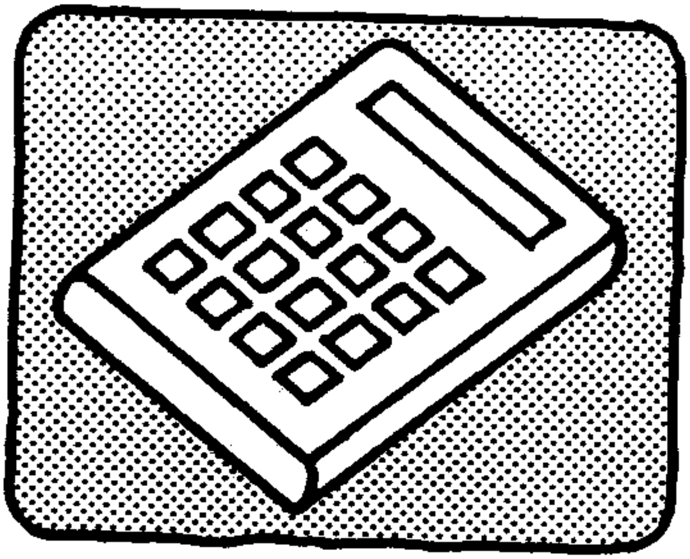
CHAPTER 5
ENGINEERING

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.

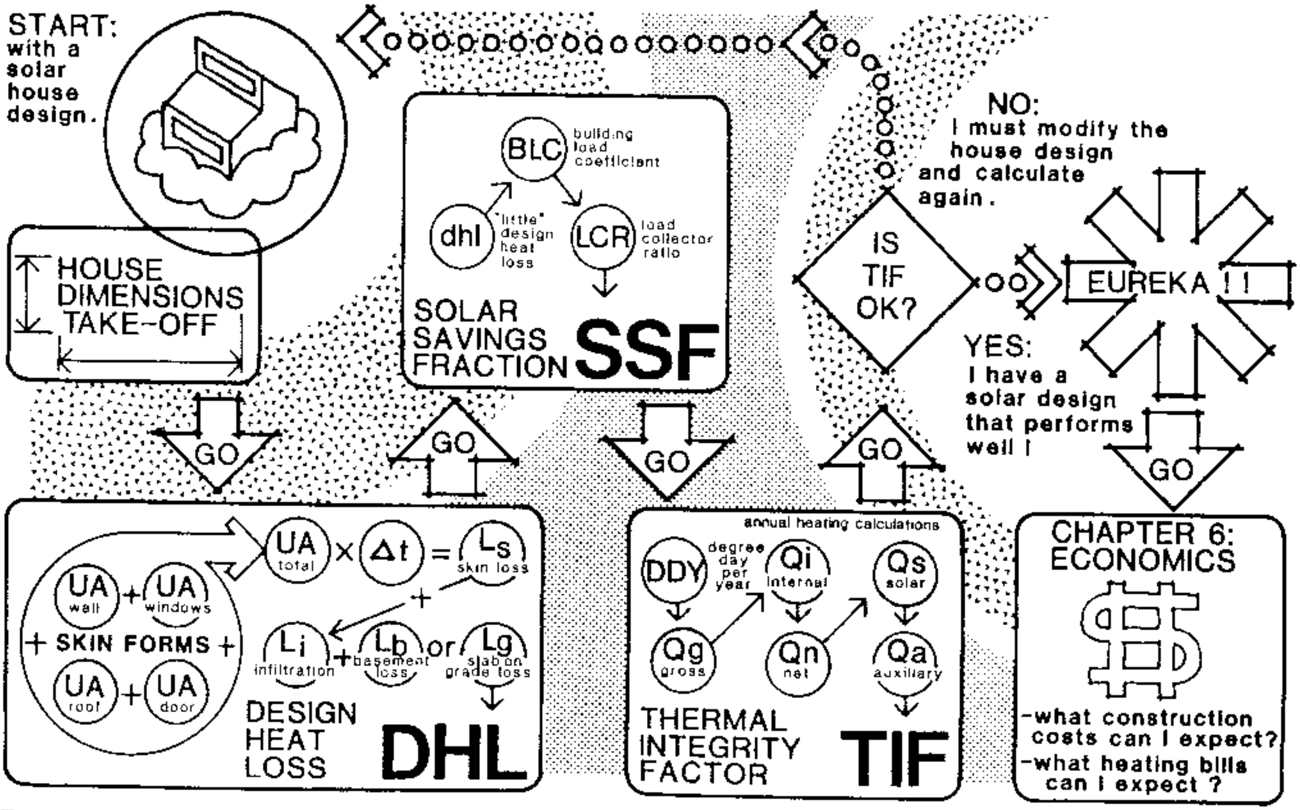
Engineering calculations can be bewildering and tedious. Calculating the energy performance of a design is nevertheless important in order to gain an understanding and appreciation of how a passive solar home will function. An additional benefit is that working through the calculations may suggest house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

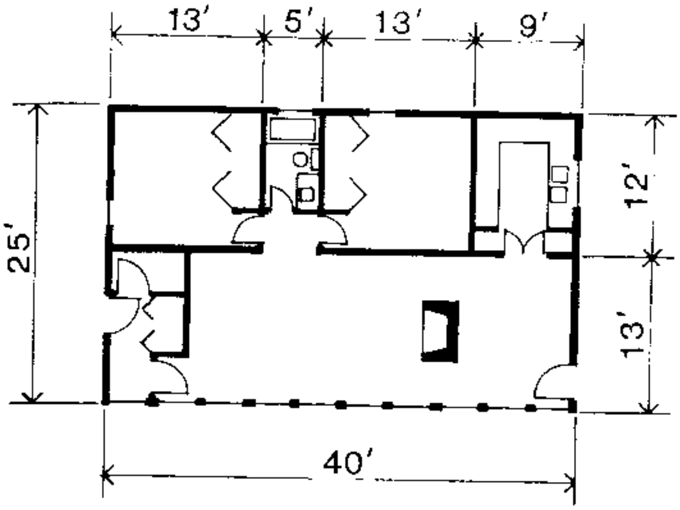
3. The calculation procedures are the same for all of the passive solar systems discussed in Chapter 3. This is because each system must contend with a balance of heat losses through its exterior surfaces offset by heat gains from solar or other means to maintain an acceptable comfort level within the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

HERBIE'S HOUSE

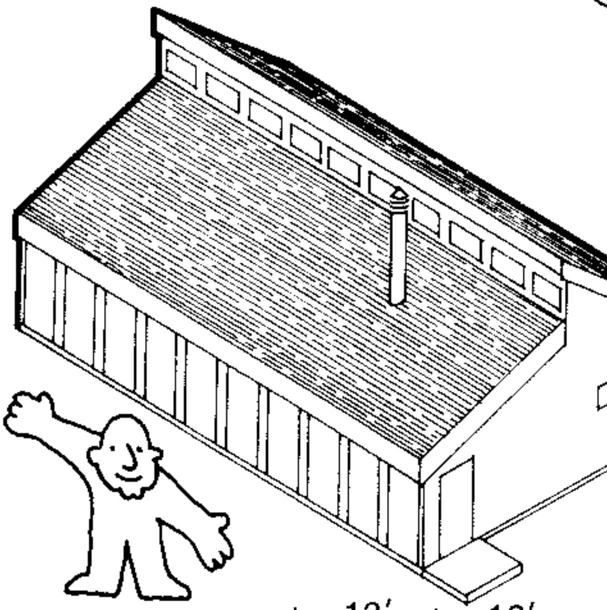
The example house (FIG 5-2), Herbie's house, is a fairly simple solar design. Living spaces are located along the south-facing glass wall to maximize daytime views, light, and heat gains. Clerestory windows admit sunlight and solar heat to bedrooms and support spaces located along the north wall. North, 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.

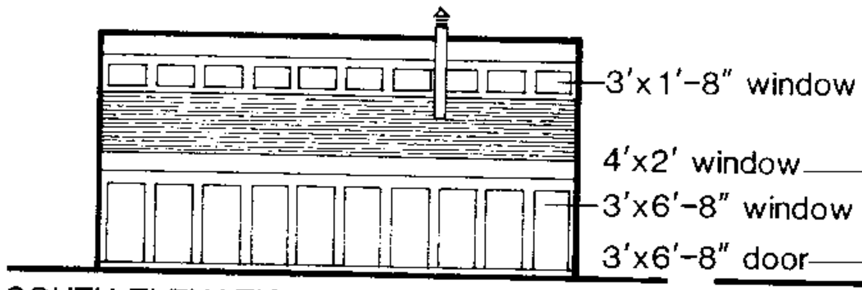
Data from Herbie's house has been entered on the House Dimensions Takeoff Form. Dimension and location information as well as annual degree days from Appendix 3 have been entered on the form. The proposed passive systems and backup systems have also been specified.

5-2 HERBIE'S HOUSE

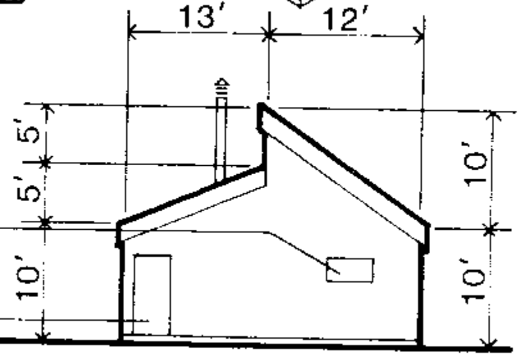


FLOOR PLAN

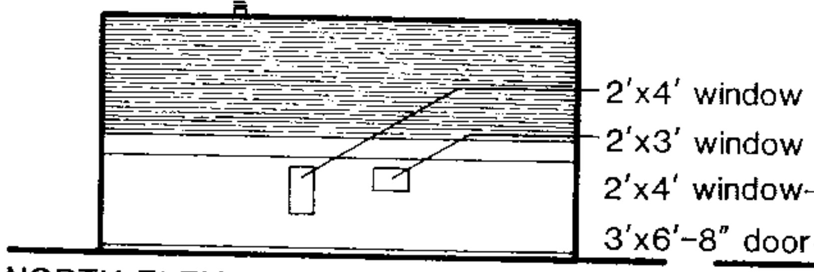




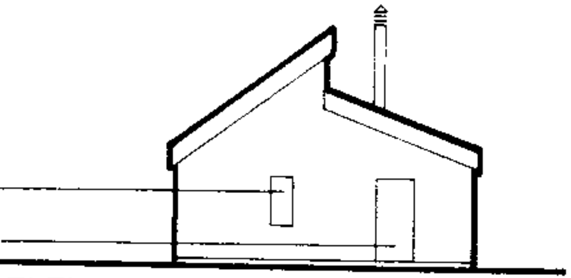
SOUTH ELEVATION



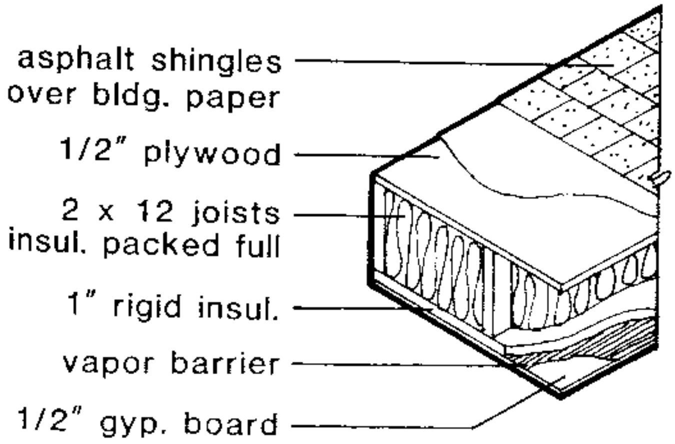
EAST ELEVATION



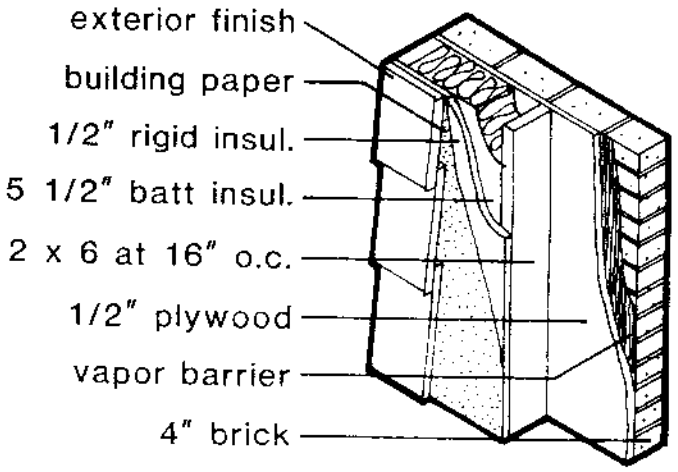
NORTH ELEVATION



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.) ________

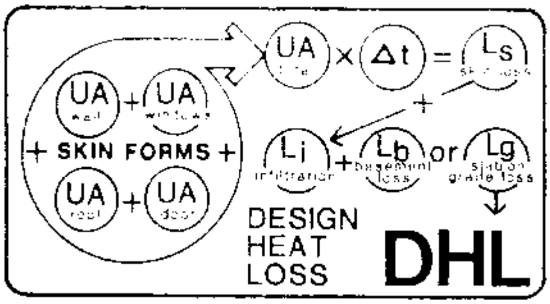
COST OF FUEL (consult fuel dealer or utility) ________

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:

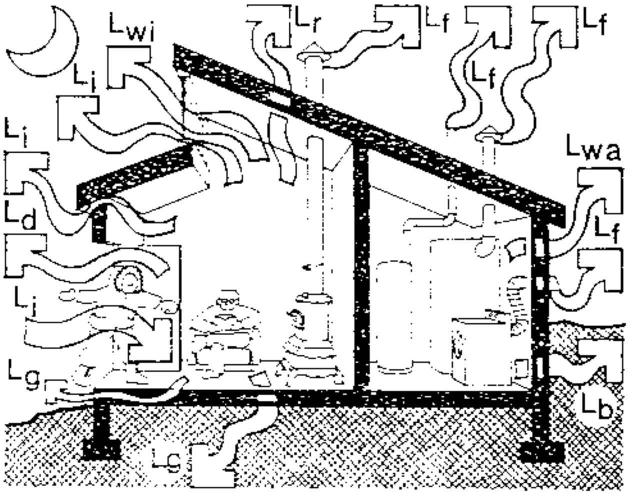
1. Skin Losses (L_s)
   (windows, walls, roof, and doors)
2. Air Infiltration Losses (L_i)
   (air leaks)
3. Basement Losses (L_b) or Slab Losses (L_g)

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

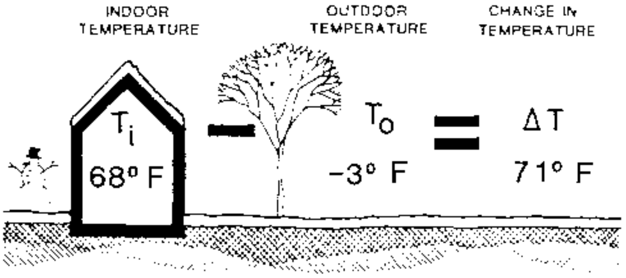
Beatrice	-2°F
Chadron	-3°F
Columbus	-2°F
Fremont	-6°F
Grand Island	-3°F
Kearney	-4°F
Lincoln	-2°F
McCook	-2°F
Norfolk	-4°F
North Platte	-4°F
Omaha	-3°F
Scottsbluff	-3°F
Sidney	-3°F

city should be chosen.

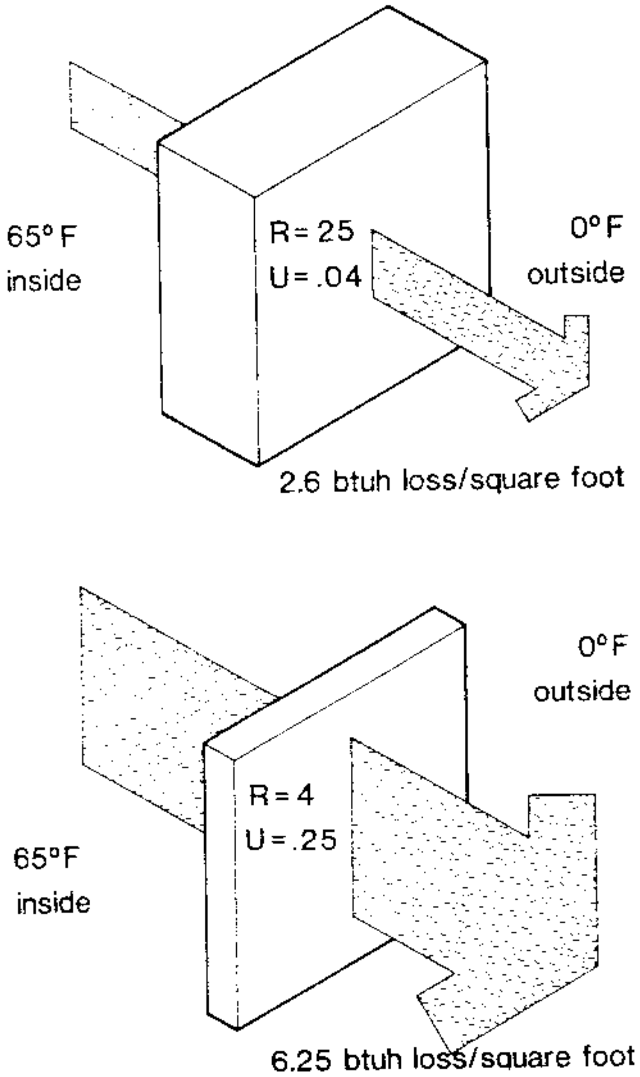
To aid the reader in this calculation process, a special Skin Form has been developed. A separate Skin Form should be filled out for each different type of skin construction found in the house, e.g., if more than one kind of wall construction or window is used, a separate form must be completed for each.

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



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

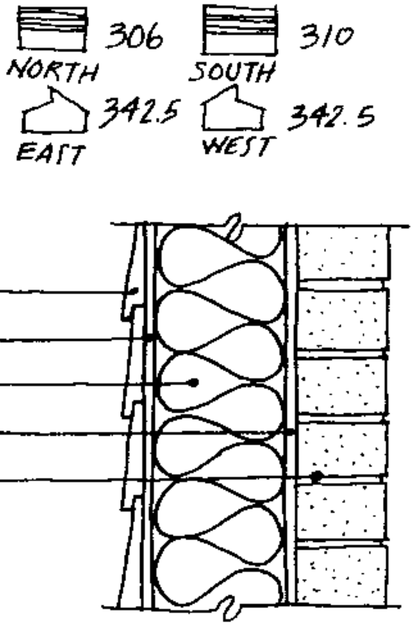
R_t = total R value = 24.28

U = $1/R_{total}$ = .045

A = skin area = 1301

UA (U x A) btu/° F = 58.54

diagram (optional)

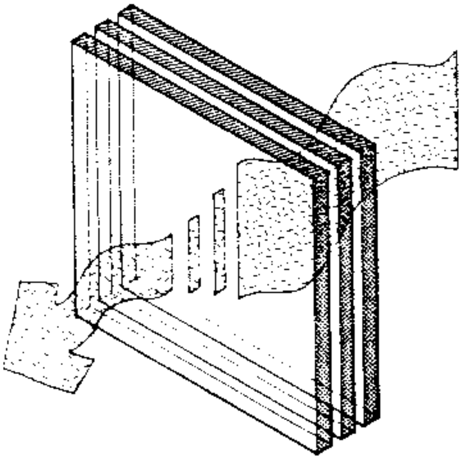


6. Compute the total wall U value (U=1/R).

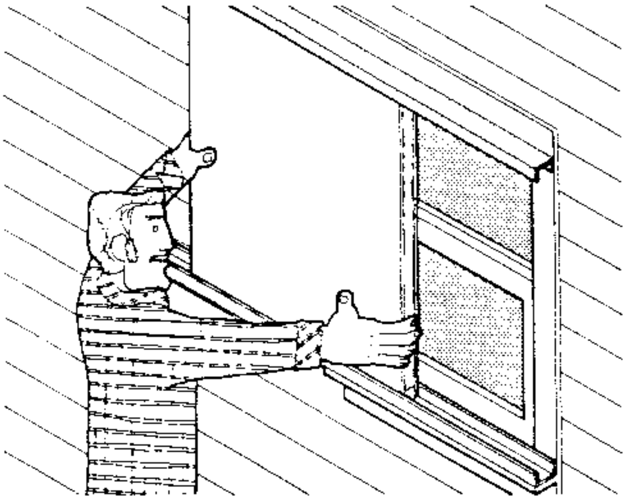
7. Transfer the appropriate skin area from the House Dimensions Takeoff Form. Remember to deduct the area of windows and doors. If more than one UA value is to be calculated, the areas can be recorded in the workspace as shown.

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)

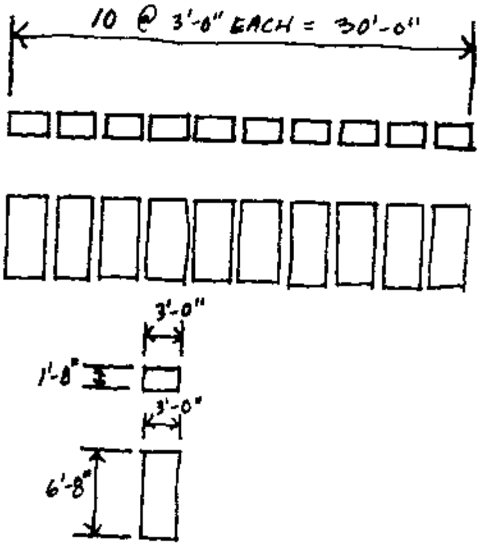
R_t = total R value = 1.72 (13.72)

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

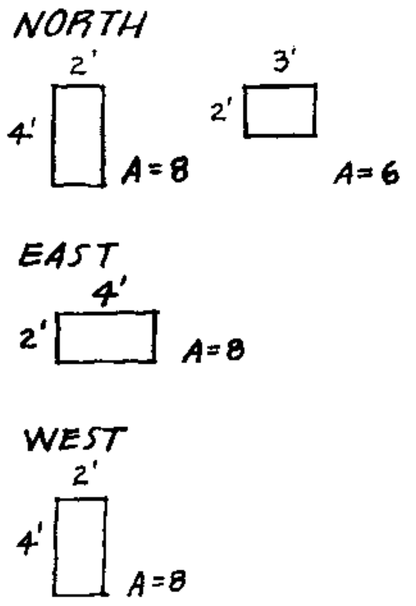
R_t = total R value = 2.56

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

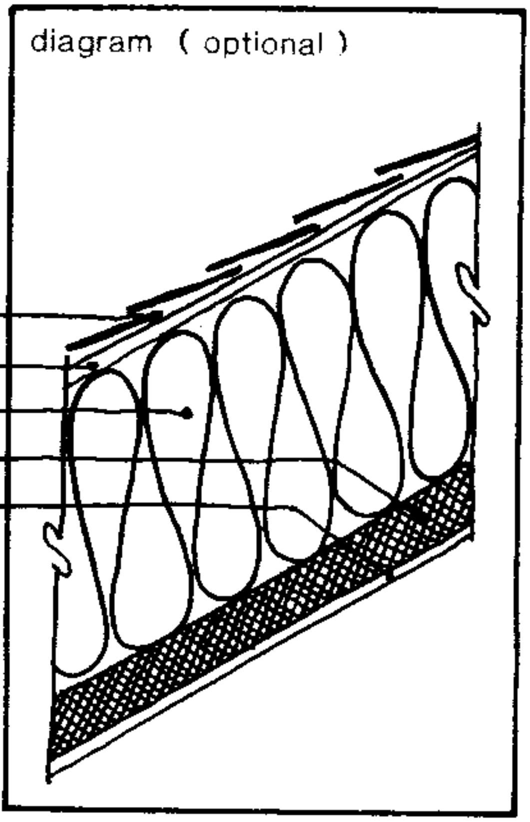
components	thickness	R value
outside air film		.68
ASPHALT SHINGLES		.44
PLYWOOD	½"	.62
BATT INSULATION	11½"	37.0
RIGID INSULATION	2"	10.0
GYPSUM BOARD	½"	.45
inside air film		.17

R_t = total R value = 49.36

U = 1/R_{total} = .020

A = skin area = 1185 SQ. FT.

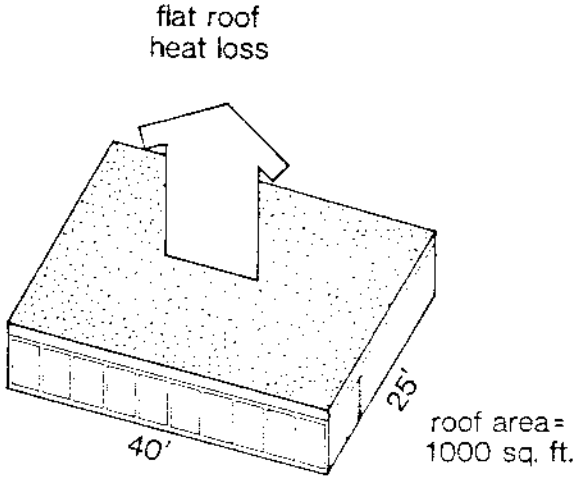
UA (U x A) btu/° F = $\boxed{23.7}$



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*

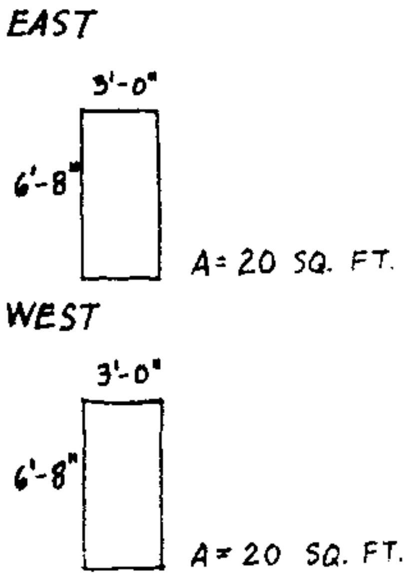
R_t = total R value = *10.85*

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/$^{\circ}$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

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

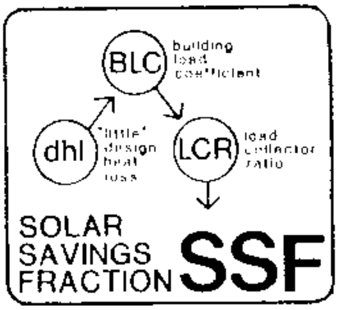
Depth of foundation wall below grade	WIDTH OF HOUSE 20 ft	24 ft	28 ft	32 ft
5	0.032	0.029	0.026	0.023
6	0.030	0.027	0.025	0.022
7	0.029	0.026	0.023	0.021

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

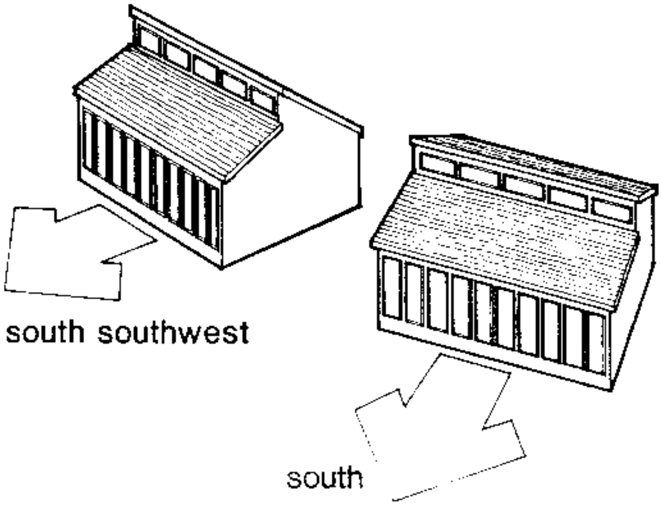


To determine the solar performance of a building, the following values must be calculated:

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:

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

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:

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

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

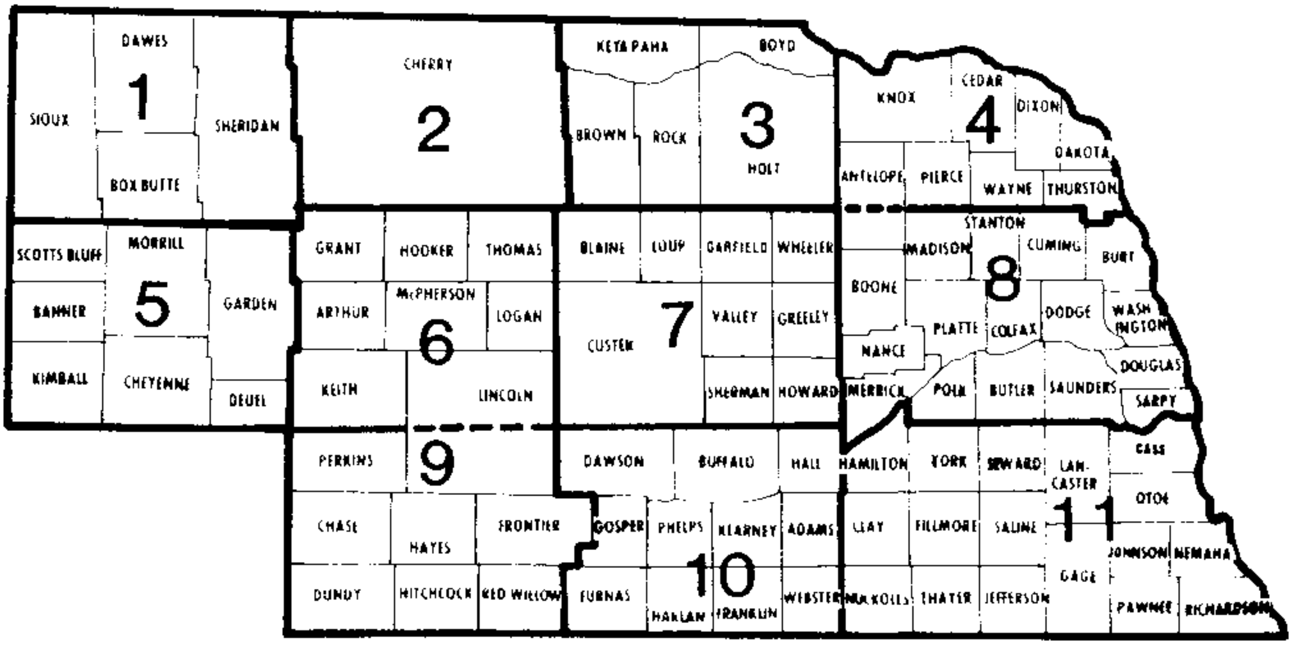
SOLAR SAVINGS FRACTION (SSF)

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

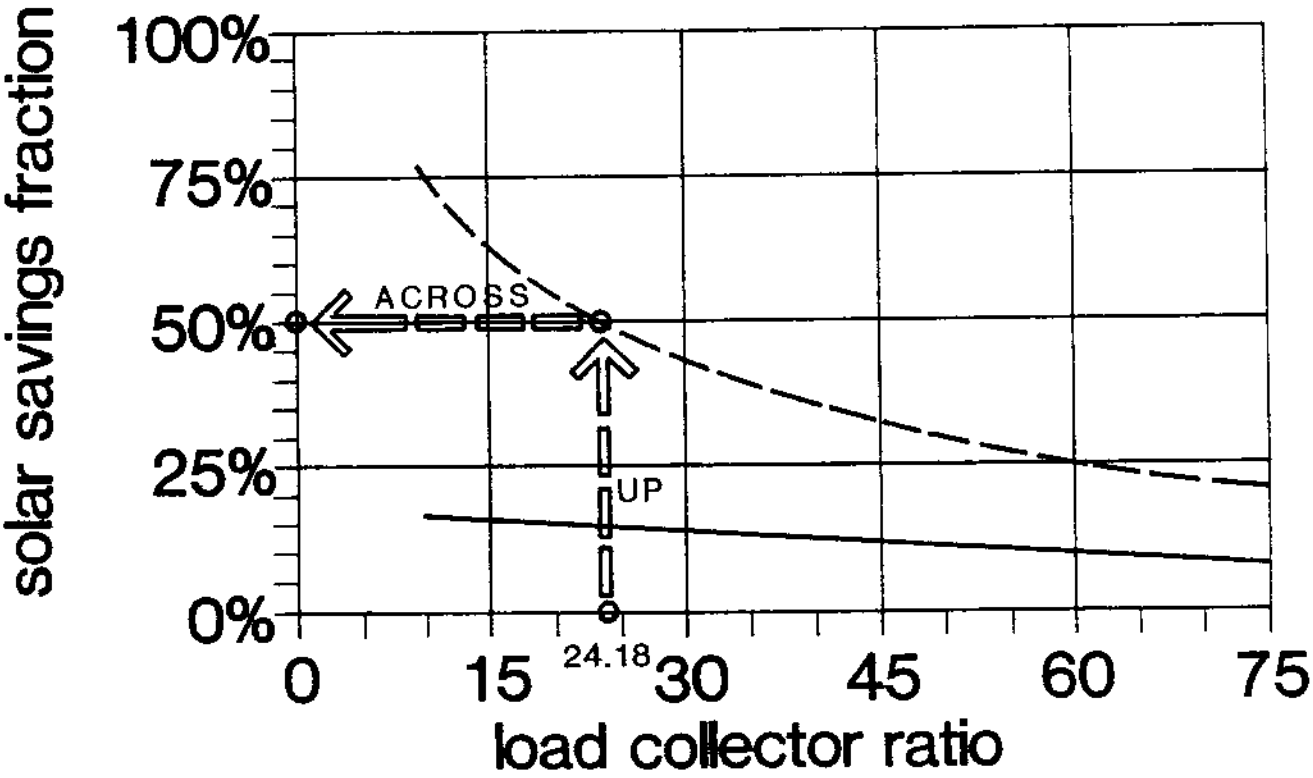
The SSF is obtained as follows:

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

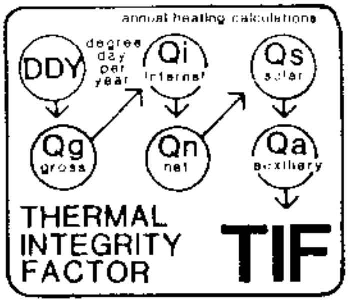
BLC (building load coefficient) = 6045 BLC

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

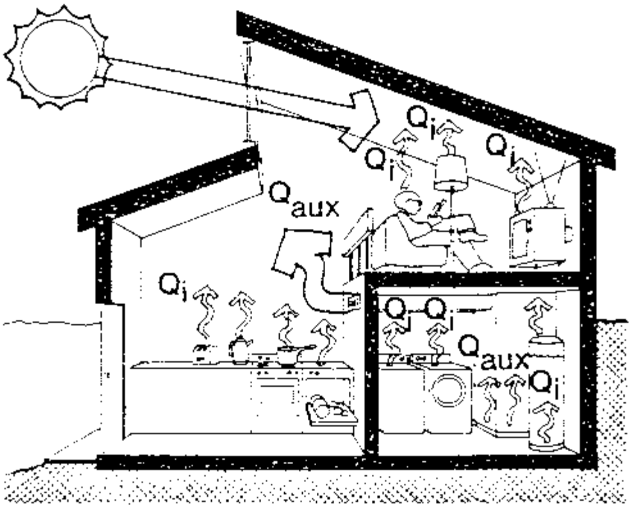
SOLAR SAVINGS FRACTION = 50% SSF



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)

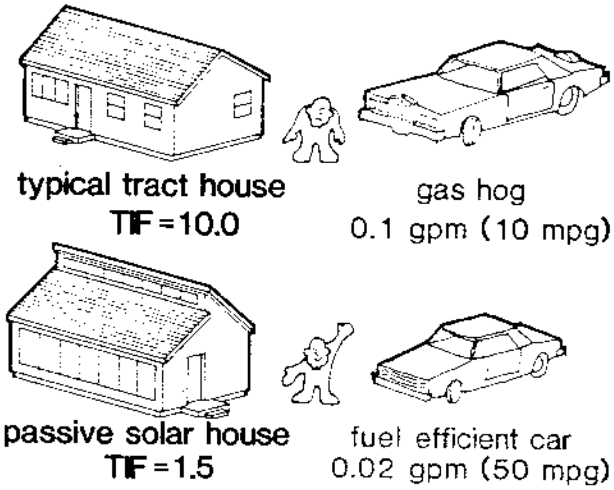
TIF is an indicator of annual thermal performance for solar as well as non-solar structures. It represents the heating load required to maintain a 65^{o}F base temperature (after the internal heat gain and solar contribution for the year are accounted for) divided by the product of the annual degree-day 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.