof track and trolley system (FIG 4-43), the insulation slides out of the way during the day. The weight of the panel ensures a tight seal at the bottom of the track.

Interior movable insulation systems can be designed to be lightweight, inexpensive and removable. The system (FIG 4-44) can be designed to accept any thickness of panel by altering the width of the block separating the pieces of the bulletin board molding frame. The bottom edge of the fabric-covered rigid insulation panel should be protected with a plastic channel.



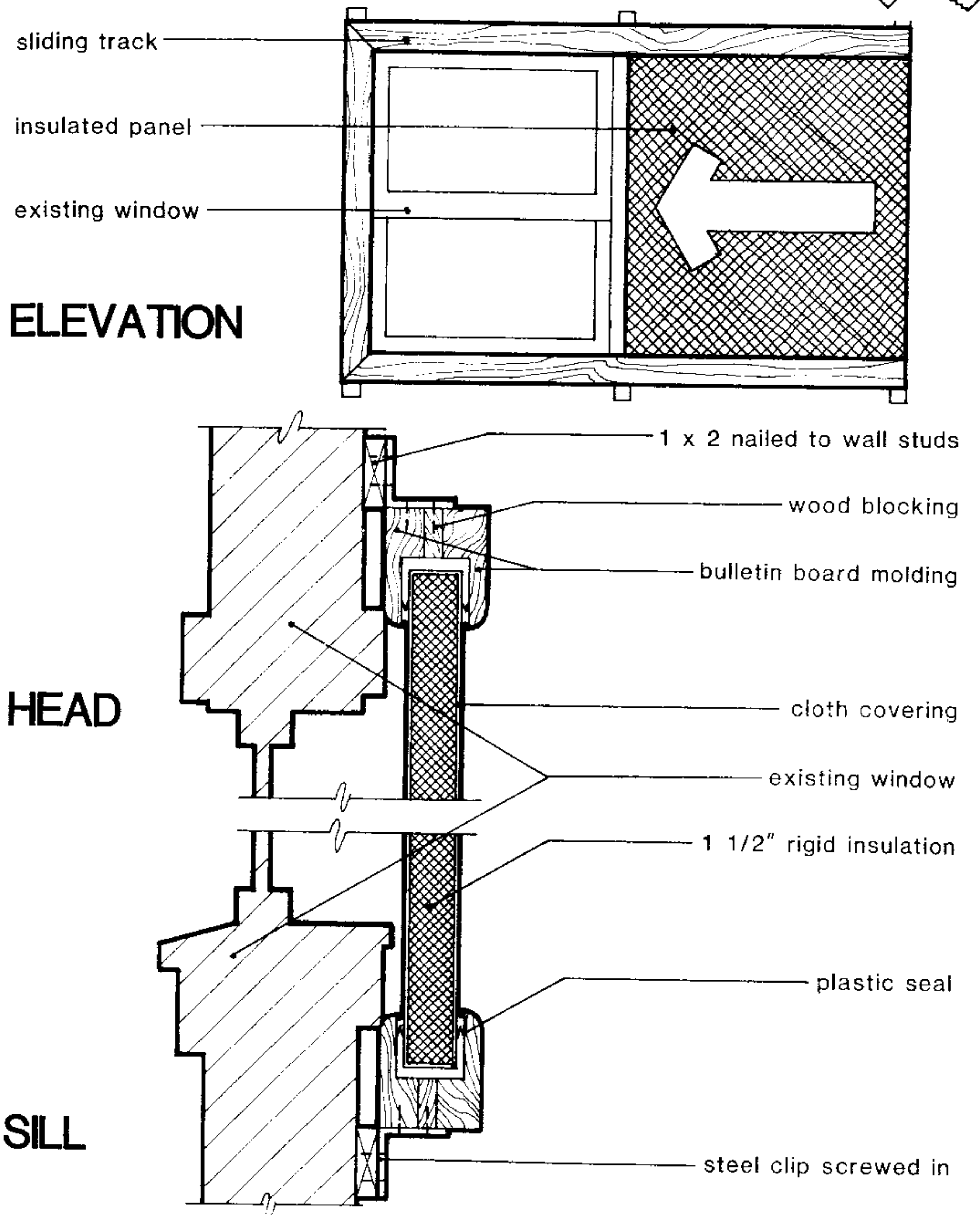
4-42 WINDOW SILL: CONDENSATION TRAY

CONSTRUCTION DETAILS



4-43 WINDOW: OUTSIDE MOVABLE INSUL.

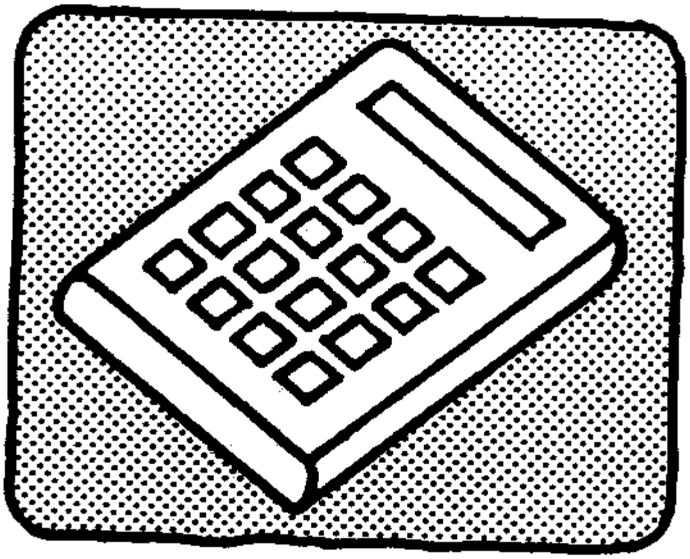
scale 1 1/2" = 1'-0"



4-44 WINDOW: INSIDE MOVABLE INSUL.
scale 3"= 1'-0"

CHAPTER 5
ENGINEERING

This chapter provides the information necessary to perform engineering calculations which predict the annual energy performance of a passive solar home.



ENGINEERING

Engineering calculations are performed to determine 1) the predicted heating requirements of a particular house design, 2) how much of the predicted heating requirements can be supplied by a passive solar energy system, and 3) how the house compares in performance with other solar and non-solar designs, i.e., when enough has been done to make the design energy-conscious.

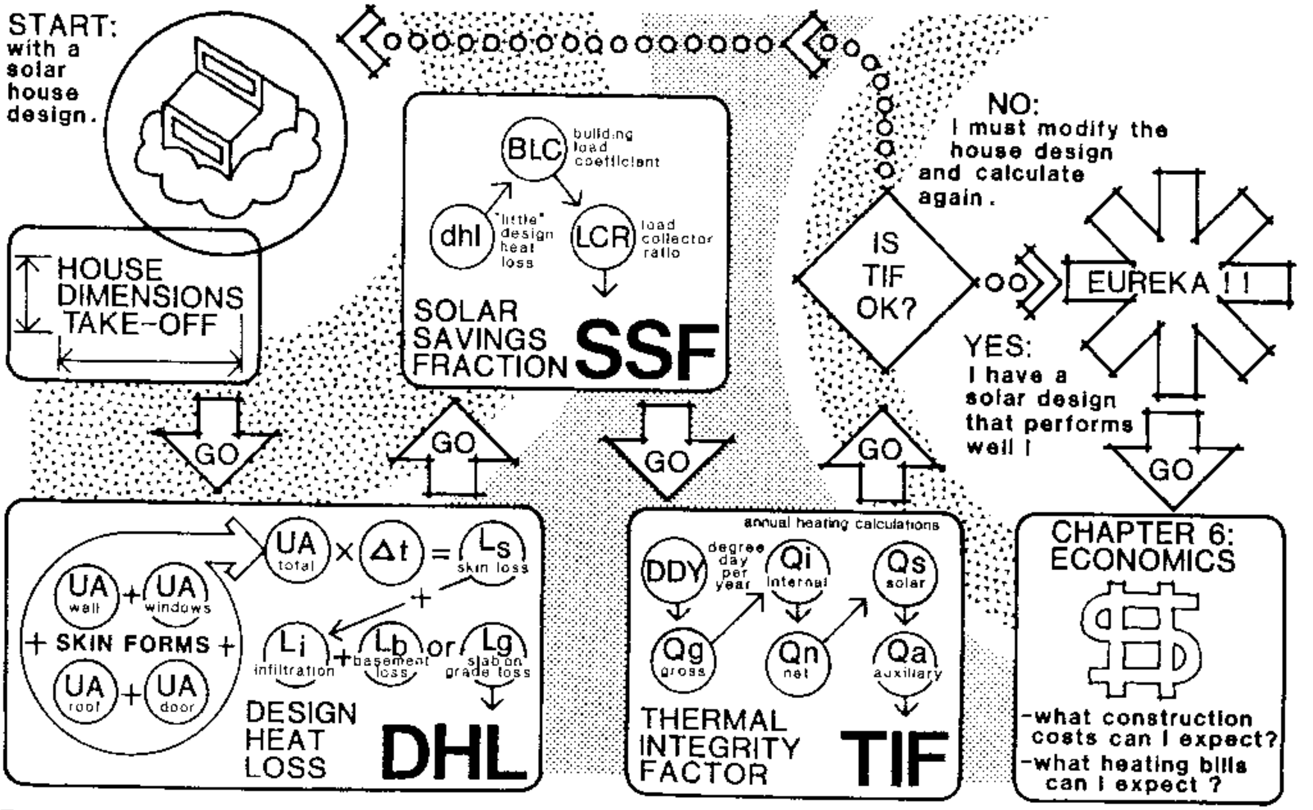
Engineering calculations can be bewildering and tedious. Calculating the energy performance of a design is nevertheless important in order to gain an understanding and appreciation of how a passive solar home will function. An additional benefit is that working through the calculations may suggest house design and performance improvements.

For these reasons, every attempt has been made to simplify the process and make it readily understandable to all readers, e.g., forms are provided to guide the reader through the process and a complete design example is used to illustrate the steps in the calculation procedure. Also, blank forms are included in Appendix 1 for use in performing the calculations on the reader's passive solar home.

The calculation procedure (FIG 5-1) consists of three primary sections:

1.Design Heat Loss (DHL)
2.Solar Savings Fraction (SSF)
3.Thermal Integrity Factor (TIF)

The calculation process begins with a solar house design. Information about the design is entered on the House Dimensions Takeoff Form. Next, all building losses are determined in the Design Heat Loss (DHL) section. The solar performance for the home is then calculated in the Solar Savings Fraction (SSF) section. Results from both DHL and



5-1 ENGINEERING CALCULATIONS DIAGRAM

SSF are utilized in the Thermal Integrity Factor (TIF) section. The TIF is a measure of the solar home's energy efficiency and can be used to compare the energy efficiency of a passive solar heated building with any other building, solar or otherwise. If the TIF value is unsatisfactory, modifications should be made in the initial building design and the engineering process repeated until a satisfactory TIF value is achieved. When the TIF value is acceptable, the economic feasibility of the proposed design can be assessed.

The following points about the calculation procedure should be noted:

1. An optimal building design is desirable because the calculation procedure is lengthy. Repeating the process more than two or three times can become a time-consuming task. Design ideas, rules of thumb, and construction details from previous chapters should be incorporated into a more or less final design before engineering calculations begin.

2. The calculation procedure is meant to serve as an estimate. It is not intended to be a complete, precise analytical tool. A professional engineer and/or architect with passive solar experience should be consulted for a more complete analysis.

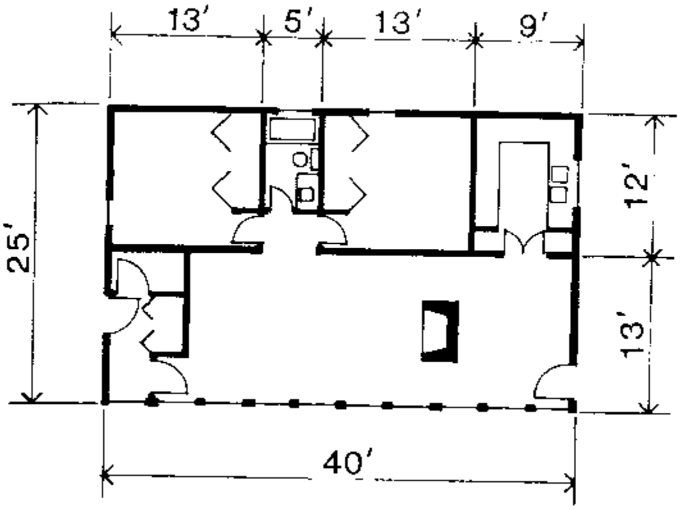
3. The calculation procedures are the same for all of the passive solar systems discussed in Chapter 3. This is because each system must contend with a balance of heat losses through its exterior surfaces offset by heat gains from solar or other means to maintain an acceptable comfort level within the house.

HERBIE'S HOUSE

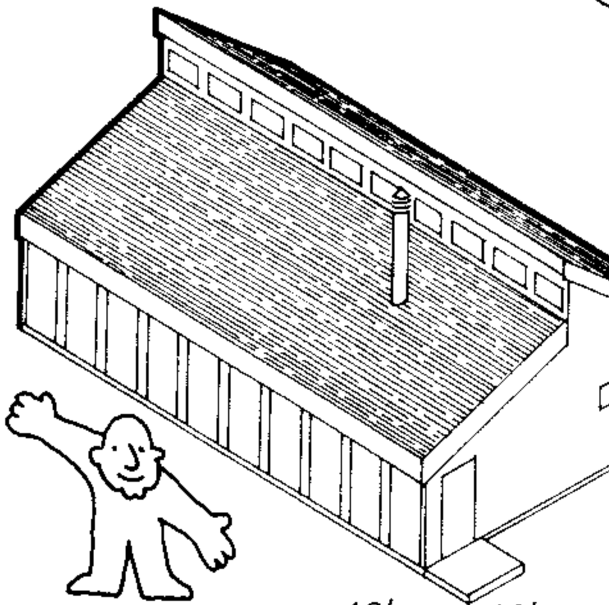
The example house (FIG 5-2), Herbie's house, is a fairly simple solar design. Living spaces are located along the south-facing glass wall to maximize daytime views, light, and heat gains. Clerestory windows admit sunlight and solar heat to bedrooms and support spaces located along the north wall. North, east, and west windows are minimized. The roof configuration is low to the north, so that winter winds flow over the house, while allowing maximum solar exposure to the south. Note that in addition to floor plan, perspective, and elevation drawings, any proposed solar design should include roof and wall construction drawings, as shown. The example wall, an interior brick thermal mass wall, is insulated on the outside.

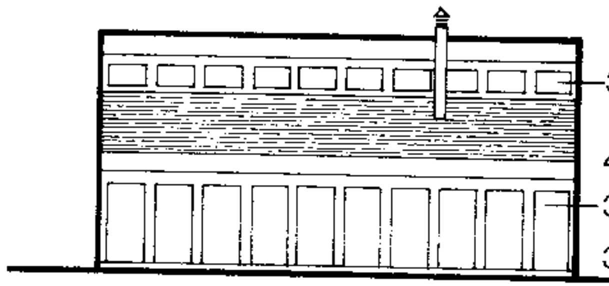
Data from Herbie's house has been entered on the House Dimensions Takeoff Form. Dimension and location information as well as annual degree days from Appendix 3 have been entered on the form. The proposed passive systems and backup systems have also been specified.

5-2 HERBIE'S HOUSE

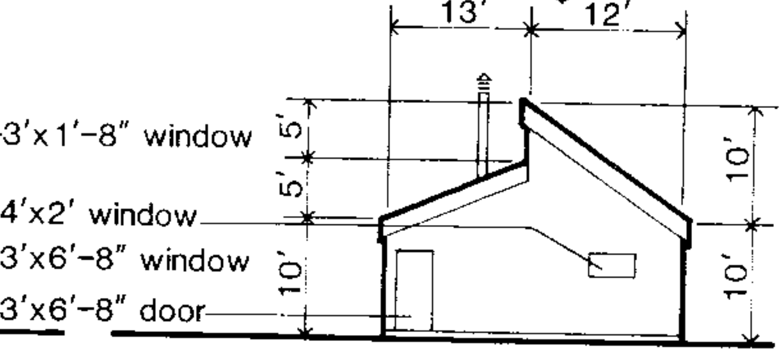


FLOOR PLAN

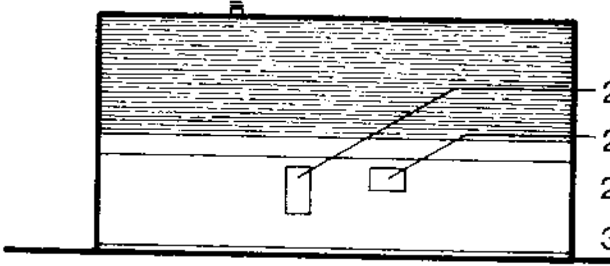




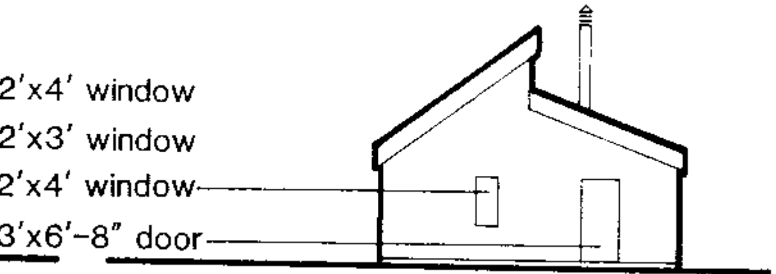
SOUTH ELEVATION



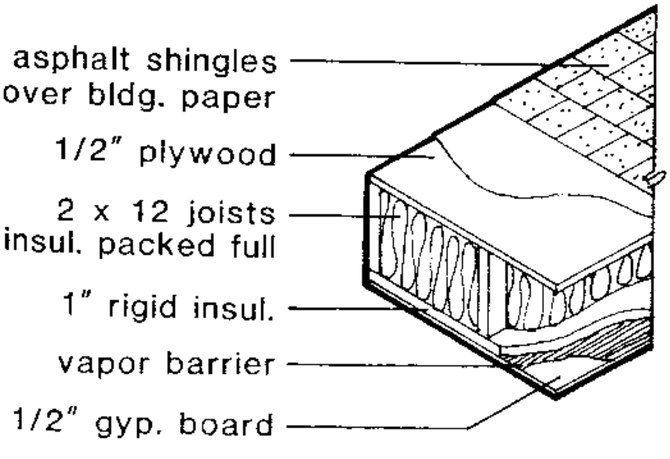
EAST ELEVATION



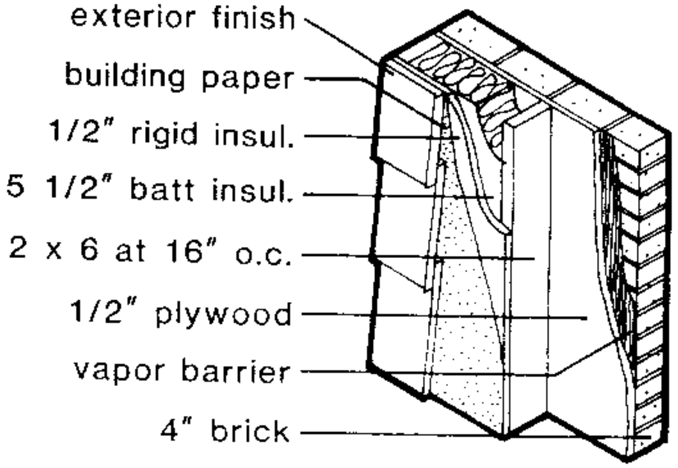
NORTH ELEVATION



WEST ELEVATION



ROOF CONSTRUCTION



WALL CONSTRUCTION

HOUSE DIMENSION TAKEOFF FORM 1

LOCATION OF HOUSE CHADRON LATITUDE 42.5°

SITE - FLAT OR SLOPING? FLAT IF SLOPING GIVE PERCENTAGE GRADE AND

DIRECTION OF SLOPE ________ (10% = 1' rise in 10' & 5% = 0.5' in 10')

DEGREE DAYS HEATING PER YEAR 7031 INDOOR DESIGN TEMPERATURE 68

FLOOR AREA 1000 PERIMETER 130 AVERAGE CEILING HEIGHT 12

WALL AREAS		INSULATION TYPE AND THICKNESS	R VALUE OF THE WALL
EAST	342.5	5½" BATT. + ½" RIGID	
WEST	342.5	5½" BATT. + ½" RIGID	
NORTH	306	5½" BATT. + ½" RIGID	
SOUTH	310	5½" BATT. + ½" RIGID	
DOORS: #1	20	R-10	
#2	20	R-10	

WINDOW AREA		SINGLE, DOUBLE, TRIPLE GLAZING	NIGHT INSULATION TYPE AND R VALUE	HOURS IN PLACE AT NIGHT
EAST	8	TRIPLE	NONE	
WEST	8	TRIPLE	NONE	
NORTH	14	TRIPLE	NONE	
SOUTH	250	DOUBLE	1½" RIGID	16

ROOF AREA 1185 ROOF INSULATION TYPE & THICKNESS ________

ROOF R VALUE 49.36 IF EARTH SHELTERED GIVE DEPTH OF DIRT ________

BELOW GRADE

Is there a basement? NO If YES what is the height? ________

Specify insulation type and thickness ________ R Value below grade ________

If slab on grade give exterior insulation specs 3" RIGID

Exposed Perimeter 130 FT. R Value R-15

HOUSE DIMENSION TAKEOFF FORM 2

PASSIVE SOLAR SPECIFICATIONS

PASSIVE SOLAR TYPE	WINDOW AREA	LOCATION
1. DIRECT GAIN	250 SQ. FT.	50 SQ. FT. CLERESTORY 200 SQ. FT. MAIN FLOOR
2. ____	____	____
3. ____	____	____

IF HOME IS A DOUBLE SHELL PROVIDE THE FOLLOWING INFORMATION:

Interior wall area: North ____ South ____ Roof ____ R Value ____

Exterior glazing area greenhouse ____ Interior wall glazing area ____

Specify fans if used ____ Specify type of night shutter ____

R Value of night shutters ____ Location of shutters ____

IF A TROMBE WALL IS EMPLOYED IS THERE A SELECTIVE SURFACE? ____

IF A SUNSPACE IS USED WHAT WILL BE THE MINIMUM TEMPERATURE ALLOWED? ____

Describe location and type of glazing ____ Glazing area ____

Specify night shutter type ____ R value ____ Hours in place ____

Sunspace floor area ____ Describe mass (brick, water, etc.) ____

Glazing area between sunspace and house ____

Wall area and R value betwen sunspace and house ____

IS SOLAR DOMESTIC HOT WATER HEATING DESIRED? ✓ YES ____ NO

ARE SOLAR COVENANTS IN FORCE? ✓ YES ____ NO ____ NOT APPLICABLE

ARE THERE LEGAL GUARANTEES TO SOLAR ACCESS? ✓ YES ____ NO

BACKUP

BACKUP SYSTEM DESIRED (gas, electricity, oil, etc.) ____

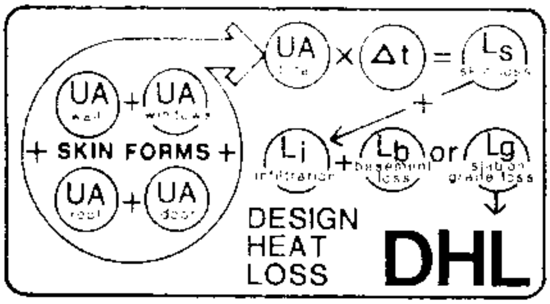
COST OF FUEL (consult fuel dealer or utility) ____

WOOD STOVES TO BE USED? ✓ YES ____ NO HOW MANY? 1 LOCATION BETWEEN LIVING ROOM AND DINING ROOM

____ HEATING CAPACITY (btuh)

FIREPLACES TO BE USED? ____ YES ____ NO HOW MANY? ____ LOCATION ____

____ HEATING CAPACITY)btuh)



Heat losses from a building (FIG 5-3) can be categorized as follows:

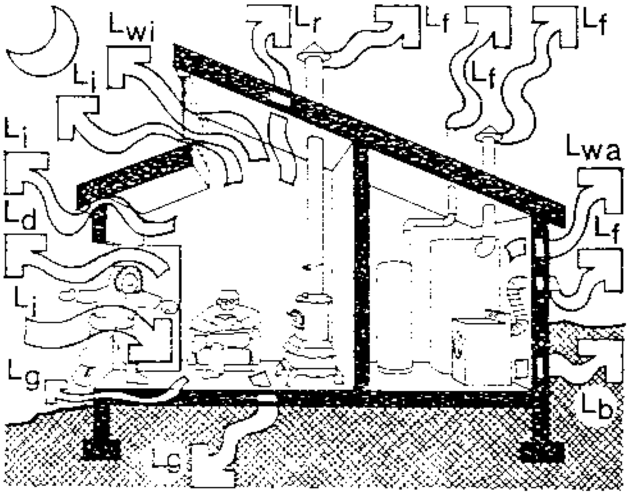
1.Skin Losses (L_s)
    (windows, walls, roof, and doors)
2.Air Infiltration Losses (L_i)
    (air leaks)
3.Basement Losses (L_b) or Slab Losses (L_g)

These three types of losses (L_s, L_i, and either L_b or L_g) are combined to give the Design Heat Loss, concluding the first section of the engineering calculations.

SKIN LOSSES

Skin losses result from energy conducted through walls, windows, doors, and the roof.

Three values are needed to compute skin losses: 1) area, 2) U value, and 3) ΔT value.



5-3 HOURLY BUILDING LOSSES

The area of each window, wall, door, and the roof is obtained from the House Dimensions Takeoff Form.

The U value, a measure of the heat conductance of a material, is the reciprocal of the R value: U=1/R. U values are expresssed in btus per hour per square foot per degree Fahrenheit. R values are found in TABLE 5-2 or its expanded form in Appendix 4.

The UA value is the product of a particular skin construction area and its U value: Conductance x Area. The UA product is computed for all windows, walls, doors, and the roof. The sum of these UA values is multiplied by ΔT, to give the total skin load in btuh. UA values are expressed in btus per hour per degree Fahrenheit (btuh/°F).

ΔT (DELTA T): ΔT is the difference between the indoor and outdoor temperatures (FIG 5-4):

$$\Delta T = T_i - T_o.$$

The indoor temperature, T_i, is typically between 65°F and 72°F. The outdoor winter design temperature, which is an indication of local temperature severity (TABLE 5-1), is the T_o value. In Nebraska, this can vary from 0°F to -6°F. If a particular city is not shown on the table, the value for a nearby

TABLE 5-1

OUTDOOR DESIGN TEMPERATURES

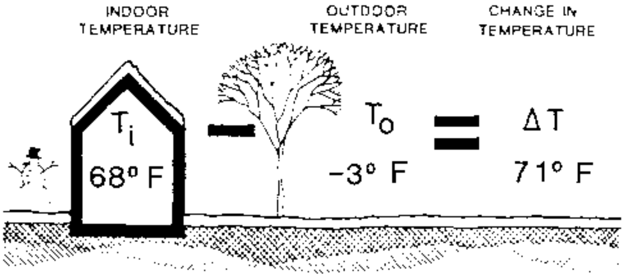
Beatrice	-2°F
Chadron	-3°F
Columbus	-2°F
Fremont	-6°F
Grand Island	-3°F
Kearney	-4°F
Lincoln	-2°F
McCook	-2°F
Norfolk	-4°F
North Platte	-4°F
Omaha	-3°F
Scottsbluff	-3°F
Sidney	-3°F

TABLE 5-2
R VALUES FOR TYPICAL COMPONENTS

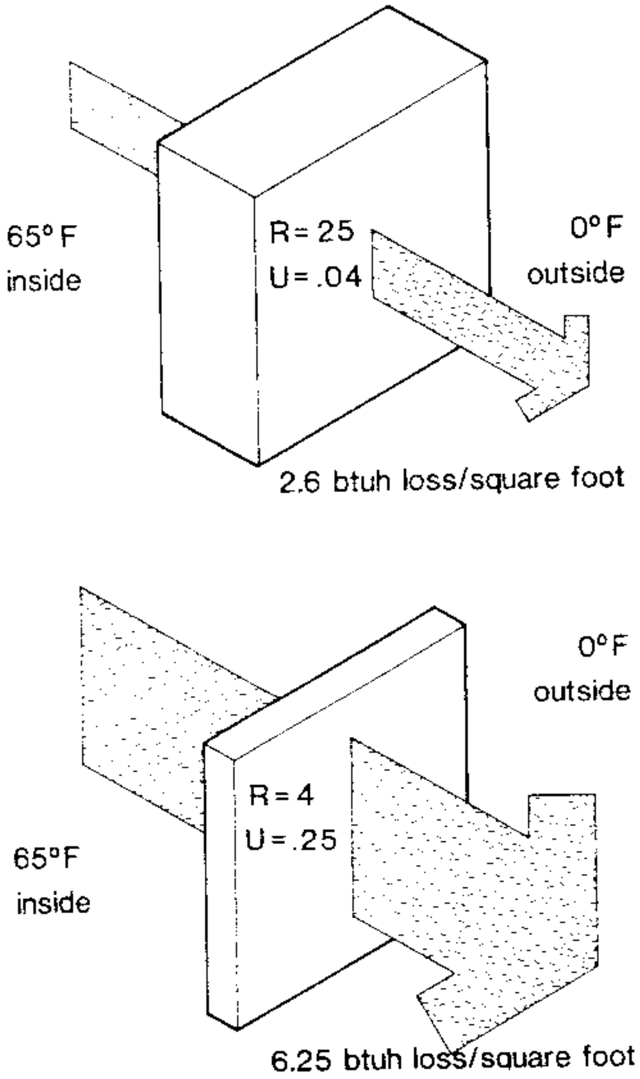
MATERIAL	THICKNESS	R VALUE
Gypsum Board	1/2"	0.45
	5/8"	0.56
Plywood	1/2"	0.62
	3/4"	0.93
Fiber Sheathing	1/2"	1.32
Hardboard	3/8"	0.38
Particle Board	5/8"	0.82
Carpet/Fiber Pad	---	2.08
Carpet/Rubber Pad	---	1.23
Batt Insulation	3 1/2"	11.00
	5 1/2"	19.00
	8 1/2"	30.00
Expanded Polystyrene	1"	3.57
	2"	7.14
	3"	10.71
Extruded Polystyrene	1"	5.00
	2"	10.00
	3"	15.00
Concrete (sand and gravel)	8"	0.64
	12"	0.96
Stucco/Plaster	1"	0.20
Face Brick	3 1/2"	0.11
Concrete Block	4"	0.71
	8"	1.11
	12"	1.28
Asphalt Shingles	---	0.44
Built Up Roofing	---	0.33
Wood Shingles (Roof)	---	0.44
Wood Siding	1 X 8	0.79
Plywood Siding	3/8"	0.59
Aluminum Siding	---	0.61
Softwood	1 1/2"	1.89
	3 1/2"	4.35
Inside Air: still and vertical	---	0.68
Outside Air Film: moving	---	0.17
Single Glass	---	U = 1.10
Double Pane Glass: with 1/4" airspace	---	U = 0.58
Triple Pane Glass: with 1/4" airspace	---	U = 0.39

city should be chosen.

To aid the reader in this calculation process, a special Skin Form has been developed. A separate Skin Form should be filled out for each different type of skin construction found in the house, e.g., if more than one kind of wall construction or window is used, a separate form must be completed for each.



5-4 TEMPERATURE DIFFERENCE (ΔT)



5-5 COMPARED WALL LOSSES

SKIN LOSSES (WALLS)

It is generally desirable to include as much insulation in the walls as is practical. By maximizing the R value of the wall, the U value is reduced, resulting in a smaller skin heat loss. Consider two example walls each 1 sq ft in area (FIG 5-5). One has an R value of 25, and the other an R value of 4. Given a temperature difference, ΔT, of 65°F between indoors and outdoors, the R 4 wall will lose 6.25 btuh in comparison with 2.6 btuh for the R 25 wall, a difference of 3.65 btuh. This difference is magnified considerably when total wall areas for an entire house are considered.

SKIN FORM (WALLS): To simplify the procedure for calculating losses through walls, a separate UA value is calculated for each wall orientation -- north, south, east, and west -- because each of these walls can have a construction different from the others. If all wall constructions are the same, as they are in Herbie's house, all UA values can be entered on the same form. Obviously, if the house uses more than one kind of wall construction, additional Skin Forms must be used -- one for each kind of construction.

The Wall Skin Form is completed as follows:

1. Circle the appropriate construction and describe the wall location at the top of the form.

2. In the space provided, sketch a cross-section of the wall.

3. List the individual building components of the wall. Include material thickness where applicable.

4. Determine the R value for each component from TABLE 5-2 or from the expanded table in Appendix 4.

5. Total the R values.

SKIN FORM (WALLS)

construction
(circle one) [✓ wall] window roof door

describe location
NORTH, EAST, SOUTH, & WEST

components	thickness	R value
outside air film		.17
EXTERIOR FINISH		.87
RIGID INSULATION		2.5
BATT INSULATION		19.0
PLYWOOD		.62
BRICK FACING		.44
inside air film		.68

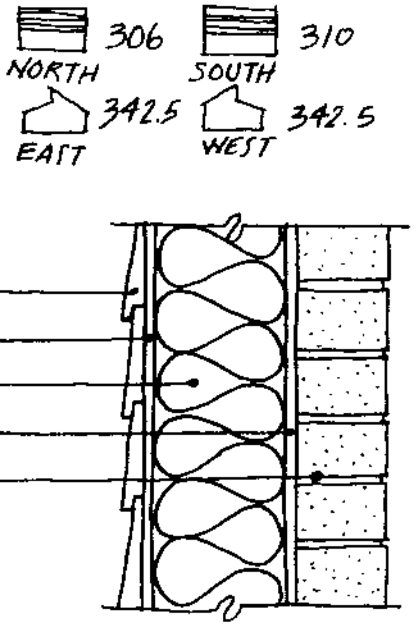
R_t = total R value = 24.28

U = 1/R_{total} = .045

A = skin area = 1301

UA (U x A) btu/° F = 58.54

diagram (optional)

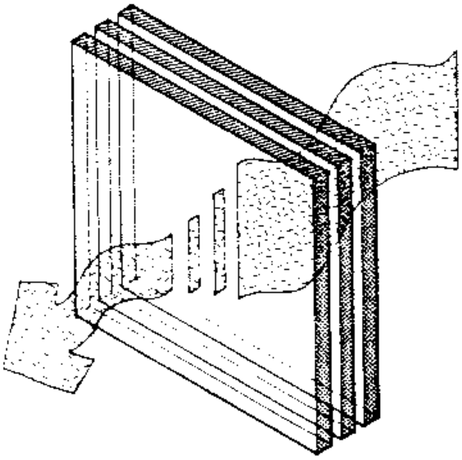


6. Compute the total wall U value (U=1/R).

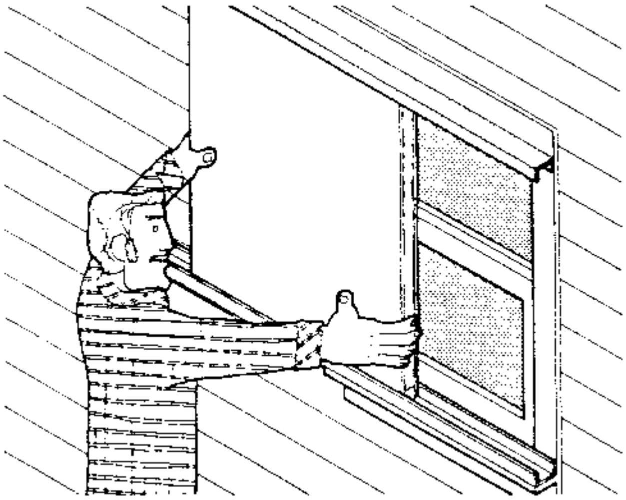
7. Transfer the appropriate skin area from the House Dimensions Takeoff Form. Remember to deduct the area of windows and doors. If more than one UA value is to be calculated, the areas can be recorded in the workspace as shown.

8. Calculate the UA product(s).

9. Note that the R value for the heat path through a wall stud is lower than that through the insulation between studs. If desired, this effect can be taken into account by multiplying the U value in step 6 by a factor of 1.1.



5-6 TRIPLE GLAZING



5-7 WINDOW WITH NIGHT SHUTTER

SKIN LOSSES (WINDOWS)

On a per square foot basis, window losses are greater than wall losses. For a typical home, the losses through a 10 sq ft window can exceed the losses through a 100 sq ft wall. Triple glazing is recommended for non-south-facing windows (FIG 5-6) as the additional air spaces between panes increase the R value.

Large areas of south glass have tremendous heat losses at night. For this reason, insulating night shutters are used (FIG 5-7). Depending on its material and thickness, a night shutter can reduce nighttime losses through windows by a factor of 10 or more. A strategy of minimizing non-south window areas and utilizing night shutters wherever possible is recommended.

SKIN FORM (WINDOWS): Herbie's house has two Window Skin Forms. The first Window Skin Form is for the double glazed south-facing glass with night insulating shutters assumed to be in place 16 hours each day. The second Windows Skin Form is for the triple glazed non-south windows.

SKIN FORM (SOUTH WINDOWS)

construction

(circle one) wall [✓ window] roof door

describe location

SOUTH WINDOWS

DAY (NIGHT)

components	thickness	R value
DOUBLE PANE GLASS		1.72 (1.72)
NIGHT SHUTTERS	1½"	(12)

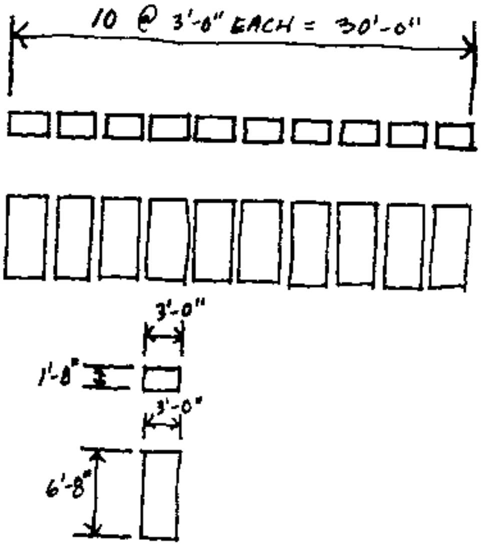
R_t = total R value = 1.72 (13.72)

U = $1/R_{total}$ = .58 (.073)

A = skin area = 250

UA (U x A) btu/° F = 60.5

diagram (optional)



TOTAL AREA = 250 SQ. FT.

The South Windows Skin Form is completed as follows:

1. Enter construction and location information.

2. Sketch the windows in the space provided.

3. If these windows will be night insulated, divide the R value column into two parts -- one for day, and one for night.

4. List the components (glass and shutters). Include shutter thickness.

5. Enter R values for both daytime and nighttime conditions.

6. Total day and night R values.

7. Compute day and night U values (U_{day} and U_{night}). These two values are used to determine an average U value (U_{ave}).

8. Enter total area of south glazing.

9. Using the average U value, calculate the window UA product.

SKIN FORM (WINDOWS)

construction

(circle one) wall [✓ window] roof door

describe location

NORTH, EAST, & WEST WINDOWS

components	thickness	R value
TRIPLE PANE GLASS		2.56

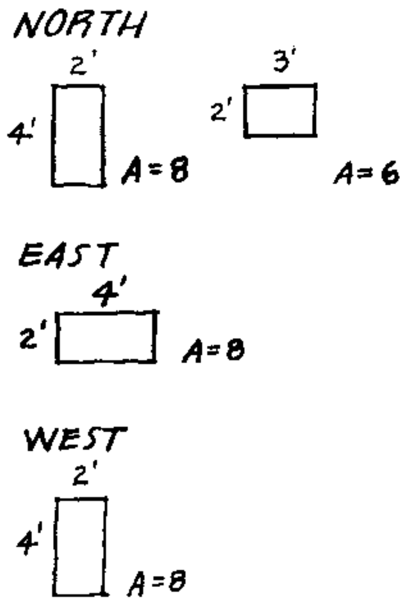
R_t = total R value = 2.56

U = 1/R_{total} = .39

A = skin area = 30 SQ. FT.

UA (U x A) btu/° F = 11.7

diagram (optional)



AREA = 8+6+8+8 = 30 SQ. FT.

The procedure for completing the Window Skin Form for the non-south windows is essentially the same as for the south-facing windows. Note that when no night insulation is used with the triple glazed windows, the calculation of the average U value is not necessary.

SKIN FORM (ROOF)

construction

(circle one) wall window [✓ roof] door

describe location

____

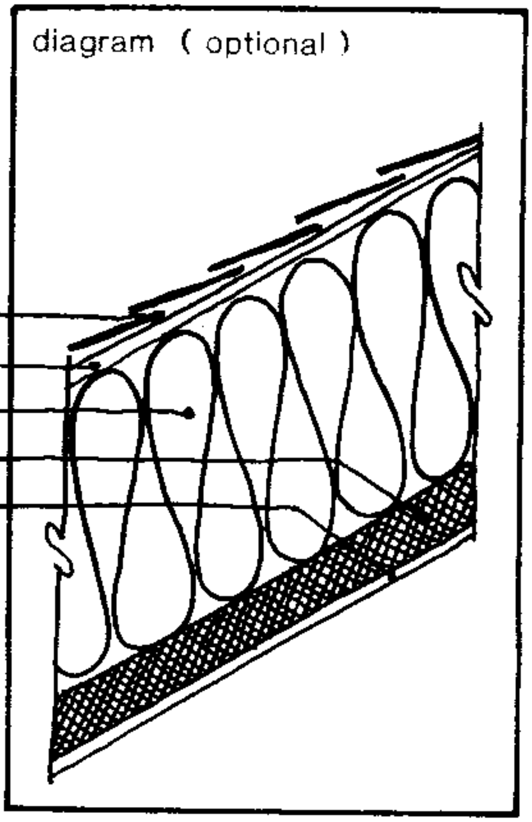
components	thickness	R value
outside air film		.68
ASPHALT SHINGLES		.44
PLYWOOD	½"	.62
BATT INSULATION	11½"	37.0
RIGID INSULATION	2"	10.0
GYPSUM BOARD	½"	.45
inside air film		.17

R_t = total R value = 49.36

U = $1/R_{total}$ = .020

A = skin area = 1185 SQ. FT.

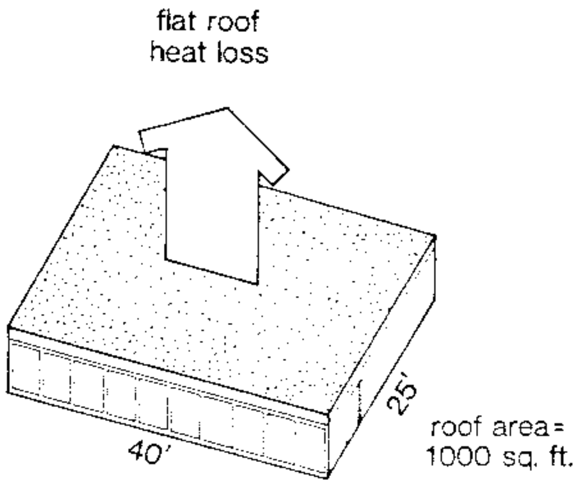
UA (U x A) btu/° F = 23.7



SKIN LOSSES (ROOF)

Roof insulation values of R 40 or higher are recommended for Nebraska. If attics are not used, a low pitched roof is preferable to a high pitched roof (FIG 5-8). This minimizes the amount of material which must be used, resulting in substantially lower material costs. Also, a flat roof helps minimize the interior volume of the home.

SKIN FORM (ROOF): To complete the Roof Skin Form, the directions for the Wall Skin Form should be followed. Herbie's house has a cathedral ceiling so the heat loss area of the roof is the sum of the areas of the two pitched surfaces. This roof area of 1185 sq ft is nearly 20% greater than the area would be if the house had a flat roof. Note that for houses with unheated attics, the heat loss area is similar to that for a flat roof, since the heat loss barrier is the insulation directly above the ceiling of the heated space.



5-8 FLAT ROOF

SKIN FORM (DOORS)

construction

(circle one) wall window roof [✓ door]

describe location

2 DOORS ONE ON EAST & ONE ON WEST

components	thickness	R value
INSULATED DOORS		10.85

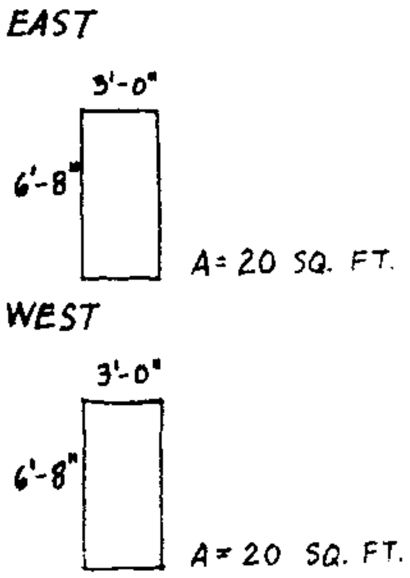
R_t = total R value = 10.85

U = $1/R_{total}$ = .092

A = skin area = 40 SQ. FT.

UA (U x A) btu/° F = 3.69

diagram (optional)



AREA= 20+20=40 SQ. FT.

SKIN LOSSES (DOORS)

Outside doors and proper entrance design are often overlooked for their energy savings potential. To limit air infiltration losses, a vestibule provides an "air lock" which seals the home from wind gusts when the door is opened. An entry vestibule is recommended for every house.

A number of doors with enhanced insulation values are available commercially. Tight-fitting door seals should be used with each door.

SKIN FORM (DOORS): The procedure for calculating the skin loss through a door is relatively simple; door manufacturers provide R values for insulated doors, and door areas are fairly standardized.

DESIGN HEAT LOSS (DHL) FORM

When heat losses have been calculated for each type of wall, window, roof, and door, the information can be entered on the Design Heat Loss (DHL) Form, which is used for calculating the total losses of the house. In the first part of the form, ΔT is calculated. The outdoor design temperature of Chadron, the location of Herbie's house, is -3°F. If a desired indoor temperature is 68°F, ΔT is 71°F.

Next, the previously calculated skin losses are transferred from their respective Skin Loss Forms. These figures are added to give a total UA value for the building. This total UA value (in btuh/°F) is multiplied by ΔT, and the result is the Total Skin Loss expressed in btus per hour (btuh). Herbie's house loses 11,227 btus per hour through the skin of the building when the outdoor temperature is at -3°F.

DESIGN HEAT LOSS FORM (DHL) 1

$\Delta T = t_{\text{indoor desired}} - t_{\text{outdoor design temperature}}$ = 68-(-3) = 71

1.1 SKIN LOSSES: UA PRODUCT (from skin form)

1. Walls

UA_{North} 13.77

UA_{South} 13.95

UA_{East} 15.41

UA_{West} 15.41

2. Windows

UA_{North} 5.46

UA_{South} 60.5

UA_{East} 3.12

UA_{West} 3.12

3. Roof UA 23.7

4. Doors UA 3.69

5. UA Total Sum of All Above 158.13

ΔT (from above) x 71

Total Skin Loss (btuh) = 11227

1.1

1.2 AIR INFILTRATION LOSSES

Volume (Average ceiling height X floor area) 1000 × 12 = 12,000 CUBIC FT

ΔT x 71

ACH (from table 5.3) x .375

CONSTANT (.018) x .018

AIR INFILTRATION (btuh) = 5751

1.2

DESIGN HEAT LOSS FORM (DHL) 2

1.3 BELOW GRADE & BASEMENT LOSSES

(Choose one of below) (A or B)

A) BASEMENT:

WALLS: Perimeter ________
Sum of values from Table 5.4 x ________
54 (constant) x 54
____
Total basement wall loss = ________ walls

FLOOR: Floor Area ________
Table 5.5 value x ________
54 (constant) x 54
____
Total basement floor losses = ________ floor

Total Basement Losses (add walls and floors) = ☐ 1.3

B) SLAB ON GRADE:

Perimeter (in feet) 130
Table 5.6 or 5.7 value x 40

SLAB ON GRADE LOSS = 5200 1.3

1.4 DHL

Total Design Heat Loss = Total Skin Loss + Air Infiltration + Below Grade or Basement

DHL = (Sum of 1.1 + 1.2 + 1.3) = 22178 DHL

AIR INFILTRATION LOSSES

As indicated previously, heat is lost from a building not only by conduction, but also by air leaks or infiltration.

Infiltration losses are calculated on the second part of the Design Heat Loss Form as follows:

1. Determine the volume of the house in cubic feet by multiplying the floor area by the average ceiling height.
2. Enter the △T determined previously.
3. Determine an approximate air infiltration rate in Air Changes per Hour (ACH) from TABLE 5-3. The table lists a succession of strategies which contribute to a building's tightness. Select the level of control which best represents the building under consideration, and use the corresponding ACH value.
4. Enter the constant 0.018. (This reflects the heat capacity of a cubic foot of air per ^{o}F).
5. Multiply the preceding four numbers to get Air Infiltration Loss expressed in btuh.

TABLE 5-3 INFILTRATION CONTROL LEVELS

Control Level	Air Changes Per Hour (ACH)	Description
1	1-2	Frame building, no vapor barrier, no weatherstripping, no special attention to sealing
2	3/4	As above plus weatherstripping
3	2/3	As above plus plastic vapor barrier and additional weatherstripping on windows and doors
4	1/2	As above but with more than one vapor barrier and seams that are lapped 6" over the framing and sill sealer
5	3/8-1/4	As above plus expanded foam around window and door frames, and electrical outlets taped to the vapor barriers
6	1/4-1/10	As above with no electrical outlets in exterior walls and air lock vestibules on all entrances

Additional Notes

1. The use of air lock vestibules improves any of the above levels by one except for a level 6 building.
2. Basement air infiltration
   1. Look up air infiltration table for house ACH as before.
   2. Compute basement volume.
   3. The number of air changes per hour in the basement is:
      1/2 ACH of the house if basement is below grade.
      5/8 ACH of the house if basement has 1 wall above grade.
      3/4 ACH of the house if basement has 2 walls above grade.
      Same as the house ACH if more than two walls are above grade.
   4. Compute basement air infiltration using the same formula as for above grade.

BELOW GRADE AND BASEMENT LOSSES

Losses from the "bottom" of the house are calculated on the second page of the Design Heat Loss Form. If a basement is included in the design, complete part "A". Part "B" is for slab-on-grade construction.

BASEMENT LOSSES:

Basement losses are divided into wall losses and floor losses. Calculation of these values is not as straightforward as skin loss calculations, primarily because of the presence of earth on the outside of the wall. However, several accurate calculation methods have been developed.

Basement Wall Losses: Basement wall losses decrease with increasing depth, since the heat escape path is longer at greater depths. (Only sub-grade basement walls require this calculation. Above grade basement walls should be treated like any other above grade walls.)

The calculation procedure for basement walls is as follows:

1. Determine the perimeter of the basement wall, the depth of the floor below grade, and the thickness of any extruded rigid insulation used to insulate the basement walls.
2. Find the column corresponding to the amount of the insulation in TABLE 5-4.
3. Add each value in the column until the depth of the floor below grade is reached.
4. Multiply this sum by the wall perimeter, and then by 54 to obtain the total basement wall loss. (This value is derived from long term weather and ground temperature data, and is valid only for Nebraska.)

Basement Floor Losses: The heat escape path for basement floor losses is primarily around the footings on the long sides of the building.

The basement floor losses are computed as follows:

1. Determine the depth of the floor below grade and the width of the home.
2. Using these values, find the appropriate value in TABLE 5-5. Multiply this table value by the basement floor area, and then by 54 to obtain the total basement floor losses expressed in btuh.

SLAB-ON-GRADE LOSSES:

If the structure is built slab-on-grade, a different technique must be used to calculate the heat losses. Only the perimeter of the slab and the quantity of slab edge insulation are needed, because heat is lost from a slab almost totally from the slab edges.

1. Using the outdoor design temperature and the thickness of perimeter insulation, obtain a value from TABLE 5-6.
2. Mulitiply this value by the slab perimeter to get total slab losses.

To prevent cold slab floors, some buildings employ heated slabs. In these designs, heated pipes or ducts pass through the slab, thus making it a radiating surface. For this type of floor, TABLE 5-7 should be used instead of TABLE 5-6.

BUILDING DESIGN HEAT LOSS (DHL)

The Design Heat Loss (DHL) for the building is the sum of the three values which have been calculated: 1) Total Skin Losses, 2) Total Infiltration Losses, and 3) Total Below Grade Losses. The DHL is measured in btus per hour (btuh) and reflects the total amount of heat lost from the building every hour at the outdoor design temperature, i.e., it represents the total number of Btus that must be supplied by a furnace (or other source) in order to maintain a comfortable indoor temperature when the outdoor temperature is at the design value. The DHL value should be used to size heating equipment to be installed in a conventional home.

TABLE 5-4: HEAT LOSS THROUGH BASEMENT WALLS

	Insulation Thickness			
Depth	None	1"	2"	3"
0-1 feet	0.410	0.152	0.093	0.067
1-2 feet	0.222	0.116	0.079	0.059
2-3 feet	0.155	0.094	0.068	0.053
3-4 feet	0.119	0.079	0.060	0.048
4-5 feet	0.096	0.069	0.053	0.044
5-6 feet	0.079	0.060	0.048	0.040
6-7 feet	0.069	0.054	0.044	0.037

TABLE 5-5: HEAT LOSS THROUGH BASEMENT FLOORS

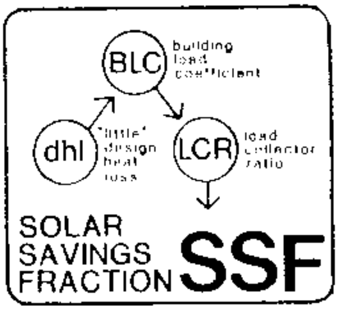
Depth of foundation wall below grade	WIDTH OF HOUSE 20 ft	24 ft	28 ft	32 ft
5	0.032	0.029	0.026	0.023
6	0.030	0.027	0.025	0.022
7	0.029	0.026	0.023	0.021

TABLE 5-6: HEAT LOSS OF CONCRETE FLOORS AT OR NEAR GRADE

Outdoor Design Temperature in degrees Fahrenheit	Heat Loss Per Foot of Exposed Edge		
	2" edge insulation	1" edge insulation	no edge insulation
-20 to -30	50	60	75
-10 to -20	45	55	65
0 to -10	40	50	60

TABLE 5-7: HEAT LOSS FROM HEATED SLABS AT OR NEAR GRADE

	btuh per perimeter foot		
	edge insulation		
Outdoor design temp.	1" vertical 18" deep	1" L-type 12 x 12	2" L-type 12 x 12
-10	95	90	75
0	85	80	65
10	75	70	55



To determine the solar performance of a building, the following values must be calculated:

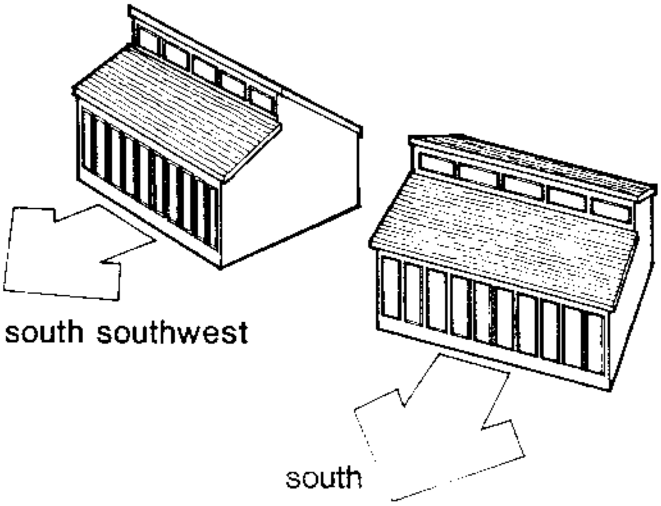
1. Design heat loss of the building, excluding the south window losses ("little" dhl)

2. Building load coefficient (BLC)

3. Load collector ratio (LCR).

When the LCR is known, the predicted solar performance (Solar Savings Fraction) is obtained from the charts in Appendix 2.

The dhl, BLC, and LCR calculations can be performed on the single-page Solar Savings Fraction Form. Note that these calculations are for south-facing buildings with vertical glass. A building with orientation greater than 15° from true south (FIG 5-9) requires a more involved procedure not covered here.



5-9 SOUTH VS SOUTHWEST ORIENTATION

"LITTLE" dhl

DHL (upper case) includes the total building losses from the skin (walls, windows, doors, and roofs), air infiltration, and below grade. "Little" dhl is this design heat loss excluding the south window losses, i.e., the south window losses, a component of the total building skin load, are subtracted from the design heat loss (DHL):

$$dhl = DHL - UA \quad T_{south\ glass} \quad btuh$$

Obviously, the dhl is smaller than the entire building design heat loss (DHL).

BUILDING LOAD COEFFICIENT (BLC)

The building load coefficient is a measure of a building's heating requirements, or load, per degree day, excluding south window losses:

$$BLC = \frac{(24 \times dhl)}{T} \text{ btu/DD}$$

The dhl, an hourly loss figure, is multiplied by 24 to obtain a daily loss figure and to be compatible with degree-day values. The BLC is expressed in btus per degree-day (btu/DD).

LOAD COLLECTOR RATIO (LCR)

The load collector ratio is the ratio of the building load coefficient to the south glass area:

$$LCR = \frac{BLC}{\text{South Glass Area}} \text{ btu/DD-ft}^2$$

The LCR value typically ranges between 5 and 50. The lower the LCR value, the better the solar performance will be.

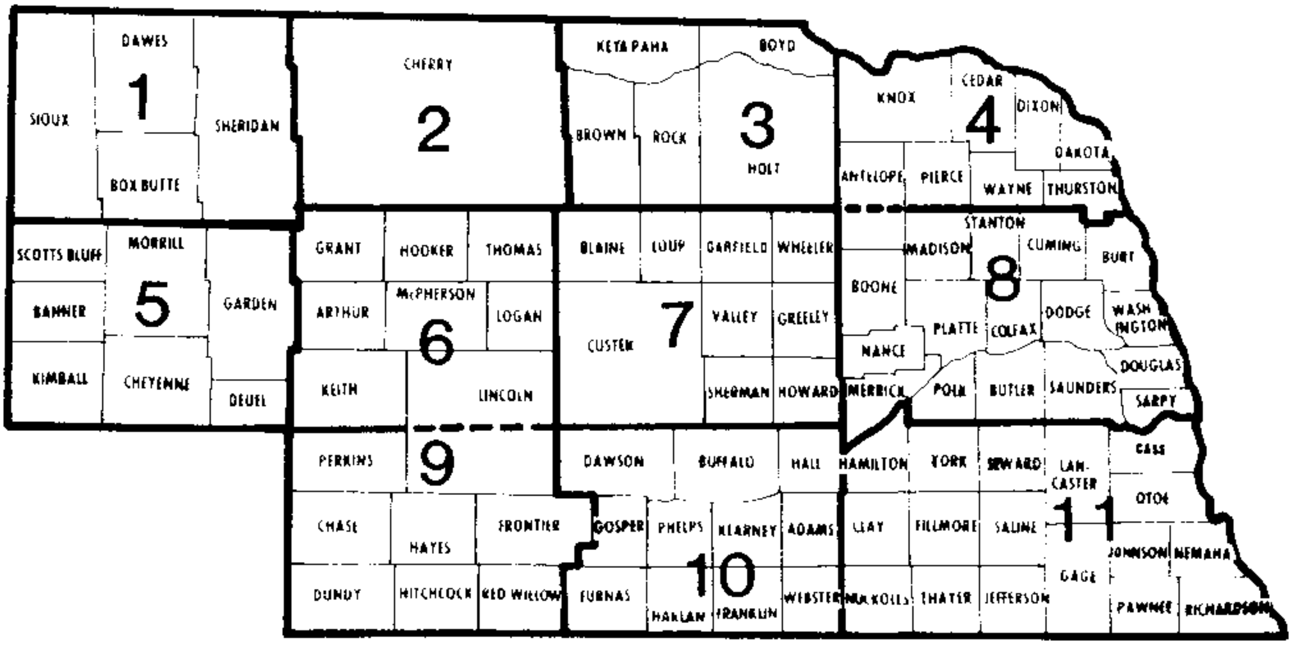
SOLAR SAVINGS FRACTION (SSF)

The Solar Savings Fraction is a measure of the solar energy supplied for an entire heating season divided by the net annual losses from the building excluding the south window losses.

Although SSF is widely used by solar practitioners, its acceptance is by no means universal as the SSF can be a misleading indicator if misused and misunderstood. The Los Alamos Scientific Laboratories used the term Solar Heating Fraction (SHF) in their early work as the measure of solar performance. The Solar Heating Fraction differs from the Solar Savings Fraction (SSF) in that in the Solar Heating Fraction, the thermal load is based on actual floating temperatures in the home rather than on the desired indoor design temperature. Thus, the SSF value for a home will be lower than the corresponding SHF value.

The Solar Savings Fraction is obtained from graphs located in Appendix 2. There is a complete set of graphs for each of the 11 regions within the state of Nebraska (FIG 5-10) and for each of the principal passive solar systems, i.e., Trombe wall, direct gain, water wall, and greenhouse. (Earth sheltered designs can be treated as direct gain structures with basement walls. For double shell or CTE homes, data from the test site of the Passive Solar Research Group (PSRG) at the University of Nebraska at Omaha indicates that Trombe wall curves with night insulation will provide a rough estimate of performance.)

For each passive system, there are two sets of curves. The dotted-line curve represents annual solar performance when night insulation is used; the solid line curve represents annual solar performance when night insulation is not used.



5-10 NEBRASKA AREAS

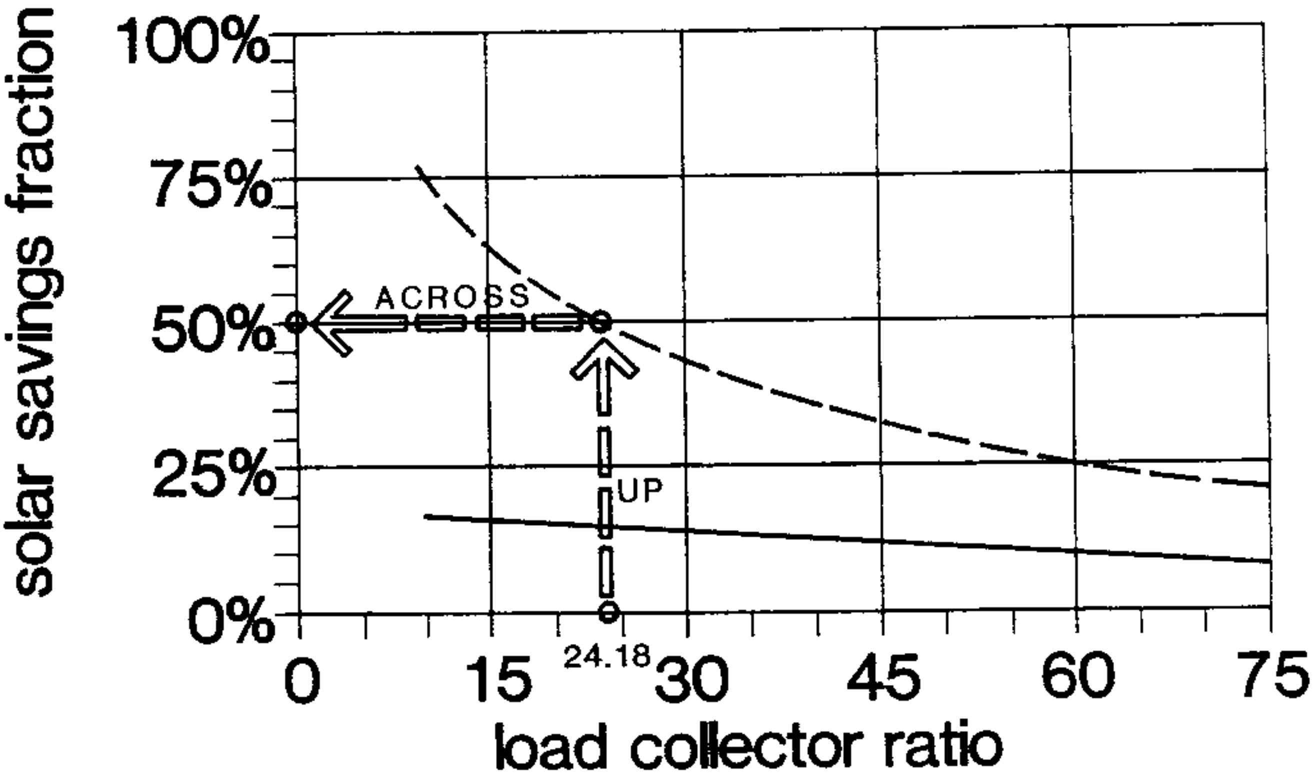
The SSF is obtained as follows:

1. Locate the LCR value on the horizontal axis of the SSF graph.

2. Read up to the intersection of the dotted-line curve which indicates solar performance when night insulation is used.

3. Read across from the intersection of the curve to the vertical axis to locate the SSF.

Herbie's house is a direct gain passive solar system with R 9 night shutters. The SSF graph for direct gain systems in Nebraska Region 1, which includes Chadron, the location of Herbie's house, is reproduced in FIG 5-11. Herbie's house has an LCR value of 24.18 (see SSF Form) which correlates with a SSF of 50%. Note that without night insulation, the SSF would be less than 20%.



5-11 SSF GRAPH: CHADRON

SOLAR SAVINGS FRACTION FORM (SSF)

PRELIMINARY DATA ENTRY

UA south (from DHL form) 60.5

ΔT (from DHL form) x 71

SOUTH WINDOW LOSSES = 4296

DHL, Design Heat Loss (from DHL form) 22178

South Window Losses (from above) - 4296

dhl (little DHL without south losses) = 17882 dhl

Constant 24 x 24

ΔT (from DHL form) ÷ 71

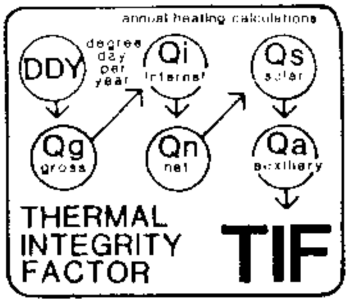
BLC (building load coefficient) = 6045 BLC

South Window Area (from House Dimensions Take Off Form) ÷ 250

LCR (load collector ratio) = 24.18 LCR

Use LCR Value to find SSF Value from SSF Graph of your Locale in the Appendix - Read SSF of your passive solar type and enter here

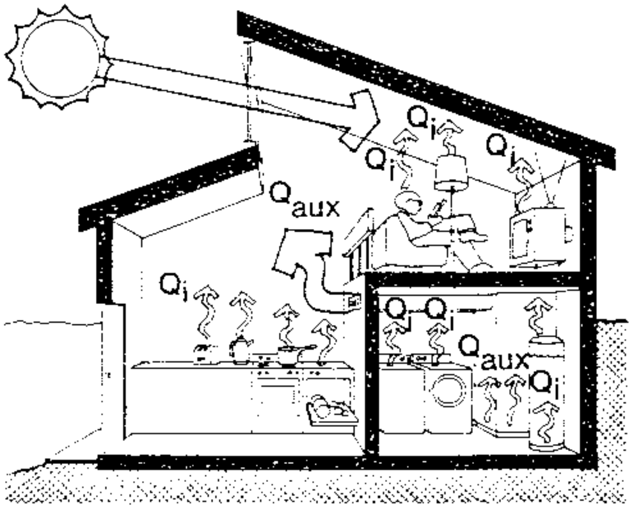
SOLAR SAVINGS FRACTION = 50% SSF



The Thermal Integrity Factor (TIF) is a measure of the net annual auxiliary heating requirements of a building. To determine this measure, the following values must be calculated:

1. Total gross annual heating requirements (Q_{gross})
2. Annual heat contributed by internal sources ($Q_{internal}$)
3. Net heating requirements after accounting for internal gains (Q_{net})
4. Total annual solar energy contribution (Q_{solar})
5. Total auxiliary heating requirements after solar and internal heat gains are accounted for (Q_{aux})

These calculations should be performed on the single-page Thermal Integrity Factor Form.



5-12 INTERNAL HEAT GAINS

TOTAL GROSS ANNUAL HEATING REQUIREMENT: Q_{gross}

Q_{gross} is the total annual heating requirement of a building assuming no solar contribution and no internal heat gain from lights, water heater, appliances, etc.:

$$Q_{gross} = \frac{24 \times DHL \times DDy}{\Delta T} \text{ btu/year}$$

The DHL, which is an hourly load, is multiplied by the constant 24 to obtain a daily value.

INTERNAL HEAT GAIN FROM APPLIANCES AND PEOPLE: $Q_{internal}$

The losses which contribute to the gross heating load are partially offset by the internal heat gains of the house. Body heat, lights, water heaters, appliances, etc., produce a significant amount of heat (FIG 5-12). The estimate of internal heat gain is based on the number of people living in the home. Three million btus per person annually is used as a conservative estimate of the internal heat gain:

$$Q_{internal} = \text{Number of occupants} \times \text{3 million btus}$$

NET ANNUAL HEATING REQUIREMENT: Q_{net}

The net annual heating requirement is the gross heating requirement less the internal gains:

$$Q_{net} = Q_{gross} - Q_{internal}$$

TOTAL ANNUAL SOLAR CONTRIBUTION: Q_{solar}

The annual solar contribution is found by multiplying the solar savings fraction (SSF) by the net annual heating requirement:

$$Q_{solar} = SSF \times Q_{net} \text{ btus per year}$$

TOTAL AUXILIARY HEATING REQUIREMENT: $Q_{auxiliary}$

The auxiliary heating requirement is the total heating requirement that must be provided by a conventional heating source such as a furnace. It is determined by subtracting the solar contribution from the net annual heating requirement:

$$Q_{auxiliary} = Q_{net} - Q_{solar}$$

Note that for a non-solar building the solar contribution is negligible, i.e., the auxiliary heating requirement of the building is the gross annual heating requirement less the internal heat gains for the year.

The auxiliary heating requirement value can be converted to a quantity of electricity or other fuel, and expressed as a dollar amount.

THERMAL INTEGRITY FACTOR (TIF)

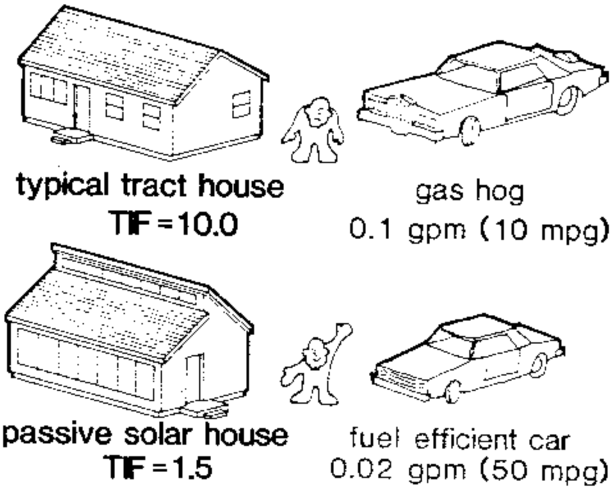
TIF is an indicator of annual thermal performance for solar as well as non-solar structures. It represents the heating load required to maintain a 65°F base temperature (after the internal heat gain and solar contribution for the year are accounted for) divided by the product of the annual degree-day requirement and the heated floor area:

$$\text{TIF} = \frac{Q_{auxiliary}}{\text{DDy} \times \text{Floor Area}} \text{btu/(DDy ft}^2\text{)}$$

TIF is expressed in btus per degree-day per square foot.

TIF makes it possible to compare the performance of a proposed solar design with that of any other building, solar or otherwise. Also, since the TIF is a "per square foot" figure, the efficiency of houses of different sizes may be compared.

TIF is analogous to a "gallons per mile per passenger" measure (FIG 5-13). It is easy to see that the TIF of an economy car will be higher than that of a large luxury car. What may be more difficult to understand is that the TIF of one car with 4 passengers will exceed that of a similar car which carries only 2 passengers. Although the miles per gallon may be the same, the 4-passenger model would give a higher TIF value than the 2-seater, since its gallons per mile per person is higher. Using such a yardstick, it is possible to see why a Greyhound Bus might have a higher TIF than a Honda Civic.



5-13 ENERGY PERFORMANCE: TIF

THERMAL INTEGRITY FACTOR FORM (TIF)

PRELIMINARY DATA

TOTAL FLOOR AREA 1000 DHL 22178 SSF 50
DDy (degree days per year) 7031 ΔT 71

$Q_{GROSS} = \frac{DHL \times DDY \times 24}{\Delta T}$

DHL (from data above) 22178
DDy (from data above) x 7031
24 (constant) x 24
ΔT (from data above) ÷ 71

GROSS ANNUAL HEAT LOSS = $\boxed{\text{52.71 MILLION}}$ Q_{GROSS}

$Q_{INTERNAL}$ = NUMBER OF INHABITANTS x 3 MILLION BTU

NUMBER OF INHABITANTS 4
3 MILLION (constant) x 3,000,000

INTERNAL HEAT GAIN = $\boxed{\text{12 MILLION}}$ $Q_{INTERNAL}$

$Q_{NET} = Q_{GROSS} - Q_{INTERNAL}$

Q_{GROSS} (from above) 52.71 MILLION
$Q_{INTERNAL}$ (from above) - 12.0 MILLION

NET ANNUAL HEATING REQUIREMENTS = $\boxed{\text{40.71 MILLION}}$ Q_{NET}

$Q_{SOLAR} = Q_{NET} \times SSF$

Q_{NET} (from above) 40.71 MILLION
SSF (from data above) x .50

ANNUAL SOLAR CONTRIBUTION = $\boxed{\text{20.35 MILLION}}$ Q_{SOLAR}

$Q_{AUXILIARY} = Q_{NET} - Q_{SOLAR}$

Q_{NET} (from above) 40.71 MILLION
Q_{SOLAR} (from above) - 20.35 MILLION

TOTAL AUXILIARY HEAT REQUIRED = $\boxed{\text{20.35 MILLION}}$ $Q_{AUXILIARY}$

TIF = ($Q_{AUXILIARY}$) / (DDY x FLOOR AREA)

$Q_{AUXILIARY}$ (from above) 20.35 MILLION
DDY (from data above) ÷ 7031
FLOOR AREA (from data above) ÷ 1000

THERMAL INTEGRITY FACTOR = $\boxed{2.85}$ TIF

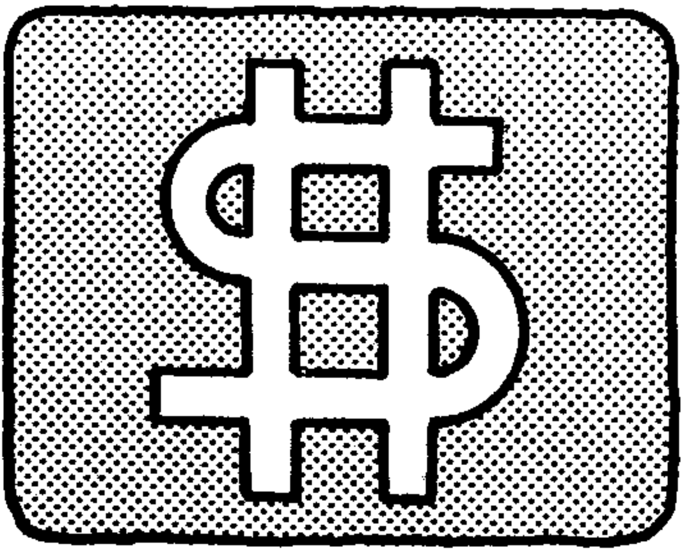
The primary goal in any design process is to achieve the lowest TIF value possible within the imposed economic limitations. Herbie's house, with a TIF value of 2.85, is a well-designed solar home. TABLE 5-8 provides a basic explanation of TIF values.

TABLE 5-8 TIF RANGES

TIF VALUE	DESCRIPTION	COMMENTS
10 +	not yet "extinct" dinosaur	Present typical subdivision construction
6-10	barely okay	Moderately insulated
4-6	good	Energy-conscious home
1.5-4	better	Well-designed solar home
0.75-1.5	outstanding	State of the art. What the world will be coming to.

CHAPTER 6
ECONOMICS

This chapter is an introduction to the economic considerations involved in the decision to build a passive solar home. The discussion includes construction costs, energy savings, investment analyses, and applicable tax benefits.



ECONOMICS

While there are numerous benefits associated with the inclusion of passive solar strategies in new home or retrofit construction, there are costs associated with the solar option as well, and any analysis of solar feasibility is incomplete without the weighing of these benefits and costs (FIG 6-1).

To keep the analysis as objective as possible, only monetary benefits and costs are considered. Non-monetary benefits and costs, i.e., those benefits or costs to which it is difficult to assign a dollar value, are not considered. Examples of non-monetary benefits include the security of relative energy self-sufficiency and the ambiance of a sunspace. While non-monetary benefits and costs will not be included in this strictly economic discussion, that is not to say that they are inconsequential. Certainly these non-monetary benefits and costs will be important considerations in any decision regarding the solar option.

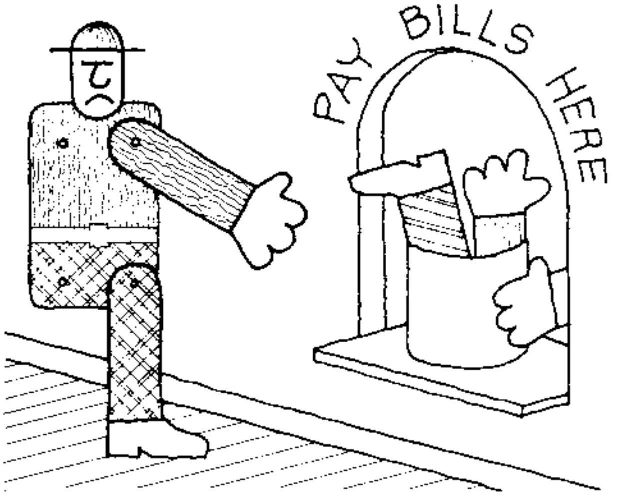
The investment in a solar home can be measured and evaluated by various economic performance indicators including the payback period, life-cycle costing, net benefits or savings, savings-to-investment ratio, and internal rate of return.

The simplest of these performance measures to understand is the payback period, and the payback period is discussed in detail and is the working example used in this chapter. The payback period is a function of 1) the additional construction cost of the solar work, and 2) the energy savings generated thereby. Once the additional costs of construction are known, and the annual heating requirements have been converted to a dollar figure, the payback period can be calculated.

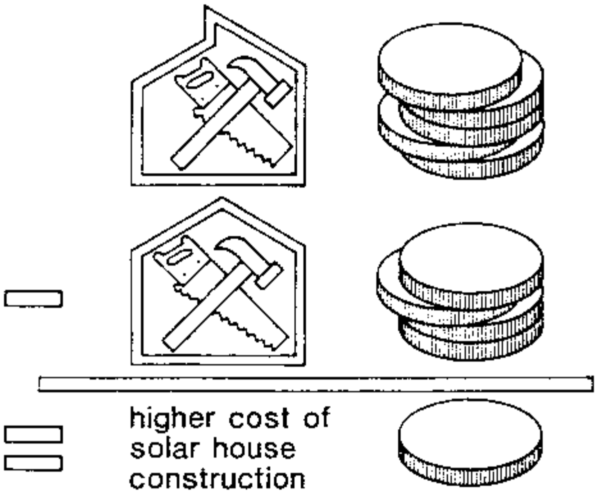
CONSTRUCTION COSTS

Passive solar heated or cooled buildings may have construction costs greater than conventional construction. These additional construction costs are due to items that would not be present in an otherwise conventionally built home. These items include thermal windows, overhangs, night shutters, thicker walls, thermal mass, extra insulation, etc. (FIG 6-2).

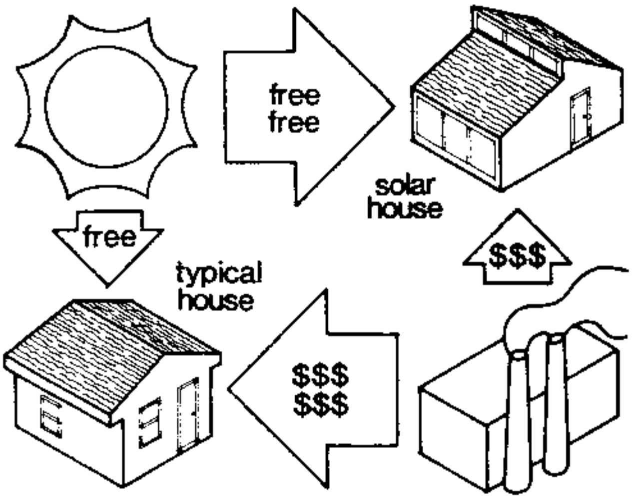
While passive solar construction will include additional cost items, reductions in cost may also occur, most likely as a result of downsizing or eliminating heating and air conditioning equipment.



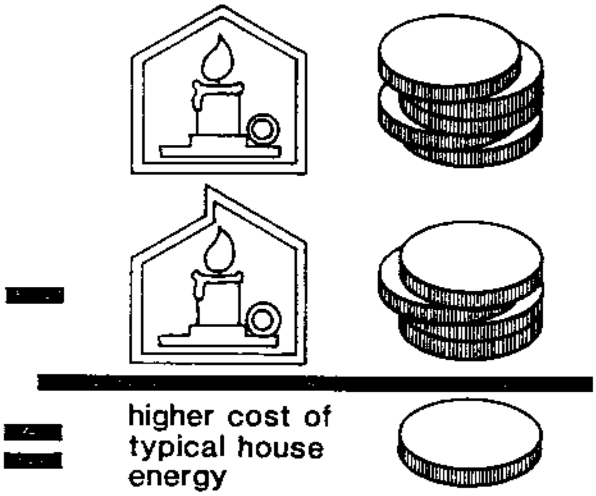
6-1 WILL GOING PASSIVE COST AN ARM AND A LEG



6-2 ADDITIONAL CONSTRUCTION COST



6-3 ENERGY COST BENEFIT



6-4 REDUCED ENERGY COST

TABLE 6-1 FUEL ENERGY EQUIVALENCY

COAL	
anthracite	6,800-10,150 btu/lb
bituminous	4,400-10,045 btu/lb
FUEL OIL #2	97,300 btu/gal
NATURAL GAS	780 btu/ft^3
COMMERCIAL PROPANE	1870 btu/ft^3
ELECTRICITY	3413 btu/kwh

The difference between these higher and lower costs can be considered the effective cost of the passive solar dwelling over a comparable, conventional non-solar house (FIG 6-3). For example, the additional insulation, night shutters, and extra south glass for Herbie's house in Chapter 5 result in an effective cost of $2500. For most passive solar homes, this effective cost of construction is usually between 5-10% more than the cost of a comparable, conventional non-solar house.

ENERGY COST SAVINGS

The energy cost savings (FIG 6-4) of a particular passive solar home will be influenced by a number of factors. These factors include the climate where the house is being built, the heating requirements of the house, the proportion of the heating and cooling requirements that will be satisfied by the passive solar system, and how these energy needs compare with the requirements of a comparable, conventional non-solar home.

The annual energy cost savings are determined by the amount of energy used, the type of fuel used, and the cost of that fuel. The amount of energy used is the product of the thermal integrity factor (TIF), the heating degree-days (DDy), and the floor area of the home:

Annual heating
requirements = TIF x DDy x Floor area

For example, Herbie's house in Chapter 5 has net annual heating requirements of 20.35 Mbtus, which are calculated as follows:

Annual Heating
Requirements = TIF x DDy x Floor Area
= 2.89 x 7031 x 1000
= 20,350,000
= 20.35 Mbtus

The annual heating requirements must next be converted to fuel energy equivalencies (TABLE 6-1). To determine the amount of fuel consumed, divide the annual heating requirements by the fuel energy equivalency from TABLE 6-1. Because Herbie's house uses electricity, the annual heating requirement of 20.35 Mbtus is converted to electrical consumption by dividing by 3413 to obtain kilowatt hours (kwh). The electrical usage for heating the home is calculated as follows:

Electricity
Required = Annual Heating Requirements / 3413
= $(20.35 \times 10^6)/3413$
= 20350000/3413
= 5963 kilowatt hours

For any fuel, the annual cost is the product of the fuel consumed and the cost of that fuel:

Annual Cost = Fuel Consumed x Fuel Cost

For Herbie's house, electricity at a cost of 5 cents per kwh results in a projected heating bill as follows:

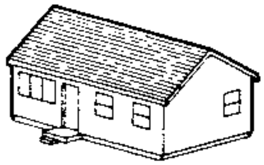
Annual Cost = Electricity Used x Cost
= 5963 kwh x 0.05 $/kwh
= $298.15

To compare Herbie's solar home with a conventional home of similar size in Chadron (FIG 6-5), the cost of heating the conventional home must be determined. For example, a 1000 sq ft tract home in Chadron with a TIF of 10 would have the following annual heating requirements:

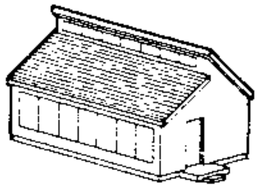
Annual Heating
Requirements = TIF x Ddy x Floor Area
= 10 x 7031 x 1000
= 70,310,000
= 70.31 Mbtus per year

The electricity required would be:

Electricity
Required = Annual Heating Requirements / 3413
= $70.31 \times 10^6/3413$
= 20600 kwh



typical tract house
TIF = 10.0



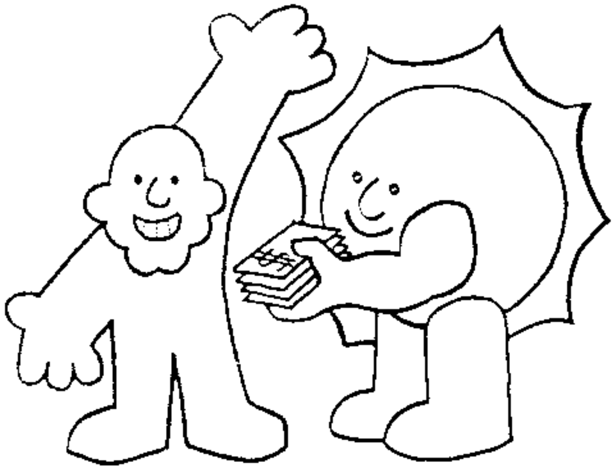
passive solar house
TIF = 1.5

6-5 THERMAL INTEGRITY FACTOR (TIF)

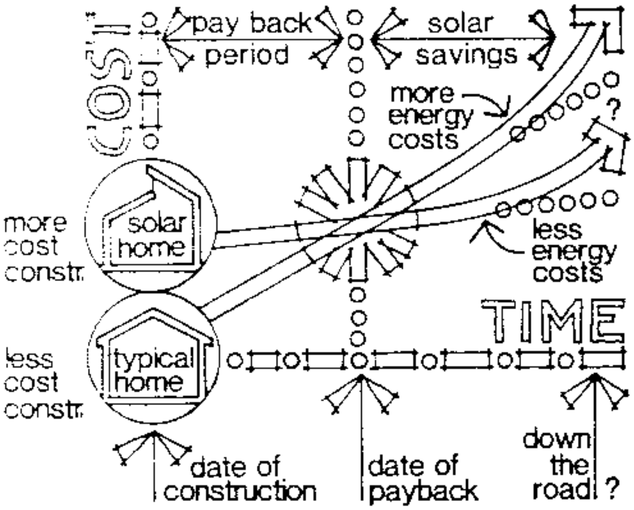
The annual heating cost for the conventional house would be:

Annual Cost = Electricity Used x Cost
= 20600 kwh x .05 $/kwh
= $1030.00

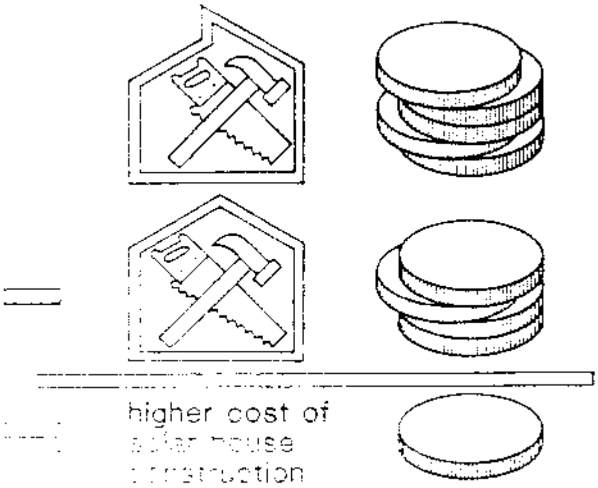
The energy costs of Herbie's home subtracted from the energy costs of the comparable conventional home give the initial annual energy cost savings, which, in this case, are approximately $731 per year. At 10 cents per kwh (which is a likely scenario by the year 1990) the savings would be nearly $1462 per year. As energy costs escalate, the impact of savings from a solar home becomes more apparent.



6-6 SOLAR PAYBACK



6-7 SOLAR ECONOMICS



6-8 ADDITIONAL CONSTRUCTION COST

THE SOLAR INVESTMENT

PAYBACK PERIOD

Having identified the effective cost of a passive solar system (house construction, heating and cooling systems) and the monetary benefits of such a system (annual energy cost savings), it is now possible to address the question: Is it worth it?

One of the most easily understood methods of calculating the monetary benefits of an investment in a passive solar home is the payback period (FIG 6-6). The payback period is defined as the number of years required to generate enough money (in energy cost savings) to pay for the initial investment (the effective cost of a passive solar rather than a conventional home) (FIG 6-7).

The simplest way to determine payback is to divide the additional cost of construction by the annual energy cost savings:

$$\text{Payback Period} = \frac{\text{Additional Cost of Construction}}{\text{Annual Energy Cost Savings}}$$

For Herbie's house, the $2500 additional cost of construction divided by the $731 annual energy savings results in a payback period of 3.42 years (FIG 6-8), calculated as follows:

$$\begin{aligned}\text{Payback Period} &= \frac{\text{Additional Cost of Construction}}{\text{Annual Energy Cost Savings}}\\ &= \$2500/\$731 \text{ per year}\\ &= 3.42 \text{ years}\end{aligned}$$

This payback period suggests that, in a period of less than four years, the passive solar home will have saved enough money in energy costs to pay for the initial extra cost of the structure.

This simplified payback analysis, however, gives only a very rough estimate of the monetary benefit of passive solar for two reasons. First, this method ignores the time value of money. The money invested in the solar house is not available to earn interest until it is recovered through energy cost savings. Calculating a simple payback period ignores this foregone interest. Second, the payback period approach ignores the fact that the benefits, in terms of energy savings, will continue long after the initial investment has been recovered. In fact, if energy prices increase according to some current forecasts, potential energy cost savings in future years will be greater than they are in the current year; the investment in passive solar would be "paid back" over and over again.

LIFE-CYCLE COSTING

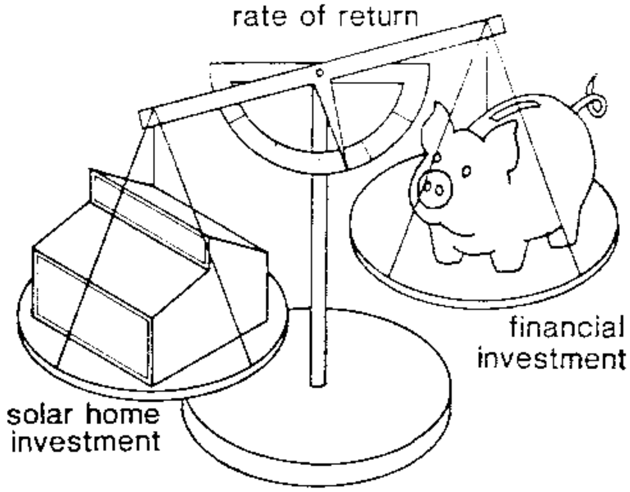
A life-cycle cost analysis takes into account all costs associated with a structure over its useful life -- purchase price (less any salvage value), energy costs, maintenance, repair, replacement, etc. -- and includes the cost of money over the life of the structure. The best investment is that which has the lowest overall life-cycle costs.

NET BENEFITS OR SAVINGS

The net benefits or savings analysis is very similar to the life-cycle cost analysis. It is determined by the difference between the life-time dollar energy savings and life-time dollar costs of the investment. Net benefits or savings may be expressed in either present value or annual value dollars.

SAVINGS-TO-INVESTMENT RATIO

In this analysis, savings and investment costs are expressed as a ratio rather than a dollar amount. A savings-to-investment ratio of greater than 1.0 indicates that the present value of the energy cost savings outweighs the cost and that the investment in the solar house is "profitable." The higher the ratio, the more dollar savings realized per dollar of investment.



6-9 RATE OF RETURN

INTERNAL RATE OF RETURN

When the construction of a passive solar dwelling is viewed as an investment, the question facing the buyer is: "Is this investment better than others I might make?" One way to answer this question is to compute the rate of return on the investment in a passive solar dwelling (FIG 6-9). The rate of return is the interest rate, stated in a percent, for which life-time dollar savings are equal to life-time dollar costs. If, for example, the rate of return on the solar investment is 25%, and interest rates on long-term financial investments (stocks, bonds, Certificates of Deposit, etc.) are 15%, the passive solar home is a better financial investment. A study performed at the University of Nebraska at Omaha computed the rate of return of a passive solar home to be 27%. This home, the "Islander", is featured in Chapter 9.

There are many unknowns in any economic calculation. Especially important is the future price of electricity, natural gas, and other fuels. Also unknown is the course of technological development in home heating and cooling designs. And, finally, one must consider the non-monetary elements involved in building a passive solar home, in particular the conservation of energy on a regional, national, and world level.

Any economic analysis of a solar investment must also include an analysis of applicable tax benefits available in conjunction with the use of solar and energy conservation techniques.

TAX BENEFITS

FEDERAL RESIDENTIAL ENERGY CREDITS

Persons -- including homeowners, renters, condominium owners, etc. -- who install certain energy conserving devices and/or renewable energy devices in their homes are eligible for a significant income tax credit. To fully appreciate this tax benefit, it is important to first understand the difference between a tax deduction and a tax credit. A tax deduction is subtracted from the taxpayer's adjusted gross income, and then the amount of tax is determined. A tax credit, however, is applied directly against the amount of tax owed. Thus, a tax credit reduces the amount of tax owed dollar for dollar and is usually a much more significant benefit than a tax deduction.

The Federal Residential Energy Tax Credit consists of two separate types of credits:

(1) CREDIT FOR ENERGY CONSERVATION COSTS.

This includes such items as insulation, storm or thermal windows or doors, weatherstripping or caulking, clock thermostats, etc. The credit is 15% of the first $2000 spent on items to save energy, or a maximum credit of $300. The cost of the items includes the cost of installation.

(2) CREDIT FOR RENEWABLE ENERGY SOURCE COSTS.

This allows credit for the installation of solar energy equipment for heating or cooling the home or for providing hot water or (after 1979) electricity for use within the home; wind energy equipment for generating electricity or other forms of energy for home use; or geothermal energy equipment. For years beginning after 1979, the credit for renewable energy source costs is 40% of the first $10,000 spent, or a maximum credit of $4,000.

PASSIVE SOLAR SYSTEMS. Under IRS regulations, "solar energy property" includes both active and passive solar energy systems. However, the current IRS position is that solar energy property does not include "materials and components that serve a significant structural function or are structural components of a home, and labor costs of installing such materials and components." The practical effect of this position is that, in most cases, significant portions of the passive system will not qualify for the income tax credit since most of the system also serves as structural components of the home. For example, windows (including clerestories and skylights) and greenhouses are not included as solar energy property and are not eligible for the tax credit. For a trombe wall, the mass wall and labor costs associated with installing it do not qualify. However, the outer (non-window) glazing and any shading, venting and heat distribution mechanisms do qualify. Hopefully, this position will be altered in the near future.

BUSINESS ENERGY INVESTMENT CREDIT

Businesses investing in certain energy property are eligible for tax credits of 10%, 11%, or 15%, depending on the type of energy property.

10% ENERGY INVESTMENT CREDIT PROPERTY

--Alternative energy property including biomass property;

--Specific equipment for which the principal purpose is to reduce the amount of energy consumed in any existing industrial, agricultural, or commercial process and that is installed in connection with an existing industrial, agricultural, or commercial facility, e.g., heat exchanger, recuperator, heat wheel, waste heat boiler, etc;

--Recycling equipment;

--Shale oil equipment;

--Equipment for producing natural gas from geopressured brine;

--Cogeneration equipment; and

--Qualified intercity buses.

11% ENERGY INVESTMENT CREDIT PROPERTY

--Qualified hydroelectric generating equipment.

15% ENERGY INVESTMENT PROPERTY

--Solar or wind energy property;

--Ocean thermal equipment;

--Geothermal equipment.

The same restrictions on passive solar energy systems that apply to the residential energy credits, also apply to the energy investment credit.

Regulations to be promulgated under the new Economic Recovery Tax Act of 1981 may affect the investment tax credit. Also, additional legislation to broaden tax credits to builders and developers and to include credits for passive solar systems is currently under consideration in Congress.

NEBRASKA SALES TAX REFUND

Under current Nebraska law, any sales or use tax paid by an owner on any alternative energy source facility approved by the Nebraska Energy Office, will be refunded to the owner. The refund applies to sales and use taxes paid on or after January 1, 1980. The refund will terminate on December 31, 1983. The refund applies to both active and passive solar energy systems. Aplication forms are available through the Nebraska Department of Revenue.

NEBRASKA PROPERTY TAX EXEMPTION

Under legislation passed during the 1981 Session of the Nebraska Unicameral, the value of major solar and energy conservation additions to a home will not be included in the valuation of the home for property tax purposes. In order to be eligible for this tax benefit, the owner of the real estate must receive approval of the improvement by the Nebraska Energy Office and must apply for the exemption to the County Assessor within 90 days after installation of the improvement or by January 1 of the year following installation. The exemption applies to both active and passive solar energy systems. The exemption applies to improvements installed after November 11, 1980, and on or before December 31, 1985. The improvement remains exempt from taxation for 5 years. The property tax exemption regulations are administered through the Nebraska Energy Office, Nebraska Solar Office, and the Nebraska Department of Revenue.

CHAPTER 7
LEGAL

This chapter discusses pertinent legal issues concerned with solar energy use -- solar access, building codes, and zoning regulations.

SOLAR ACCESS

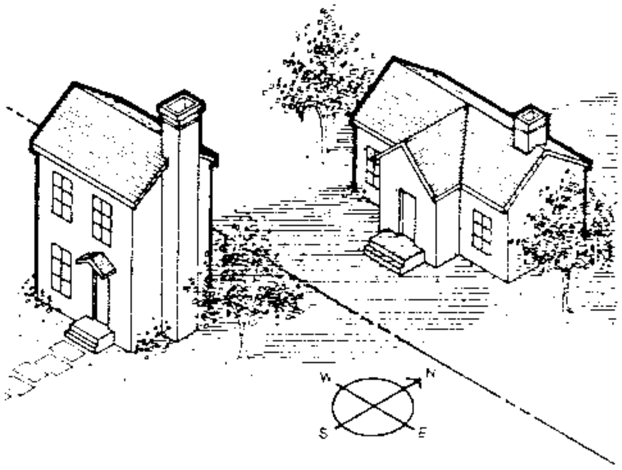
The solar access issue -- preventing the shading of the solar collecting surface -- is the primary legal concern involved in solar energy use. Solar access poses a potential problem because for hundreds of years American courts have held that, in the absence of a private agreement, a property owner has no inherent right to receive incident sunlight on his property. Thus, a property owner could plan and install a solar energy system for his home and, in the event a neighbor built or grew anything which obstructed the sunlight, the solar owner would be powerless to prevent the obstruction (FIG 7-1).

Recent cases concerning solar access have been consistent in upholding the right of the neighbor to build whatever he wants on his property against the necessity of the solar owner to receive unobstructed solar energy. E.g., in the 1980 Wisconsin case of Prah v. Maretti, Prah installed an $18,000 active solar energy system on his home. His neighbor to the south -- Maretti -- then began construction on his home which, when completed, would shade the Prah's solar energy system and render it non-functional. Despite Prah's monetary loss, the Wisconsin court refused to enjoin construction of the Maretti home and found against the solar owner, even going so far as to rebuke the solar owner for his lack of foresight and planning.

Assuring adequate solar access requires a combination of technical processes and legal considerations:

(1) Proper site planning and orientation (as discussed previously); and

(2) Providing an adequate legal mechanism to assure solar access.



7-1 SHADING CAUSED BY NEIGHBORING STRUCTURE

As noted above, courts have held that, in the absence of a private agreement (or applicable zoning regulations), a landowner has no inherent right to receive incident sunlight on his property. Obviously, the key is for the solar owner to take advantage of private agreements that can assure adequate legal access to solar energy.

Currently, the two most effective private agreements for assuring legal access to solar energy are restrictive covenants and easements. Generally speaking, restrictive covenants will be used only to provide solar access protection in new subdivisions; easements will most often be used to provide solar access protection for a solar system on a particular lot.

RESTRICTIVE COVENANTS

When land is subdivided for new development, there are a number of activities involved in the process of turning the undeveloped land into a neighborhood. These include planning how streets will run, where homes and vegetation will be, developing a plat, obtaining necessary approval from the city or county, etc. At some time during this process, and prior to the time lots are sold to prospective homeowners, the developer will usually prepare restrictive covenants that will control activities and land uses within the subdivision. These covenants will be included as part of the deed to each lot in the subdivision.

New subdivisions offer a tremendous opportunity for providing solar access, because the entire planning process -- how streets are laid out, where houses and vegetation will be, etc. -- can be planned from the start with an eye to providing maximum solar access for every lot. At this same time the developer can utilize restrictive covenants which will provide the necessary legal protection for assuring continued solar access.

There are a number of legal requirements to ensure the enforceability of restrictive covenants:

(1) General Scheme of Development: The restrictive covenants must be part of a general scheme of development. This legal requirement is easily satisfied in a situation where the development has been specifically planned for solar access.

(2) Notice to Purchaser. All purchasers of lots within the subdivision must have notice of the restrictive covenants. This requirement is satisfied by recording the covenants in the public land records.

(3) The conditions in the covenants must be stated in the negative, (i.e., prohibiting a certain use or activity) rather than the affirmative (requiring a landowner to take some action). Most solar covenants will satisfy this requirement, however, some problems could arise if the proposed covenants require a landowner to trim vegetation -- an affirmative action. This is primarily a drafting problem and can perhaps best be solved by drafting the covenants to provide that a landowner could only plant vegetation according to a vegetation plan developed for the subdivision, or prohibiting the planting of species of trees or bushes that could grow over a specified height in particular areas. Here again, the process will involve combining technical aspects with legal requirements.

(4) Enforcement. Perhaps the most important legal requirement to ensure the enforceability of a restrictive covenant is rigid enforcement. The Architectural Control Committee, Homeowner's Association, developer and landowners within the development must be vigilant regarding breaches of the covenants, since in a situation where a covenant has been breached and action is not taken immediately, a court will usually hold that the particular covenant is no longer enforceable in the development. Thus, in the use of solar covenants, if any breach occurs -- if a structure is built outside the limits of the solar envelope or any unapproved vegetation is planted or any unauthorized shading of a solar energy system occurs -- immediate action must be taken to correct the breach.

(5) Defining the Protected Space. In drafting restrictive covenants to provide for solar access, it is necessary to define specifically what areas of the development are protected from shading. This satisfies a number of requirements, both legal and practical. Restrictive covenants which simply state "no solar energy system in the subdivision may be shaded," are generally unworkably vague: they do not define where solar energy systems are

located, no guidelines are given as to what landowners can build or where they can plant so as not to shade another system, etc. Rather, it is important from the standpoint of future workability and enforceability that the development be planned so as to provide specific guidelines and that these guidelines be included in the covenants.

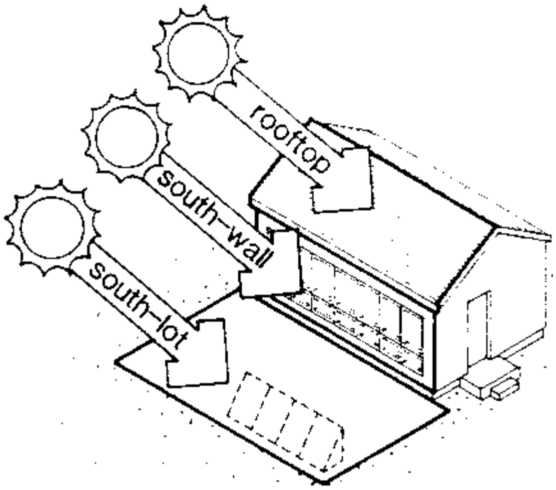
In defining the protected space, the first determination to be made is of the exact type of protection which will be afforded -- i.e., roof-top protection for active solar energy systems, protection to ground zero for passive systems, or a combination of the two. Generally, protection of passive systems requires a greater area of protection (FIG 7-2). Once this determination is made, there are a number of methods which will provide the necessary means of protection, such as designing bulk planes, determining height and setback restrictions specifically for solar access, the use of solar envelopes, etc.[1] To date, the most effective method of protection appears to be the use of solar envelopes.[2] Solar envelopes are three dimensional and define the maximum allowable space within which buildings can be built or vegetation grown so as not to shade solar collecting surfaces on surrounding parcels of land.

Solar envelopes offer many advantages for use in defining solar access protection:

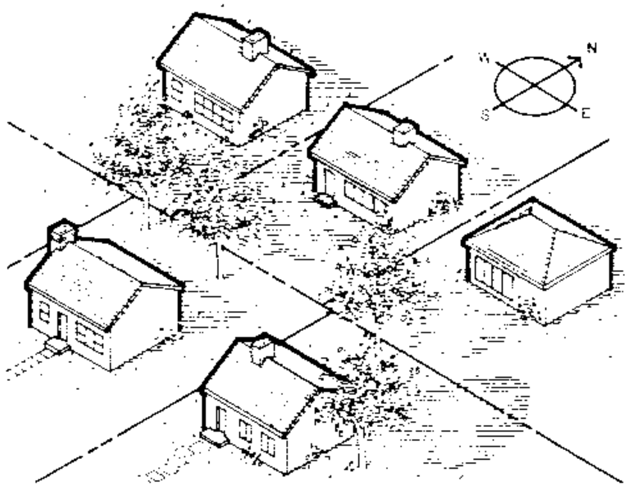
(1) Solar envelopes are relatively easy to design;

(2) Solar envelopes can be used in defining restrictions for both structures and vegetation;

(3) Solar envelopes can be an effective sales tool for the developer as potential buyers can easily understand them and their purpose.



7-2 AREAS OF DIFFERING SOLAR ACCESS REQUIREMENTS



7-3 SHADING CAUSED BY VEGETATION

After the solar envelopes have been designed by the solar consultants or architect (see detailed discussion following), the solar covenants can be drafted. They should include a statement of the purpose and intent of the solar covenants and a precise definition of the solar envelopes. If the envelopes are being used only in conjunction with structures, separate provisions for vegetation control must be specifically enumerated in the covenants -- as growing vegetation will be a periodic source of potential problems (FIG 7-3).

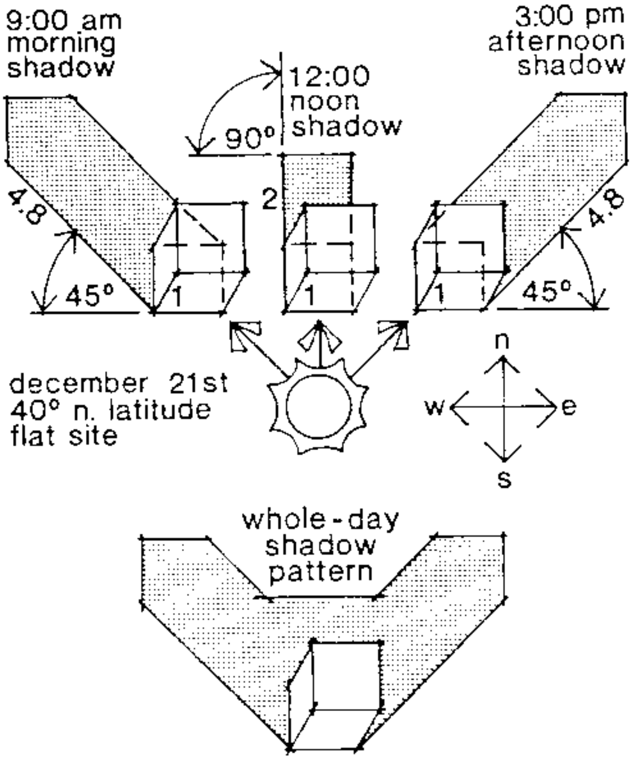
In addition to provisions for solar access, restrictive covenants can also be used to implement other energy conserving strategies, e.g., requirements for insulation, double or triple glazing, etc.

PLANNING A SOLAR SUBDIVISION USING SOLAR ENVELOPES

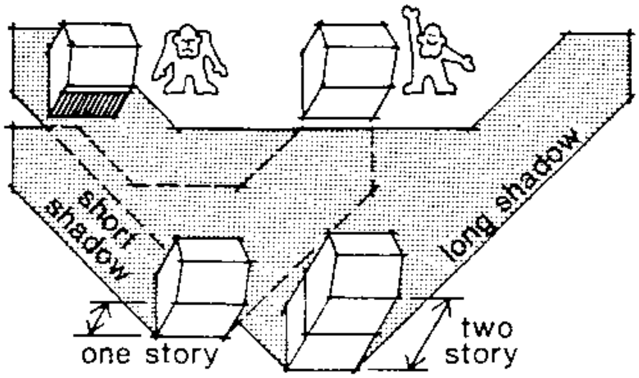
Planning a solar envelope for a lot limits the height of all structures and vegetation on that lot to prevent their casting shadows on the solar collection areas of neighboring lots. The greater the area of a lot set aside for solar collection, the more limited the heights of the solar envelopes on surrounding lots. Thus, designing a solar subdivision requires a balance between freedom to build or to plant anywhere within standard setbacks, and greater restrictions on the placement and location of plants and structures.

Basic guidelines used to plan for solar access are based on the following: 1) a particular latitude, 2) the direction of sun angles on December 21, and 3) the direction and degree of slope of the land. For illustration purposes (FIG 7-4), assume a piece of land located at 40^{0} north latitude , sun angles based on December 21, and no slope to the land, i.e., a flat piece of land. At noon, a 10' high object will cast a shadow 20' in length to the north, or a 1:2 ratio. At 9:00 AM and 3:00 PM, this 10' high object will cast a shadow 48' in length at a 45 degree angle from south, or a 1:4.8 ratio (FIG 7-4). By using these ratios, shadows can be projected for any existing or proposed object in the subdivision (house, garage, tree, etc.) and a determination can be made as to whether or not proposed solar collection surfaces will be shaded.

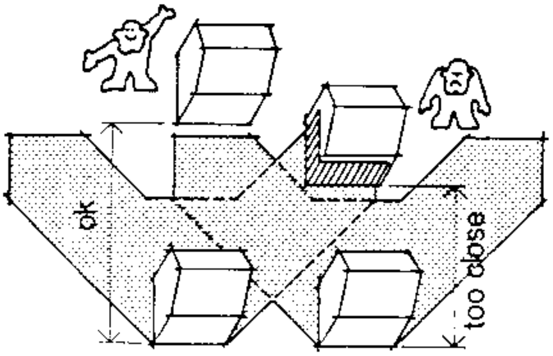
In planning a solar subdivision with rectangular lots twice as long as they are wide, the above guidelines indicate east-west streets tend to provide better solar access than north-south streets: the east and west shadows of early morning and late afternoon affect the solar envelope design more than south shadows. Some conflicts can develop when: 1) structures are built which are taller than the north-south distance will permit (FIG 7-5), 2) there is not enough north-south distance between two



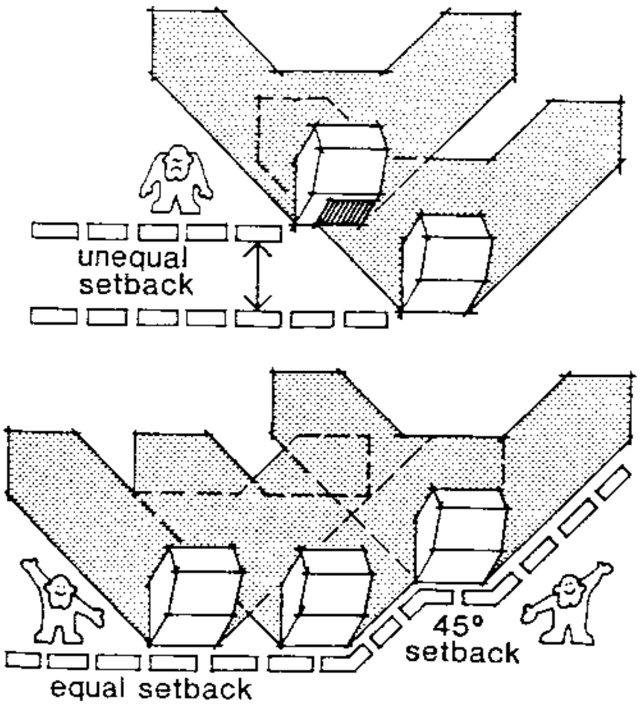
7-4 SHADOW PATTERNS: DEFINITION



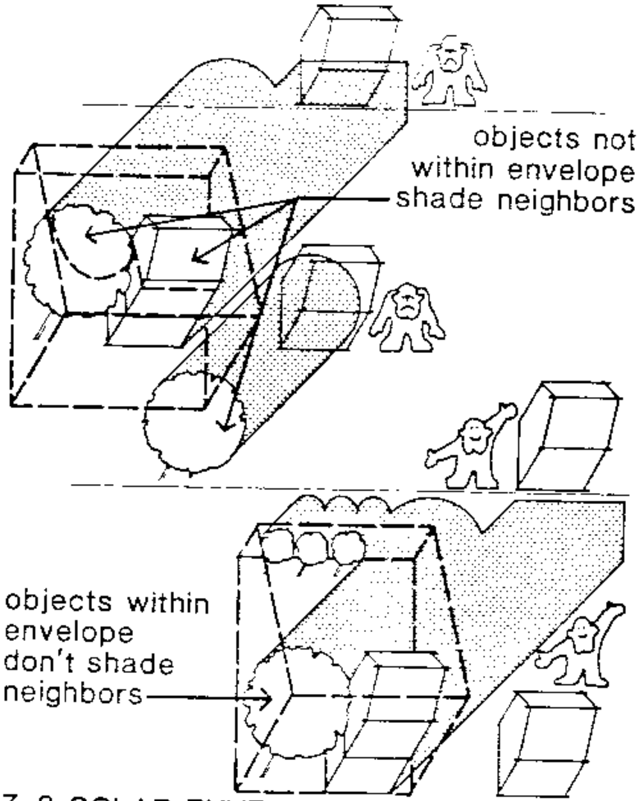
7-5 TALLER BUILDINGS CAST LONGER SHADOWS structures (FIG 7-6), or 3) little thought is given to offsetting the south facades more than 45 degrees from each other (FIG 7-7). In designing a solar envelope, an attempt is made to ensure that these conflicts do not occur and that structures and vegetation do not penetrate the envelope roof, as penetrations of the envelope roof cast shadows beyond the intended maximum shadow line (FIG 7-8).



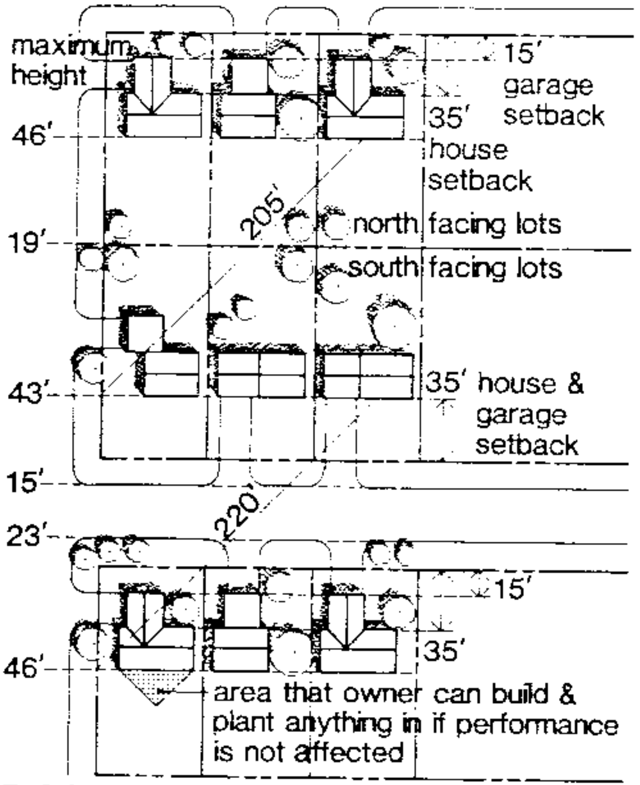
7-6 NORTH-SOUTH SEPARATION IS NEEDED



7-7 KEEP SETBACKS UNIFORM



7-8 SOLAR ENVELOPES PROTECT NEIGHBOR'S ACCESS TO SUN

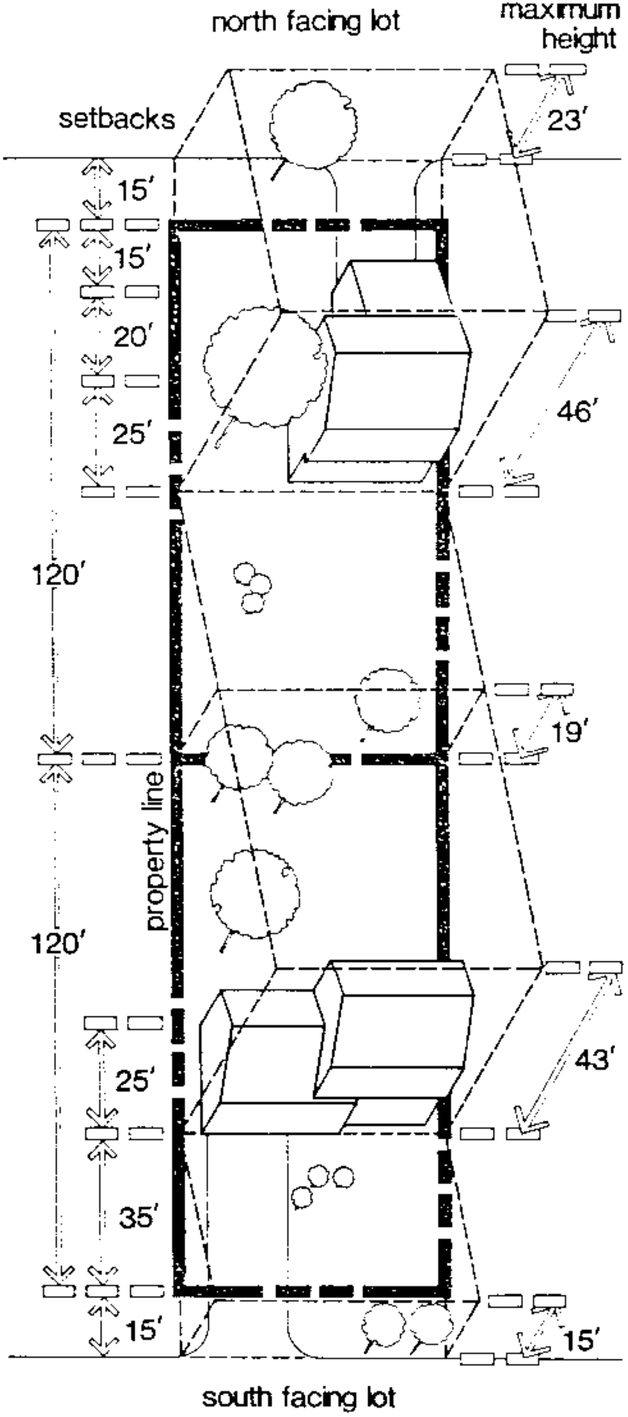


7-9 TYPICAL SOLAR SUBDIVISION

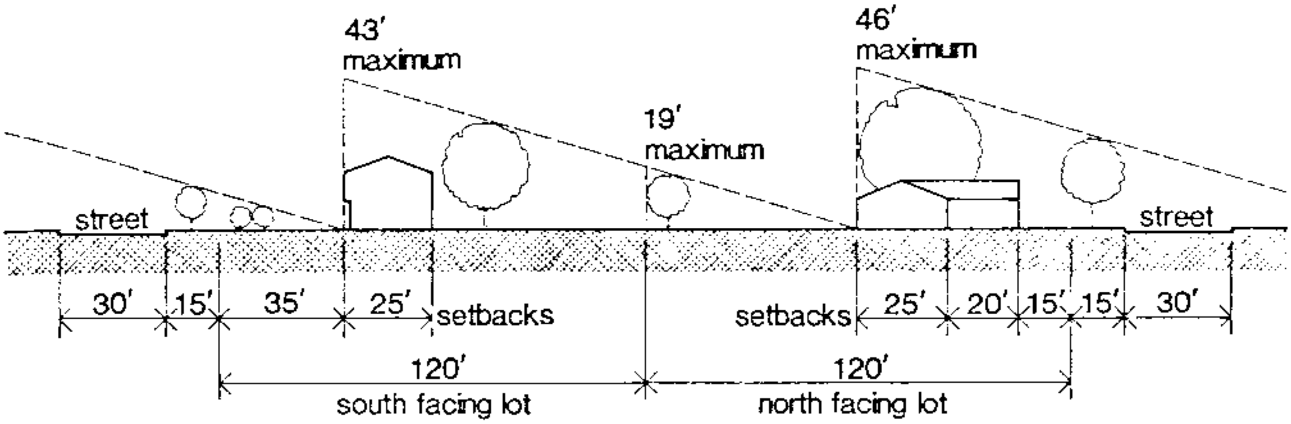
Solar envelopes can be designed for a typical single-family lot subdivision with slight modifications to the typical layout (FIG 7-9). The setback for north-facing lots can be decreased to 15' from the property line; the south-facing lots have a 35' setback; garages can be located on the north side of the house to block winter winds and provide greater south wall exposure. In the north lot of the example, a building depth of 15' has been allotted plus the 20' depth for the garage. From this south facade of a building on the north-facing lot, a line is drawn to the southwest at a 45 degree angle to the 35' front setback line of the south-facing lot. This 205 foot line is then divided by 4.8 which will give the maximum height of 43'. Any height may be determined by measuring along a 45 degree line and then dividing by 4.8.

After all vertical heights have been established, an axometric drawing may be prepared to show heights for purposes of legal documentation. This drawing will normally show all important vertical and horizontal dimensions and may also include a verbal description. For illustration purposes, a north-facing and south-facing lot with buildings and trees placed within the envelope has been included (FIG 7-10 and 7-11).

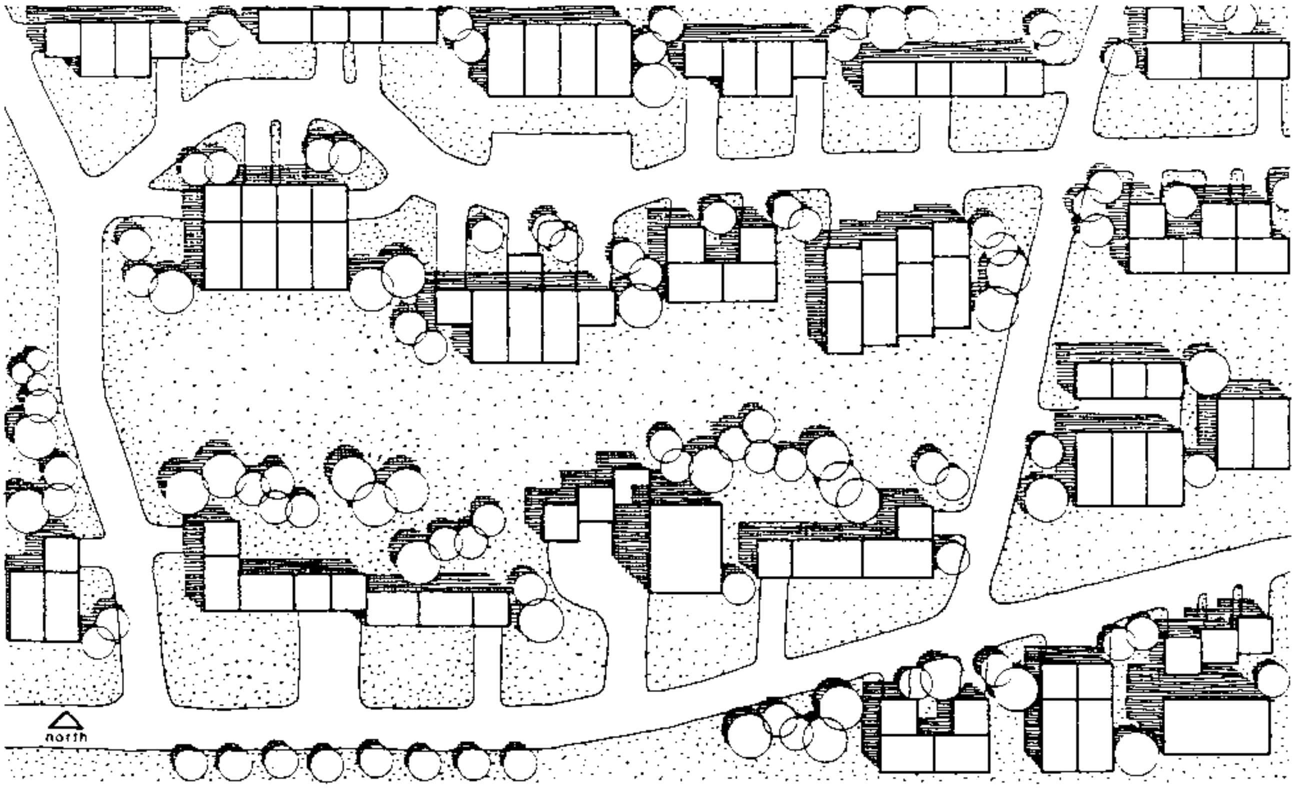
The last illustration is intended to show the improved solar access that a planned development utilizing multi-family, row house, duplex and zero lot lines can provide. This type of development increases the north-south separation between buildings and also reduces street, utility and building cost while providing open space and other amenities (FIG 7-12).



7-10 ENVELOPES FOR NORTH FACING & SOUTH FACING LOTS



7-11 SIDE VIEW OF ENVELOPES



7-12 SOLAR PLANNED URBAN DEVELOPMENT

SOLAR EASEMENTS

In 1979, the Nebraska Unicameral approved the Nebraska Solar Access Act now codified at Neb. Rev. Stat. Sections 66-901 through 66-914 (1981 Supp.). The Act provides a first step in providing protection for solar access through the following:

(1) It authorizes the creation and recording of solar easements.

(2) It gives the power to local zoning boards to enact zoning regulations dealing with solar access.

To date, Lincoln is the only Nebraska community which has adopted solar access zoning regulations. Under these regulations, developers who provide solar access protection in new developments can increase the density in the development by 20%. The Lincoln regulations do not make solar access a requirement in the development, rather they provide an incentive to the developer who initiates solar access protection.

Thus, for the individual homeowner, the primary focus will be on solar easements. Unlike restrictive covenants, which are used to provide protection throughout an entire development, solar easements will most often be used by individual landowners to protect access for a particular system on a particular lot. Since an easement is a private land use control (unlike zoning regulations which are public land use controls) it is voluntarily negotiated between private landowners. This means that the solar owner must obtain permission from his surrounding neighbors for the solar easement. If they will not give their permission, there can be no easement.

Negotiating the easement with surrounding neighbors is entirely dependent upon the needs and demands of the landowners involved. In some instances, money may be paid for the right to access.

After negotiations are completed, the easement will be drafted by an attorney. Under the Nebraska Solar Access Act, the easement must be in writing, signed by all landowners involved, and filed with the Register of Deeds in order to be enforceable.

The Nebraska Solar Access Act provides that the solar easement should include the following:

(1) A legal description of the real property burdened and benefitted by the easement;

(2) A description of the vertical and horizontal angles, expressed in degrees and measured from the site of the solar energy system, at which the easement extends over the burdened property, or any other description which defines the three dimensional space, or the place and times of day in which an obstruction to solar energy is prohibited or limited. (The use of a solar envelope will satisfy this requirement);

(3) Any terms or conditions under which the solar easement is granted or may be terminated;

(4) Any provisions for compensation of the owner of the benefitted property in the event of interference with the enjoyment of the solar easement, or compensation of the owner of the burdened property for maintaining the solar easement; and

(5) Any other provisions necessary or desirable to enforce the purpose of the easement.

The Act further provides that a solar easement shall run with the land, unless the easement specifically provides for termination at a later date. To "run with the land" means that the easement attaches to the land itself and will always be a condition of the land, even if the land is sold to another. This is an important element of the easement, and it is advisable to make specific reference in the written easement that it runs with the land.

Finally, if there are any exceptions to the easement -- e.g., existing shading, utility poles, television antennae, etc. -- they should be specifically exempted in the written document to ensure enforceability of the easement.

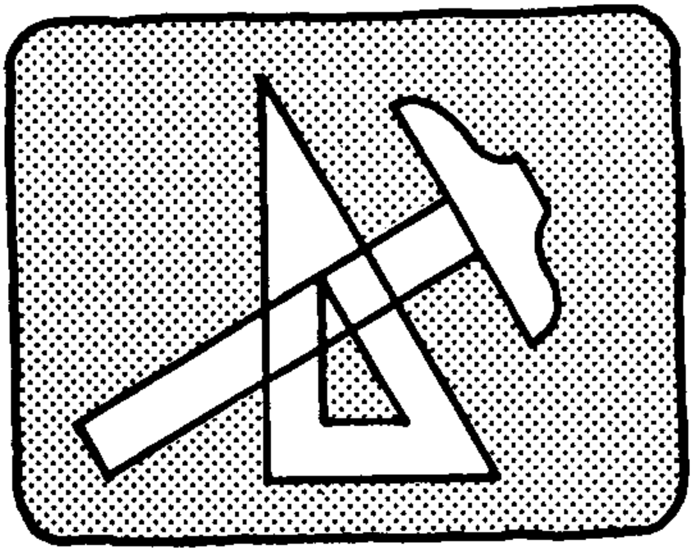
BUILDING CODES AND ZONING REGULATIONS

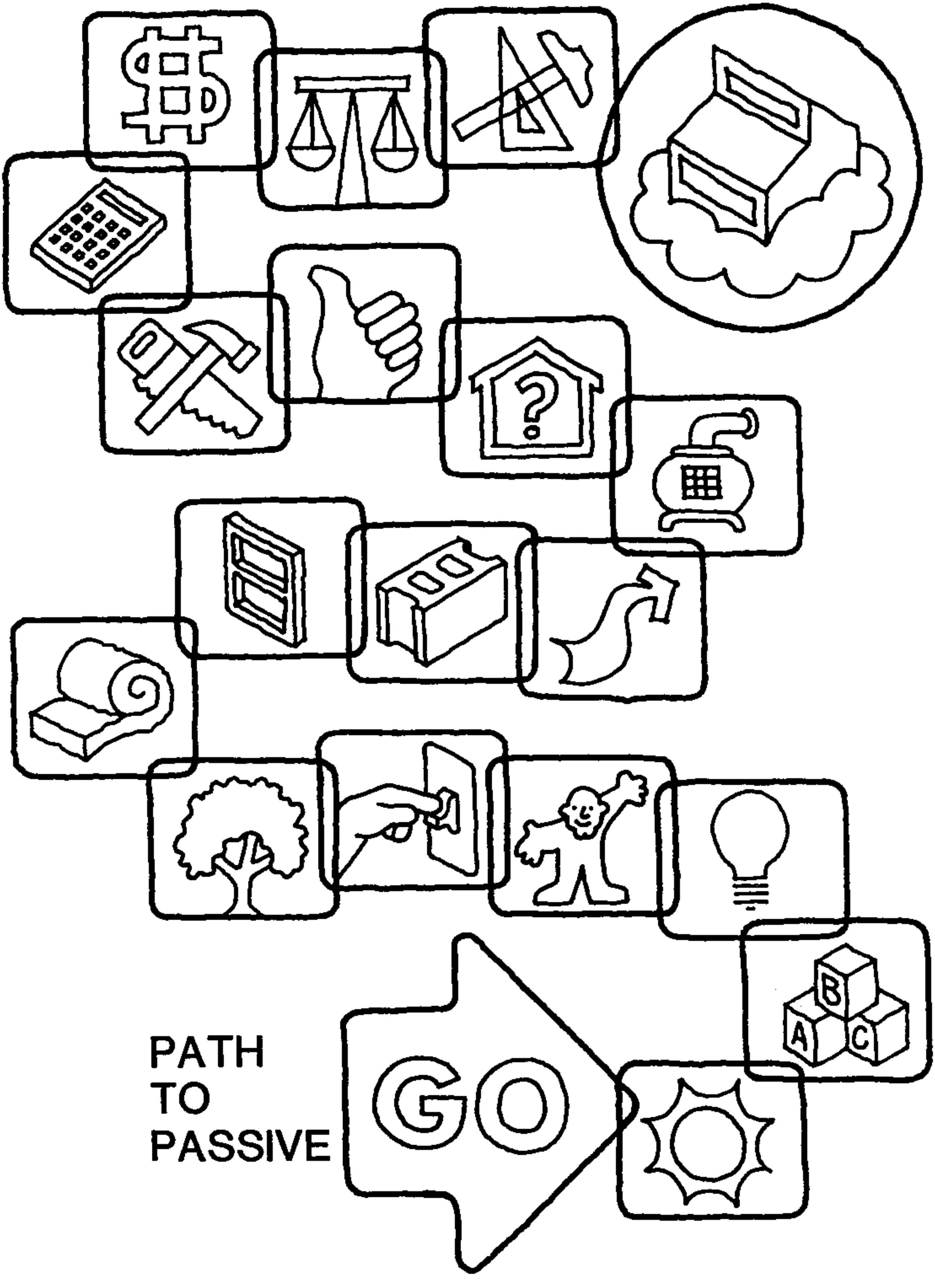
As with any other new building or addition work, building a passive structure will require a building permit and approval of the planned structure. Specific requirements will vary from city to city.

In the situation of adding a solar greenhouse to an existing structure, zoning regulations may be of particular relevance. If the southern-facing wall of the existing structure is built up to the applicable setback, a variance from the setback may be required. Under Section 66-914 of the Nebraska Solar Access Act, applicable zoning boards in Nebraska are specifically given the power to grant variances in these situations.

CHAPTER 8
SOLAR PROCESS

This chapter is an overview of the steps that should be taken in planning and building a passive solar home.





PATH
TO
PASSIVE

SOLAR PROCESS

The preceding chapters have discussed solar energy fundamentals, design ideas, passive solar systems, engineering, etc., and with this background it is possible to discuss the steps (FIG 8-1) that should be followed from a project's inception to living in the solar structure.

STEP 1: EDUCATION

In many extremely important ways, the design and construction of passive solar homes is significantly different from conventional residential design and construction. Therefore, the prospective owner of a passive solar home must become as knowledgeable as possible about what passive solar is and what it involves; what it can and cannot do; what the homeowner is qualified to handle; where and when he must or should rely on professionals; and how to deal knowledgeably with those professionals.

Thus, the solar process begins with information. Fortunately, much information is available. Reading this book is a good first step in the education process. Additional reading may be helpful, and a bibliography of recommended books is included in Appendix 7. Information may also be gathered at workshops, seminars, classes, conferences, etc., sponsored by, among others, the Nebraska Solar Office, the Nebraska Energy Office, community colleges, universities, etc.

STEP 2: I WANT SOLAR !!

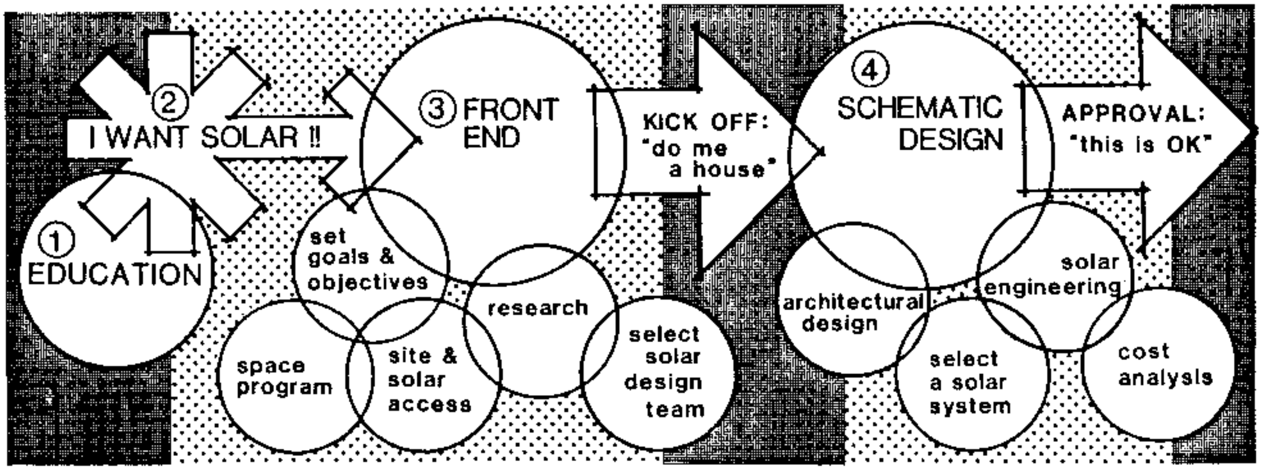
Once initial information has been gathered. the advantages and disadvantages of various passive solar and conservation strategies can be evaluated. This knowledge and a desire to build makes possible an informed commitment to build a passive solar home.

STEP 3: FRONT END

With an affirmative decision to proceed, the "front end" work begins. This work includes selecting a solar design team, conducting specialized research, setting goals and objectives, establishing a space program for the house, and choosing a site.

Unless the homeowner is a design professional with solar experience, he should obtain the services of a solar consultant or architect with solar experience. These professionals play an important role in setting project goals and objectives, site selection, and preliminary design.

The information gathering process, which should continue throughout the course of



the project, would at this stage include research such as visiting an existing passive solar home. These visits give the potential passive solar homeowner a chance to understand the architectural features, to check the quality of construction, and to get a feeling for the ambiance of solar living.

The goals and objectives of the design must be established early in the process. For example, the goals and objectives of Herbie's home discussed in Chapter 5 would be to provide their family of 4 with a passive solar home of 1000 sq ft, with construction costs not to exceed $65,000.

Once the goals and objectives have been determined, the space plan can be determined. The space plan is a list of individual spaces such as the living, kitchen and dining areas, bedrooms and bathrooms, and the desired size of each.

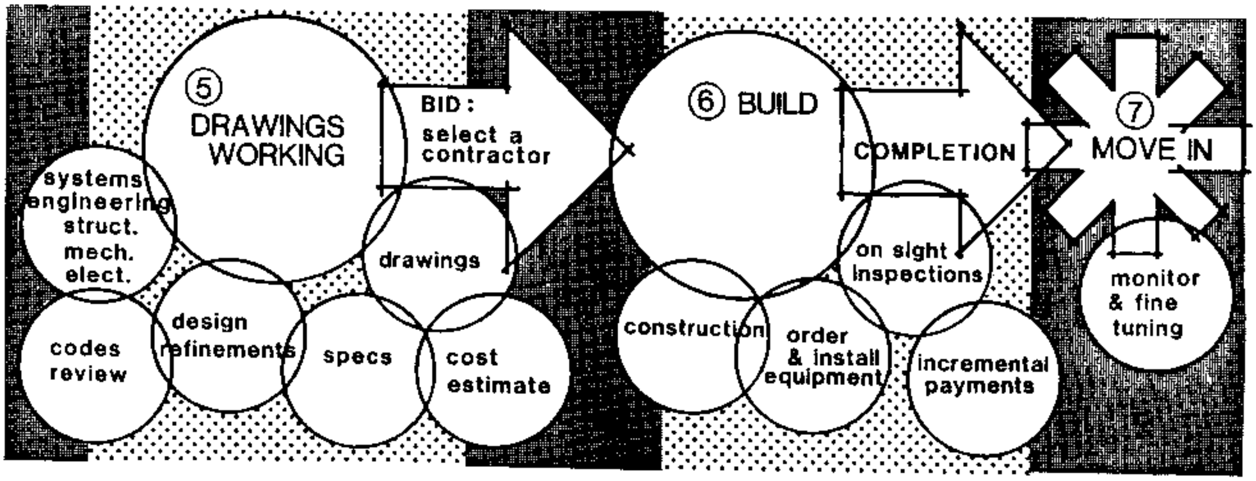
Because a passive solar home is site specific (i.e., it must be designed specifically for its particular site and site conditions), site selection is a very important initial step in the solar process. Considerations in site selection include lot size, views, noise, vegetation, climate, soil conditions, and local zoning and building codes.

One of the most important considerations in selecting a site is whether or not provisions have been made or can be made for solar access: does the proposed collection area receive adequate sunlight; is legal protection for continued solar access assured through restrictive covenants or easements, or would it be possible to obtain solar easements from surrounding landowners?

STEP 4: SCHEMATIC DESIGN

When the owner is satisfied with the goals and objectives of the project, the professional design team -- i.e., those individuals with the requisite knowledge and experience to design a successful passive solar home -- can begin the task of designing the passive solar house.

The goal of the design phase is to create a proper blend of energy efficiency, aesthetic considerations, and cost limitations. During this phase, the owner's input and review is essential, and should include a healthy evaluation of alternative systems strategies. The final product of the design stage will be a visual description of the project including floor plans, elevations, sections, and three dimensional representations such as perspectives or scale models.



SOLAR PROCESS

An important element in the design process is the selection of the solar system or combination of systems that will be used in the home. In order to make an informed decision, the architectural designer must be well-versed in the use of passive solar fundamentals and other energy efficient strategies. The selection of a solar system should not be made on its solar performance alone but should also depend on initial design parameters and cost considerations.

Usually, heating and cooling systems engineering is left to the end of the design process. However, rising energy costs have dictated that energy performance studies be conducted very early in the design process. This input can have a dramatic effect on the visual character of the building by influencing the exterior surface to interior volume ratio, quantity and placement of glass, insulation requirements, types of building materials, and other design features.

When the basic design is completed, a preliminary cost analysis can be conducted. The cost analysis should include a preliminary estimate of construction costs as well as a prediction of annual energy costs.

When the schematic design has been completed and the owner has approved the design, the working drawings phase can begin.

STEP 5: WORKING DRAWINGS

During the working drawings phase, the professional team -- consisting of architects, engineers, consultants, and technicians -- will turn the basic design into a buildable solution. The final product will be in the form of drawings and specifications that contain the information necessary to bid and construct the building.

Structural, mechanical, plumbing, and electrical systems must be engineered during this phase to work in conjunction with the passive solar design. For example, if the project is to be earth sheltered, a structural engineer should be consulted to ensure the structural integrity of the building with regard to stresses caused by the earth load on or against it.

The working drawings phase should include a complete review of applicable building code requirements as well as energy code standards which may affect the structure. For example, a structural engineer's certification may be required on plans for an earth sheltered home before the building permit is granted.

Energy codes have been adopted in some cities to protect the consumer from the construction of energy inefficient buildings. These energy codes may limit the ratio of glass area to floor area. Most solar buildings would not satisfy the strict application of such codes, however, exceptions can be granted for passive structures by showing that the solar contribution to energy efficiency exceeds the energy savings of using smaller windows.

With the code review completed, design refinements can be made. The selection of interior finish materials should enhance solar system performance, e.g., thermal masses should have dark, non-reflective finishes, and light colors should be used on non-mass surfaces. Carpets should not be used over mass storage floors as this will greatly reduce the heat storage capacity of the floor.

Building specifications are written after design refinements have been made. These specifications describe the type and quality of materials and provide installation instructions.

Complete working drawings and specifications form the basis for a final cost estimate. If this final estimate exceeds the budget, the quality of materials can be lowered, the size of the building can be reduced, or a less expensive passive solar system can be incorporated.

STEP 6: BUILD

Selecting a builder before the design process begins can be very beneficial in assisting the designer and owner in choosing the most appropriate materials and details. If a builder has not been involved prior to completion of the working drawings phase, the building phase begins with the selection of a builder. Care must be taken in selecting the builder of a passive solar home because of the many new construction techniques and materials with which the builder must be familiar. This means that either the architectural plans must be more detailed than customary, or only builders with passive solar experience should be considered. All the planning will be for naught if the builder does not understand the purpose of the design features.

One way to select a builder is through competitive bidding. To be a valid process. selection by competitive bidding requires more detailed working drawings and specifications and this will increase the cost of the working drawings. It is possible, however, that this expense could be offset by a sufficiently low bid.

Periodic site inspections by the design team are recommended during the construction period to monitor progress and ensure that all details and techniques have been followed by the builder so that the predicted thermal performance of the building can be achieved.

STEP 7: MOVING IN

With the building completed and the owners moved in, the experience of living in a passive solar home can begin. To be successful, the passive solar home will require the active involvement of its occupants. An operations manual may be helpful in instructing or reminding the owners of particular steps that should be taken to ensure the superior performance and maximum benefit of their building. A manual might include such information as when to open and lower movable insulation, when to perform routine maintenance, etc.

The building performance should be monitored and records kept to see if results meet predictions. Desired data would include energy consumption, heating degree-days, solar insolation, etc. With sufficient monitoring data, an evaluation of performance can be made, and modifications of the original building or its operation can be considered.

Several example projects which are the result of the passive solar design and construction process are contained in the final chapter.

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