# TECHNICAL NOTE 14
# DETAILS AND ENGINEERING ANALYSIS OF THE ILLINOIS LO-CAL HOUSE

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TECHNICAL NOTE NO. 14

# DETAILS AND ENGINEERING ANALYSIS OF ILLINOIS LO-CAL HOUSE

A Supplement To:

Circular 2.3, ILLINOIS LO-CAL HOUSE

and

Circular 3.2, SOLAR ORIENTATION

SMALL HOMES COUNCIL - BUILDING RESEARCH COUNCIL

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| Chapter | | Page |
|---|---|---|
| I | Design Considerations | 7 |
| II | Computer Analysis | 17 |
| III | House Plans and Construction Details | 41 |
| IV | Special Window Studies | 63 |
| V | Heating and Cooling Systems | 87 |
| VI | Infiltration Rates and Air Changes | 99 |
| VII | Passive and Active Solar Systems | 107 |

This publication is dedicated to the memory of Warren S. Harris, 1908-1979, who contributed so much to this project.

# FOREWORD

Since the publication of Circular C2.3 on the ILLINOIS LO-CAL HOUSE in the spring of 1976, a large number of houses in various parts of the United States and Canada have been built incorporating most or all of the features recommended for this energy-conserving solar house. Reports of the energy needed to heat and cool these houses will influence the optimum design of the Lo-Cal House, especially for climate conditions other than those presented in the Circular.

This Technical Note gives details, both architectural and engineering, and a review of an extensive computer study (made in 1976) of predicted energy requirements for a large number of special cases in which various components affecting energy requirements were separately studied. At the present time (1979), no Lo-Cal Research Residence has been built on the Urbana campus under the direction of the Council. The computer analyses and the results presented here are analytical studies based upon the best available computer program (CERL Thermal Loads Analysis and Systems Simulation Program, Department of the Army, Construction Engineering Research Laboratory, Champaign, Illinois, 61820) applied to typical hourly weather data for an entire year for Madison, Wisconsin, and Indianapolis, Indiana.

Reports voluntarily supplied to the Council by homebuilders and owners around the country indicate that the basic concept of a solar-oriented house with super-insulated construction is a valid one. The solar house design principles that were published by the Small Homes Council in 1945, modified by careful analyses of the solar gain of windows and the energy storage of a super-insulated structure, offer a simple low-energy-use and low-maintenance building in the current market.

# CHAPTER I. DESIGN CONSIDERATIONS

## Objective

The objective of this research program was to design a house with minimum energy needs for heating and cooling using standard building materials and methods. The house shell would have extremely high thermal resistance. The solar heat gain for the house would be high in winter and low in summer.

## General Procedure

First, an example house was designed on the basis of architectural experience with solar houses, plus analyses of insulation, internal heat, and solar effects.

Next, the daily energy demand of this example house was predicted for one year, using computer simulations with hourly weather data for two northern cities. In computer simulation, a house is mathematically described with the areas of walls, ceilings, floors, windows, and doors; mass and thermal resistance of the building components; rate of air change (infiltration); internal heat gains (as from lights, body heat etc.); and building orientation. This house is then subjected by computer simulation to weather conditions as given by hourly data for outdoor temperature, humidity, wind, and sunlight for a given location over a selected period of one year.

In several computer analyses shown later, the characteristics and amounts of insulation, windows, orientation, rate of air change, and mass were altered to observe their effects on energy demand.

Finally, the performance of the example house was compared with those for the various alternative designs. Also, as a basis of comparison, an equivalent-sized house built to HUD-MPS requirements[1] for houses in a climate with 4500 to 8000 degree days was analyzed by the same computer program. This house is referred to hereafter as the "HUD House".

## Design for Solar Orientation

The solar benefit of facing a building to the south has long been known.

[1] See Notes at end of chapter.

> "In houses with a south aspect, the sun's rays penetrate into the porticoes in winter, but in summer the path of the sun is right over our heads and above the roof, so that there is shade." from Xenophon, about 360 B.C.

In 1945, a circular published by the Small Homes Council, (Circular <u>C3.2</u>, <u>"Solar Orientation"</u>) presented the basic principles for design of a solar house. These consisted of four elements:

1. A long south wall,
2. The main rooms on the south,
3. Predominantly south-facing windows, and
4. A roof overhang designed to
    a. admit sunlight to the south windows in winter, and
    b. to shade the south-facing windows in summer.

Many architects (including the authors) have applied these principles in the design of solar houses. In retrospect, some deficiencies were observed in some of these earlier solar houses. Since houses of that era were poorly insulated[2] by today's standards, a solar house had high heat loss and consequently needed large south windows to supply adequate solar heat. During sunny hours, the extra-large south windows provided ample solar heat, even overheating on many days. At night and on cloudy days, the heat loss was high through the large glass area as well as through the poorly insulated walls, ceiling, and floor.

In the design of the Illinois Lo-Cal House, the deficiencies of some of the early solar houses were corrected. The house was designed as an average-sized house to serve as a basis for studies of energy requirements, with careful attention to solar orientation and window design as well as to super-insulation of all components of the house shell. The house designs shown serve as examples, since an architect or builder can vary room arrangement, size, configuration, and style of house to adapt to the climate, building site, and owner's needs.

From the standpoint of energy conservation, the initial design incorporated super-insulation for the shell of the house. It was anticipated that super-insulation would:

1. Reduce the total energy demand of the house to a practical minimum,
2. Reduce the requirement for solar gain from the south windows,

3. Enlarge the fraction of the total heat requirement provided by internal heat gains,

4. Reduce the requirement for heat storage in the internal mass of the house, and

5. Produce more comfortable interior surface temperatures, especially of the windows.

Following the initial design, computer analyses were used to aid in the determination of: a. the optimum thermal resistances of ceiling, walls, floor, and foundation, and b. the optimum thermal resistance, orientation, shading, and areas of windows.

## Design Details for the Illinois Lo-Cal House

Ceiling Insulation. The roof-ceiling construction was designed to accomodate at least 12" of ceiling insulation extending at full thickness over the exterior wall, and for an attic air space between the insulation and roof sheathing. The total ceiling resistance was designed to be about R-40.

In extremely cold climates (over 8000 degree-days per season) with heavy winter snowfalls, a steeper roof is more appropriate, which allows for 18" of ceiling insulation, or R-60.

Wall Insulation. Many builders, architects, and homebuyers cannot conceive of a wood-frame construction that deviates from the common 2 x 4 stud wall. Of course, a wall 10" thick (of brick or stone veneer with wood frame) has been commonly used for generations. The common 2 x 4 stud wall is structurally adequate to withstand the wind loads and stresses, but the 3½" wall insulation does not provide sufficient thermal resistance for today's energy conservation. Various means can be utilized to increase the thermal resistance of the exterior walls to R-30 or more, using readily available materials. In the three cases listed below, the structures are stronger than the common 2 x 4 stud wall.

2 x 6 Stud Wall. A 2 x 6 stud wall (with studs placed 24" on centers) with R-19 batt insulation, 3/4" insulation board (R-6) on both exterior and interior, ½" dry-wall and wood siding would develop a total resistance of R-33. From the outside face of sheathing to the inside face of the drywall, this wall would be 7½" thick.

Double-Wall, 8½" cavity. The wall used in the Lo-Cal House was a double-framed wall of 2 x 4 studs at 24" o.c., with an 8½" cavity filled with insulation. The 8½" cavity combines two 3½" stud walls with 1½" blocking between top plates. This wall is 9½" from the outside face of sheathing to the inside face of the drywall, and the common low-cost insulation materials develop a total R-33 for the wall. This wall is about the same thickness as a brick veneer wall.

Double-Wall, 10½" cavity. In very cold climates, a thicker wall may be used; for example, a 10½" cavity filled with insulation would develop a total resistance of R-40, comparable with the ceiling value. The 10½" wall uses two 3½" stud walls with 3½" blocking. This wall may be cost effective in some northern states and Canada. From the outside face of sheathing to the inside face of the drywall, this wall would be 11½" thick.

The double-framed wall was selected because it uses low-cost insulation material and common 2 x 4 framing. Since framing lumber is frequently not absolutely straight, 2 x 4 framing is easier to draw flat with sheathing than 2 x 6 framing. It provides a chase which simplifies installation of electrical and plumbing lines in the space between the inner and outer framing of the wall. Obviously, the wall can be modified to be as thick as required for climate conditions. The wall has better acoustic qualities because the framing lumber is not continuous from outside to inside the house.

Floor and Foundation Insulation. The most important insulation of the crawl space is the perimeter of the floor system (the band joist area) and of the upper part of the crawl space wall. In moderate climates, insulation of the house floor in addition to the insulation of the crawl space perimeter may be of little value.

The insulation of the house floor and of the foundation wall of the crawl space was designed so that the heat flow through the floor would equal the heat flow through the crawl space wall, with the temperature of the crawl space at or near earth temperature. (Details of the heat flow analysis are given in Chapter II).

With R-19 insulation applied below the flooring, the floor would have a total resistance of R-22. Also, R-10 insulation board applied to the crawl space wall would produce a total R-13 for the foundation wall above grade. Since the resistance of the earth increases with depth, the resistance of the wall below grade may increase to as much as R-30 at the bottom of the crawl space wall. The average wall resistance has been assumed to be R-20. Insulating the entire crawl space wall is strongly recommended.

Experimental data from other sources indicate that insulation of the floor may decrease the heat loss in the heating season, but may increase the cooling load during the cooling season by preventing heat loss to the ground under the house. All ductwork in the crawl space should be insulated.

Window Analysis. During the winter, every window exposed to the sun will have periods of solar gain, as well as continuous heat losses, which can be especially high during the night. If the proper multiple glazing option is selected, considering average hours of sunshine and average outdoor temperature, a south-facing window will show a net daily heat gain. The study reported in Chapter IV showed that the average daily solar gain of a south-facing triple-glazed window exceeds the 24-hour heat loss by 200 to 400 Btu per square foot during the heating season for the specified conditions.

This solar heating advantage applies to most of the colder areas of continental United States and southern Canada. In regions with more sunshine and milder winters (less than 4500 degree-days), the solar gain of a south-facing double-glazed window may also be much larger than the heat loss through the window.[3] See also Figures 4-8, 4-16, and 4-19.

East and west windows, which have relatively low solar gain in winter and high gain in summer, and north windows, which have insignificant solar gain, should be as small as practicable or omitted. An east window could provide morning solar gain in late winter and early spring, but most of the time it should be covered with an insulated panel or shutter. See Chapter IV for discussion of east and west window effects.

In the Lo-Cal House, about 85% of the window area for the house was placed on the south wall. The window areas specified were slightly more than the HUD-MPS requirements for daylight, ventilation, and emergency egress, which are:

10% of habitable room area for light,

5% of habitable room area for ventilation opening area, and

width and height compliance for egress.

The total window area of 144 square feet is 14% of the habitable room area of the house. The south-facing window area of 122 square feet is 8% of the total floor area of the house. The original design of the Lo-Cal House had 101 square feet of triple-glazed windows and a 21 square foot quadruple-glazed window on the south wall. Later tests and analyses indicated that the heat requirements for the house were essentially the same when triple glass was used for all 122 square feet of the south windows. Hence, the house described in Circular C2.3 assumes that 122 square feet of triple-glazed south windows would produce approximately the same heating effect as the original design. The North window area of 22 square feet was included to meet HUD-MPS.

The triple-glazed[4] windows were assumed to have a U-Value of 0.37 and a shading coefficient of 0.82. Assuming an average daily solar gain of about 800 Btu per square foot, the usable solar gain of the south windows was estimated to be from 12 to 15 million Btu for the heating season in Madison, Wisconsin. On a clear winter day, especially with sunlight reflected from snow cover on the ground, the solar gain of the south windows may overheat the house. However, during such days the house can be ventilated and air freshened by opening windows and doors.

The vertical glass surfaces, which transmit solar gain, not only do not collect snow, but because of the wide overhang will seldom be coated with sleet. That is, the vertical solar collector surfaces (the windows) are seldom made inoperative in a region where both snow and sleet are experienced each winter. See Chapter VII for discussion of passive and active collector surfaces.

Roof Overhang Design. The details of the roof overhang, or horizontal projection of 30", located 16" above the windows, were shown in the two Circulars mentioned earlier. See Figure 3-8. Such a roof design also accommodates 12" of ceiling insulation, extending over the top of the wall. With this design the solar gain of a south window remains undiminished for most of the heating season, but is reduced to a very low level in the cooling season. This design adapts well to most houses in the temperate zone since the sun angle changes with the latitude and the seasons.

Since the sun angle is about the same in March and September, too large an overhang may shade a south window too much in the late winter or early spring, when heat is needed in the house. On the other hand, too small an overhang will not provide adequate shade in September when cooling loads may be large. Additional shading in September may be desirable in some climates, and this can be provided by using foil, heat-absorbing films, shade screens, or awnings.

Tree Shading. In the computer analyses, the house was assumed to be fully exposed to the sun and without benefit of shading from trees or neighboring houses. The shade of deciduous trees, located east, south, or west of a house, can minimize solar gain through the shell of the house during the warmer months and significantly reduce air-conditioning costs, especially in early fall.

If solar heating equipment is to be installed, especially for domestic water heating, a portion of the house, garage, or yard should be left unshaded by trees to allow for sun exposure of this solar hardware.

## Computer Simulations

Computer analyses to determine heating and cooling requirements for the Lo-Cal House were made on a comparative basis. That is, the requirements for the Lo-Cal House were compared with those of a house of the same size and proportions designed to current HUD Minimum Property Standards. Even though the computed data for the Lo-Cal House might include some errors because of the input format and the computer program, the results would be validated by a comparison with the HUD-MPS model house, using the same input format and computer program. To insure that the comparison would be on an equal basis, the long dimension of the HUD House was oriented in the same manner as the Lo-Cal House.

The HUD House was designed to the following standards: R-20 for the ceiling, R-12.5 for the walls, and R-12 for the floor. The U-value of the windows was assumed to be 0.65 (for double-glazed windows), and the shading coefficient was 0.9. The doors for both the Lo-Cal and HUD House were assumed to be R-15 (including storm door). The air infiltration was assumed to be one-half air change per hour for both the Lo-Cal and the HUD House. In this regard, it would have been unfair to assume a lower air change rate for the Lo-Cal House in order to show less energy use. However, the air change rate of the Lo-Cal House may be very low because of the double wall, heavy insulation, and polyethylene vapor retarder (barrier) on all exposed surfaces. (An extended discussion of air-change rate and ventilation is presented in Chapter VI).

The interior mass of each building was assumed to be 30,000 pounds for the building and furnishings. The internal heat gains from lighting, cooking, bathing, television usage, etc. were assumed to be equivalent to 10 kilowatts per day, and occupancy by two persons, totalling about 51,000 Btu per day. Some researchers have used much higher internal gains, as much as 120,000 btu per day. The lower value for internal gain is considered more conservative, and results in estimated heat requirements that are larger than those based on higher internal heat gains.

The distribution of the 144 square feet of windows for the HUD House was assumed to be one-third each facing south and north and one-sixth each facing east and west. (In this connection, the most favorable solar orientation of the house was also used for the HUD House, so that the most favorable energy requirements would be shown for both houses. If, for example, the HUD House had been oriented to face east or west, the comparison with the Lo-Cal House would have been biased in favor of the Lo-Cal House.)

The window distribution of the Lo-Cal House was 122 square feet facing south, 22 square feet facing north, and none on the east and west walls. A window height of 50" was used, with the window head 81" above the floor. The roof overhang extended 30" out from the face of the window and the bottom of the overhang was 16" above the head of the window.

[1] Department of Housing and Urban Development Minimum Property Standards for One and Two Living Units, 1973 edition with 1974 revisions.

[2] Fuel Savings Resulting From Use of Insulation and Storm Windows, Bulletin No. 355, University of Illinois Engineering Experiment Station (1944), A. P. Kratz and Seichi Konzo. The original research on insulation of concrete floor slabs was reported in Research Report 48-1 by the Small Homes Council in 1948.

[3] "Effects of Building Orientation on Energy Savings", Wayne L. Shick, in *Energy Efficiency in Wood Building Construction*, Forest Products Research Society, Madison, Wisconsin, 1977.

[4] A double-glazed window plus a storm window. Factory-sealed triple-pane windows have a lesser insulating value.

# CHAPTER II. COMPUTER ANALYSES

Prior to the advent of computer technology, the estimate of seasonal heat requirements for a building was based mainly upon the design heat loss and seasonal degree-days by a simple equation that required some modifying factors, based upon experience. Usually, the effects of internal heat gain and solar gain were hidden in these modifying factors. With relatively poor building insulation, these internal and solar gains were a small fraction of heat requirements for the building. With the computer, the estimates of seasonal heat requirements can be made with greater precision, depending upon the computer program in use. Although the best computer program available at the time was used, the program could be improved to include other factors. For example, solar gain from sunlight reflected from ground snow cover was not considered. Also, the estimates of infiltration rates will never be exact, since there is no simple correlation between assumed infiltration rates and wind direction and velocity, and living habits of occupants.

Computer programs allow comparisons of various insulation and solar alternatives, and present a more reliable evaluation of alternatives than field test houses, which have highly variable occupancy. The only field tests that can be relied upon to provide better accuracy than the simulation programs are those similar to the ones made in the Research Residences and Research Homes at the University of Illinois that were built and provided with complete instrumentation during the period between 1924 and 1970 in Urbana and Champaign. However, in order to cover the various options described in this computer study, a given Research Home would have been involved in a ten-year program of intensive field research. The main advantage of the computer program is that once the characteristics of the house and the weather have been introduced into the machine, the calculations are made rapidly. Furthermore, the effects of changing one variable can be quickly established--a process which was extremely tedious in pre-computer days.

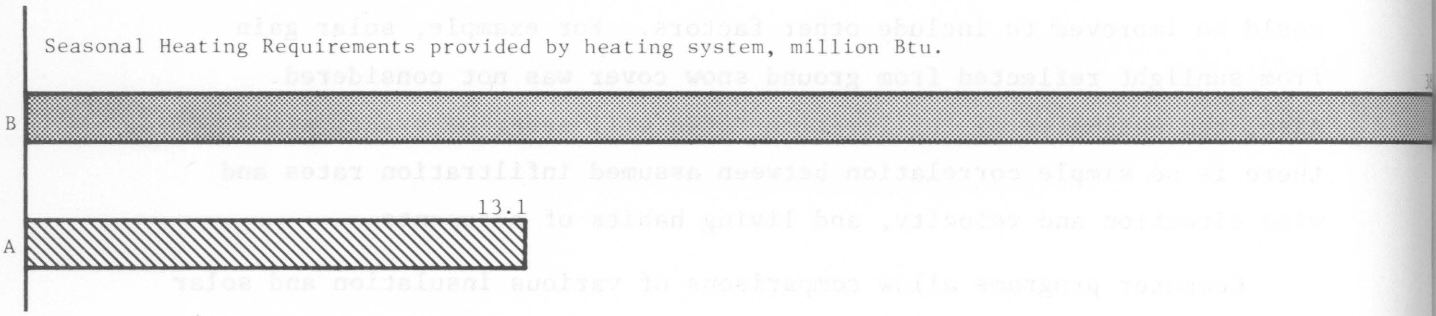
The analyses were made by using the CERL Thermal Loads Analysis and System Simulation Program of the Department of the Army, Construction Engineering Research Laboratory, Champaign, Illinois 61820 (a modification of the NBSLD program). One series of analyses was made with 1961 weather data for Madison, Wisconsin, (7564 degree days) and another series with

1953 weather data for Indianapolis, Indiana, (5015 degree days). In the following section, summaries from the analyses are presented.

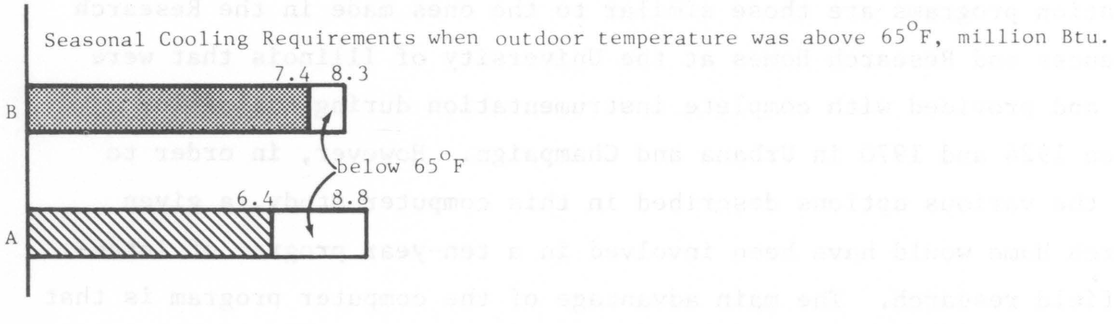
The Madison analyses are presented as Analyses A through L, and Indianapolis analyses in analyses M through V. Each test shows the changes in energy requirements resulting from some change in the design or construction details.

A-1 and A-2 (Madison). LO-CAL AND HUD HOUSES

The same internal heat gain and air-change rates were used for both the Lo-Cal and the HUD houses, and the room-air temperatures were maintained between 68F and 78F.



The difference in heating requirement is striking: the Lo-Cal house requires only 34% of that for the HUD House.



The difference in cooling requirement was not significant, but again the Lo-Cal value is smaller.

There were some days in which the room temperatures exceeded 78F in both houses during the normal heating season. These unseasonal cooling requirements are indicated by the blank area in the graphs for Test A between 6.4 and 8.8, or 2.4 million Btu. The obvious solution for cooling an overheated house in fall, spring, or even winter is to open windows and doors for ventilation, rather than to operate an air conditioning system. Some overheating during the heating season is acceptable.

## Analyses C-1 and C-2. (Madison). SOUTH-FACING WINDOW SOLAR GAIN

The solar gain from the south-facing windows could be convincingly shown if the assumption was made that the windows existed but the solar effect was practically nil. This was possible by reducing the shading coefficients for the sun-exposed windows to the extremely small value of 0.01 (only 1% of the solar energy striking the window entered the house)[5]. This 0.01 coefficient was used instead of the 0.82 for the triple-glazed windows for the Lo-Cal House, and of the 0.90 for the double-glazed windows for the HUD House (for west-, south-, and east-facing windows).

These analyses indicated that the solar gains through the windows during the heating season (namely 14.3 and 10.9 million Btu's respectively for the Lo-Cal and HUD Houses) were relatively large for both houses. Note that both were properly oriented with the long side of the houses facing south. The Lo-Cal House, which had more windows facing the south, showed a larger gain, as would be expected. Since the heating season for the HUD House was several weeks longer because of less insulation, the east- and west-facing window solar gains made a more significant contribution of heat in Spring and Fall. The solar gain for each month for each house is shown in Table 1.

TABLE 1

| MONTH | LO-CAL HOUSE<br>WINDOW SOLAR HEAT | <br>HEATING REQUIRED | HUD HOUSE<br>WINDOW SOLAR HEAT | <br>HEATING REQUIRED |
|---|---|---|---|---|
| January | 3304 | 3183 | 1974 | 8839 |
| February | 2323 | 1670 | 1693 | 5311 |
| March | 1779 | 1760 | 1437 | 4979 |
| April | 845 | 1492 | 1052 | 3356 |
| May | 315 | 270 | 571 | 879 |
| June, July, August | 0 | 0 | 89 | 25 |
| September | 186 | 38 | 300 | 388 |
| October | 757 | 279 | 788 | 1535 |
| November | 2037 | 1012 | 1455 | 4228 |
| December | 2751 | 3273 | 1546 | 8578 |
| | 14297 | 12977<br>or<br>13.0 million | 10905 | 38118<br>or<br>38.1 million |

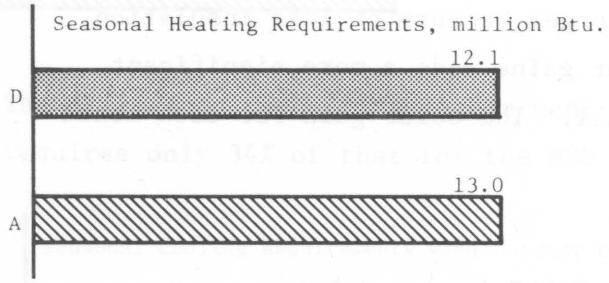
Note: For both houses the internal gain was assumed as 51,000 Btu/day consisting of 10 kwh and 2 persons.

For both houses, the months of December, January, and February showed the largest solar gains through the windows, the same three months in which the heating requirements were largest.

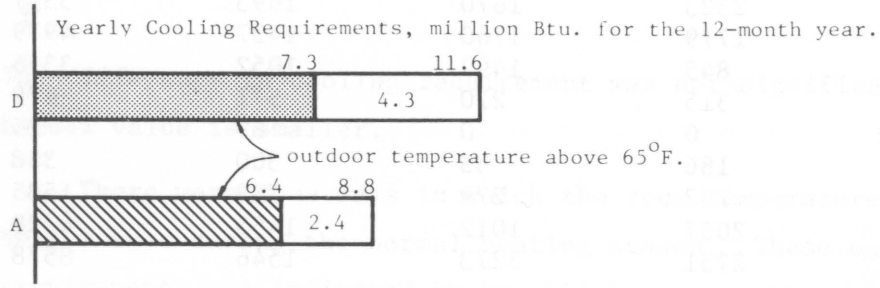
The solar gain of the south-, east-, and west-facing windows during the cooling season was 4.1 million Btu for the HUD House and 3.2 million Btu for the Lo-Cal House. It can be concluded that the south-facing windows (with overhang), when combined with the solar orientation of the house, do provide a substantial reduction in the heating requirements in winter, and reduce the summer cooling requirements as well.

Analysis D. (Madison) LARGER SOUTH-FACING GLASS AREA

What are the consequences of increasing the south-facing glass area by 25%? Instead of the 122 square feet of south-facing glass for the initial Lo-Cal House design, this analysis assumed that 153 square feet of south-facing triple-glazing (windows and sliding glass door units) were used.



The seasonal heating requirement was reduced from 13.0 million Btu (A) to 12.1 million Btu (D), or a 7% decrease when the south-facing glass area was increased about 25%.



On the other hand, the larger south-facing glass area resulted in a slightly larger cooling requirement of 7.3 million Btu instead of 6.4 million Btu. It can be concluded that considerable leeway exists in the amount of glass used on the south, since a 25% increase in glass area resulted in only a 7% improvement in heat requirement, and a 14% increase in the cooling requirement. Also, for cloudy and/or colder climates, the use of larger areas of south-facing windows and doors might be more desirable than in warmer areas with more sun.

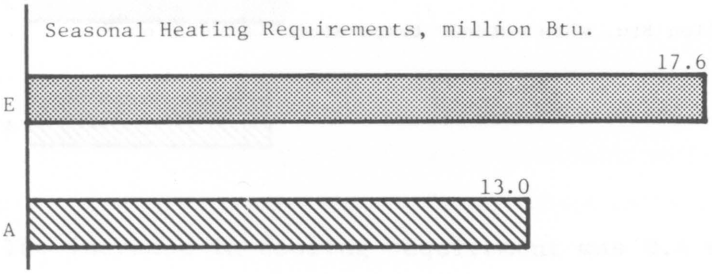
## Cooling During the Heating Season

In the graphs showing the cooling requirement, the 11.6 million Btu represents the value for the entire year, including the heating season, whereas the 7.3 million Btu represents the cooling requirement only when the outdoor average temperature is above 65F. The difference of 4.3 million Btu represents the overheating of the house during the heating season. Obviously, this difference should not be too great because it represents a deviation from a desired temperature control. When 25% more south glass was used, this excess solar gain was increased from 2.4 million Btu to 4.3 million Btu. Since the passive solar system utilized in this design does not include a storage unit (such as a heat-absorbing storage wall or rock bed), this surplus heat must be dissipated, either by the cooling system or by ventilating (opening windows and doors). The latter is preferable because it brings in fresh air without energy use.

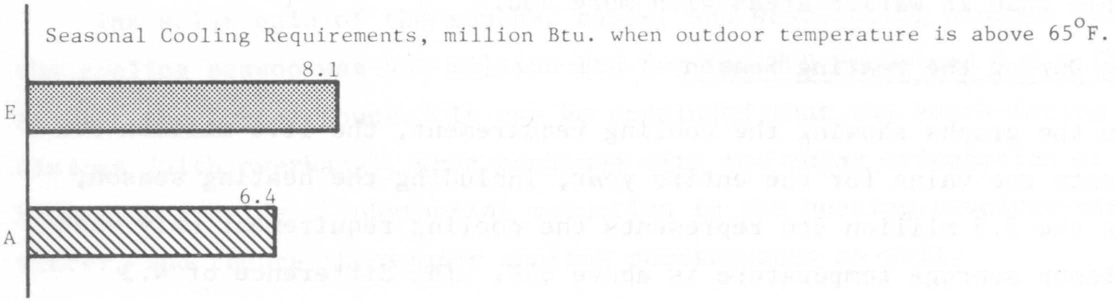
The overall conclusion might be reached that although 25% oversizing of the south window areas is not critical, the usable heat gains from the larger window area are relatively small and the problem of overheating becomes more noticeable.

## Analysis E. (Madison). WINDOW AREA DISTRIBUTION

The Lo-Cal House was analyzed with the same window distribution as the HUD House--with 1/3 of window area facing south, 1/3 north, 1/6 east, and 1/6 west (all triple-glazed).



In comparison with the results for Analysis A, the re-distribution of the windows resulted in an increase of 4.6 million Btu in heating requirements or an increase of 35%.

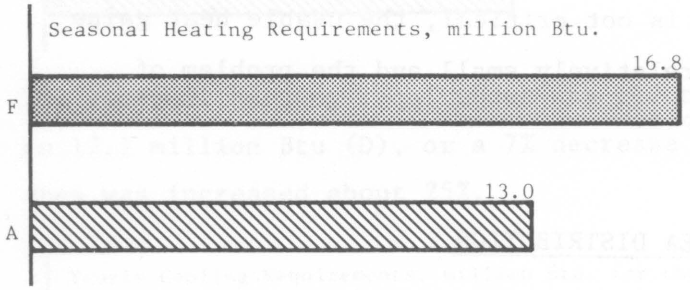


The seasonal cooling requirement increased 1.7 million Btu, or 27%, when the window distribution was changed.

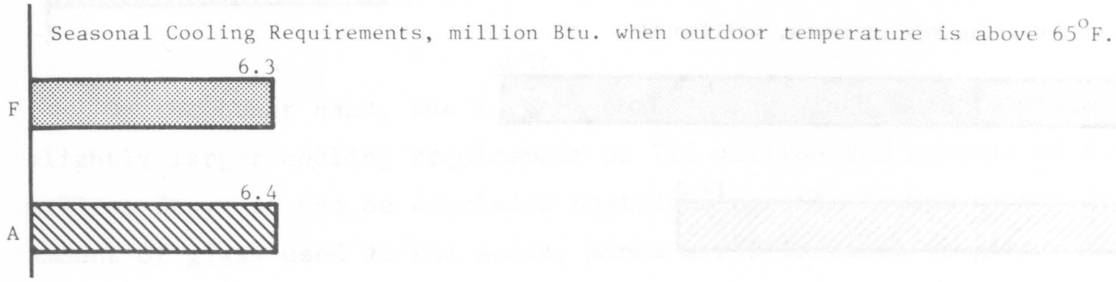
The analysis shows that placing the largest portion of the total window area facing south gave the best results as measured by the least requirements for heating and cooling.

Analysis F. (Madison). DOUBLE GLAZING

In this analysis, the triple-glazed windows facing south (122 square feet) were replaced with double-glazed windows of the same size. The north windows remained triple-glazed.



In comparison with Analysis A, the heating requirement increased by 3.8 million Btu or 29% by changing the triple-glazed windows to double-glazed windows (122 square feet facing south only).



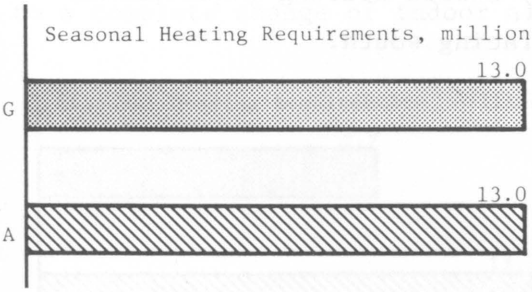
The change in cooling requirements (from 6.4 million to 6.3 million Btu) was negligible.

These results favor triple-glazing over double-glazing in a cold climate. As will be shown later, triple-glazing is most effective in climates having a heating season greater than 4500 degree-days. In climates which are warmer than 4500 degree-days, the advantage of triple-glazing over double-glazing may not be cost-effective.

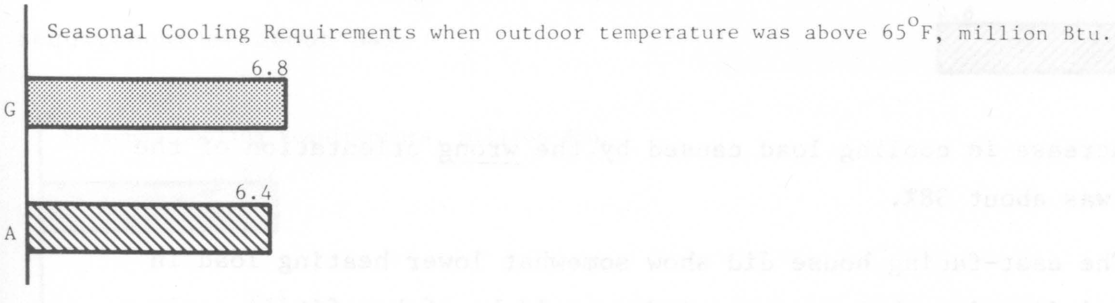
Since the inside surface temperature of triple glass is several degrees warmer than that of double glass in cold weather (Figure 4-12), triple-glazed windows should provide for greater comfort at the same room temperature. Also, higher window surface temperatures permit slightly lower room-air temperatures to be maintained in the house with no decrease in comfort. Under such conditions, the difference in heating requirements would be greater than the 29% obtained.

Analysis G. (Madison). ROTATION OF HOUSE BY 10 DEGREES

In order to determine the effects caused by relatively small changes in house orientation, this test was conducted with the house rotated 10 degrees east of true south.



The change in heating requirement was less than 0.1 million Btu and was negligible.

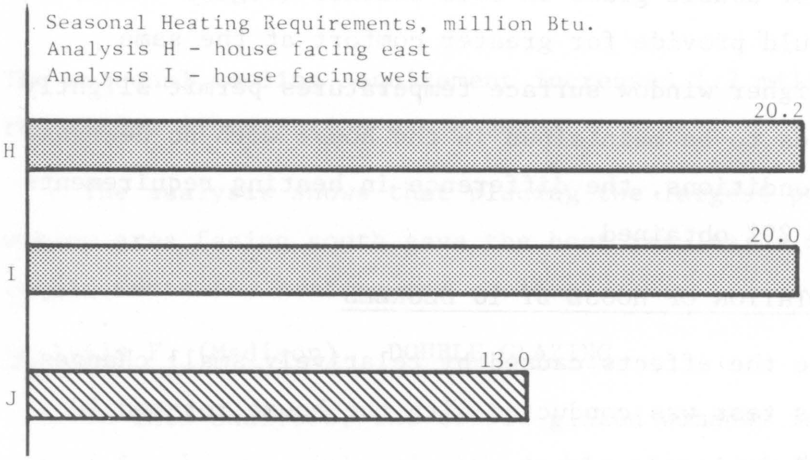


The increase in cooling requirement was 0.4 million Btu, or only 6%.

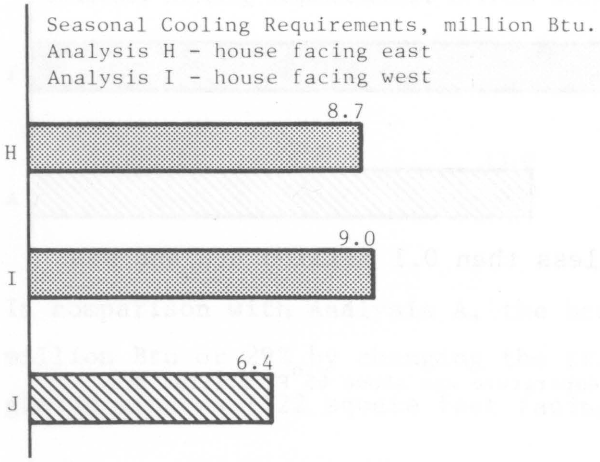
Both changes were not significant, indicating that small deviations from true south orientation would not greatly alter the requirements for heating and cooling.

Analyses H AND I. (Madison). HOUSE FACING EAST AND THEN WEST

In these Analyses the Lo-Cal House was faced in the wrong direction--first east and then west. That is, in analysis H, the window area facing east was 122 square feet and that facing west was 22 square feet. In Analysis I the areas were reversed.



Both orientations of the building (H and I) showed heating requirements about 55% greater than that for the house facing south.



The increase in cooling load caused by the wrong orientation of the house was about 38%.

The east-facing house did show somewhat lower heating load in April, indicating that an east window could be of benefit in early spring, but not at other times. If minimum energy requirement were desired, such east windows should be well-insulated (with a panel or shutter) during most of the heating season, and be well-shaded by a tree, a reflective coating, or external shading in warmer weather.

These two tests (H and I) confirmed the fact that south orientation of a building is a basic requirement of solar house design.

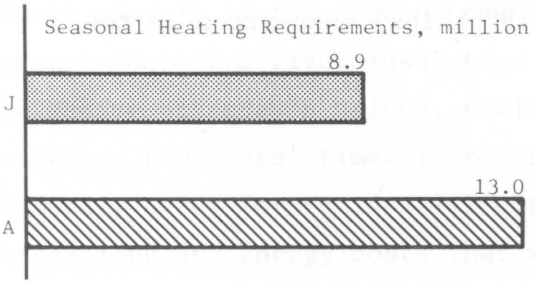
### Analysis J. (Madison). REDUCED AIR-CHANGE RATE

An extended discussion of the important subject of infiltration and ventilation is presented in Chapter VI. For both the Lo-Cal House and the HUD House, the infiltration of outdoor air into the structure was assumed to be 0.5 air change per hour, for all tests except Test J. As explained in Chapter VI there is no easy way of measuring the actual rate of air change taking place in any house, so that whatever rate is assumed is as valid as any other. The only conditions imposed on these analyses were that:

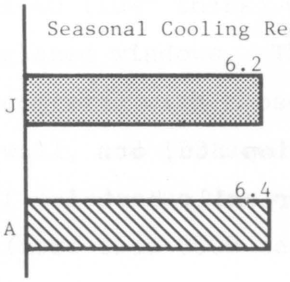
a. the assumptions made on air change rate be applied equally to both the Lo-Cal and the HUD Houses, and

b. the pro's and con's of using reduced air-change rates be clearly explained.

For Test J an air-change rate of 0.3 per hour was assumed, corresponding to a complete change of indoor air every 3-1/3 hours.



The reduction in air-change rate resulted in a reduction in heating requirement of about 34%.



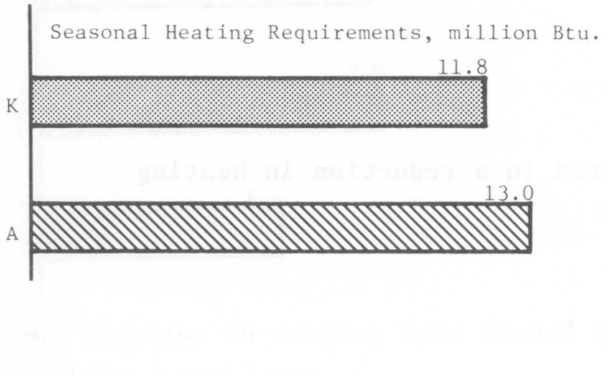
The cooling requirement was relatively unaffected by the reduction in air-change rate--the difference ammounted to about 3%. The winter overheating for Analysis J was quite large.

The simulations indicate that the infiltration load represents a large portion of the winter heating requirements, and that a tight house is desirable. However, as discussed in Chapter VI, the assumption that infiltration rates can be maintained much below 0.5 air changes per hour is not reasonable under ordinary living conditions. It is probable that any air-change rate as low as 0.3 per hour would require almost total prohibition of smoking, cooking, and keeping of pets. The use of deodorants and perfume is not a satisfactory substitute for a reasonable amount of ventilation air for the house. Furthermore, very low infiltration rates result in high humidities in the house, necessitating the continuous use of a dehumidifier.

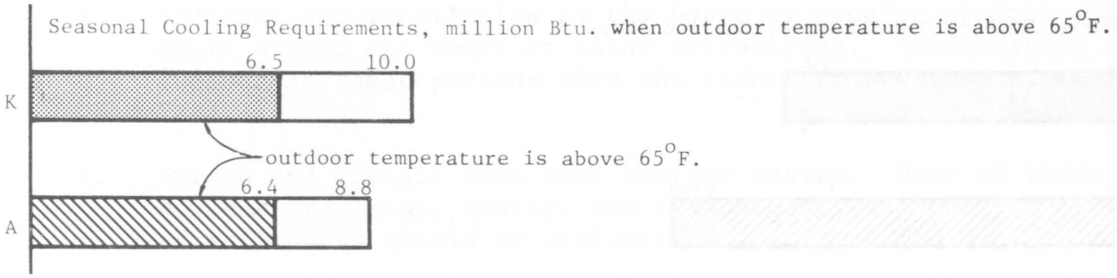
Hence, although a more favorable presentation of the energy savings possible with a Lo-Cal House could be made by assuming infiltration rates as low as 0.3 per hour, the more reasonable air change of 0.5 per hour was used for all computer analyses, unless specifically noted.

### Analysis K. (Madison). R-60 CEILING

As an extreme case of super-insulation, a study was conducted to ascertain the effects of installing R-60 (18" thick) insulation in the ceiling.



The reduction in heating requirement amounted to 1.8 million Btu, or about 13%. This saving could be cost effective for electrically heated homes in very cold climates.

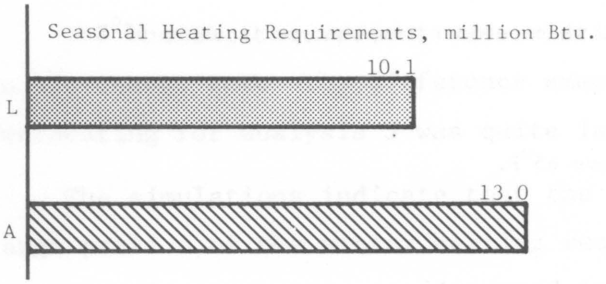

Seasonal Cooling Requirements, million Btu. when outdoor temperature is above 65°F.

During the summer season there was substantially no difference in the cooling requirement. It was observed, however, that the overheating in the heating season (3.5 million Btu) was greater after the heavier ceiling insulation was installed, since the overheating in the basic house was 2.4 million Btu.

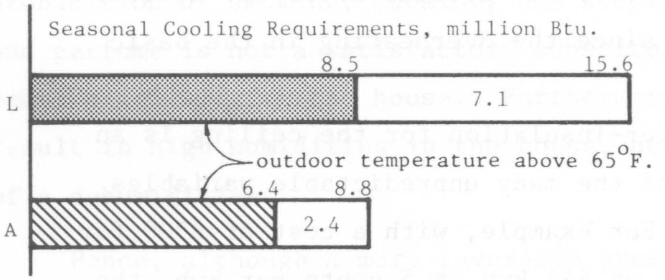
The cost-effectiveness of super-insulation for the ceiling is an uncertain figure at best because of the many unpredictable variables that must be taken into account. For example, with a cost of $300 for the added insulation, and a saving of 544 kwh at 5 cents per kwh, the annual saving would be about 9% of cost. With high fuel costs it may be cost-effective to use R-60 ceiling insulation in climates colder than 7000 degree-days. Any change in the installation cost, future price of energy, and cost of mortgage money could alter the estimates of the payback period. The only predictable cost that seems to extend indefinitely upwards is the cost of energy itself. In general, it is safe to assume that if a given insulation option appears to be almost cost-effective at today's prices, the chances are good that it will be practical within a few years' time. Therefore, even if 18" thick insulation appears absurdly heavy for residential applications today, there could be weather conditions and energy costs that would make it a practical option.

### Analysis L. (Madison). EXTREME INSULATION AND LARGE SOUTH GLASS AREA.

The final analysis for Madison, Wisconsin, weather data was made for an extreme insulation option, consisting of R-60 (18" thick) ceiling, R-40 (10½" thick) wall, and 153 square feet of south-facing triple-glazed windows. These insulation levels and south glass areas are compared with those for the Lo-Cal House: namely, R-39.5 ceiling, R-33 wall, and 122 square feet of triple-glazed windows facing south. This final design was considered for cost-effectiveness in the coldest climates (more than 8000 degree days).



The extreme insulation case showed a reduction of 2.9 million Btu, or about 22% in heating requirement. This large reduction is not unexpected.



The increase in cooling requirement of 2.1 million Btu, or about 33%, requires explanation. The large solar gain from the 153 square feet of south-facing triple-glazed windows and the extremely heavy insulation of the house tends to overheat the house even in cold weather. The house loses heat very slowly, after the sun has gone down.

Also note the (7.1) and (2.4) values in the graph. These represent the solar overheating that occurs during the heating season. That is, the 15.6 and 8.8 values represent not only the normal cooling requirement during the summer months, but also the cooling requirements for winter overheating. As mentioned previously, the winter overheating need not represent an energy usage by house-cooling equipment, but can be handled by ventilating the house during these periods.

There are several possible ways of handling this overheating or "greenhouse" effect if the optimum insulation and south window area have been exceeded. Some of the suggestions are as follows:

a. Reduce the area of south windows to more closely approach the value of 8% of the floor area utilized in the Lo-Cal House (Analysis A). This can be done in an existing house by using foil, awnings, or reflective curtains on a few windows.

b. Increase the ventilation of the house by opening windows and doors during the hours of solar overheating. (Overheating is defined as those periods when the indoor temperature exceeds 78F).

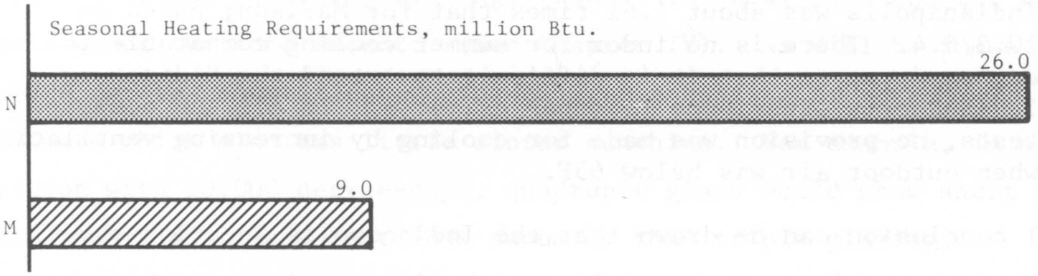
c. Devise and install some heat storage device. Most of these devices are large, costly, and custom made; the cost-effectiveness should be evaluated.

The overall conclusion to be drawn from Analysis L is that extreme insulation, combined with a larger south glass, may be suitable for very cold climates (more than 8000 degree-days) or for localities with less solar gain than Madison.

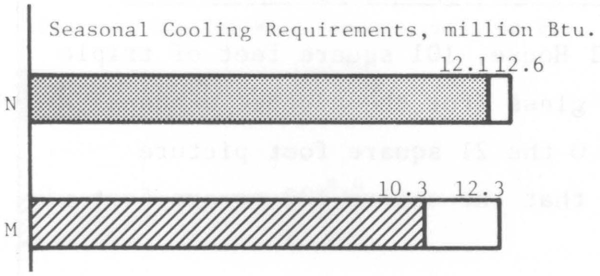
## INDIANAPOLIS ANALYSES

The same basic Lo-Cal House and the HUD House were processed with weather data from Indianapolis, Indiana, (5015 degree-days).

## TESTS M AND N. (Indianapolis) BASIC LO-CAL AND HUD HOUSES.



The results were similar to those reported for Tests A and B for Madison, Wisconsin, which showed a total of 7564 degree-days. The heating requirement of the HUD House was 2.93 times greater than that for the Lo-Cal House in Madison; the comparable ratio was 2.89 in Indianapolis.



The cooling requirement of the HUD House in Indianapolis was 1.17 times that for the Lo-Cal House; the comparable ratios were 1.16 for Madison. The better performance of the Lo-Cal House has been shown to be almost identical in the two cities with different weather patterns.

For comparisons of energy requirements and weather data, the requirements from an earlier Analysis are repeated here:

| | |
|---|---|
| Seasonal Heating Requirement, Btu (Madison--Lo-Cal House only) | 13.0 million |
| Seasonal Cooling Requirement, Btu (Madison--Lo-Cal House only) | 6.4 million |

A comparison of the data from the two cities shows the following:

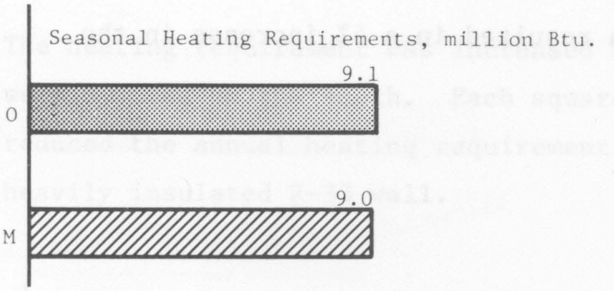
a. The seasonal heating requirement for the Lo-Cal House in Indianapolis was about 69% of that for Madison (9.0/13.0). The degree-day ratios for the two cities was about 0.66 (5015/7564). That is, the seasonal heating requirements corresponded closely to the seasonal degree-day values. The assumption has been made that the seasonal energy requirements for heating given in this study can be converted readily to corrected values for any other locality by using ratios of degree-days.

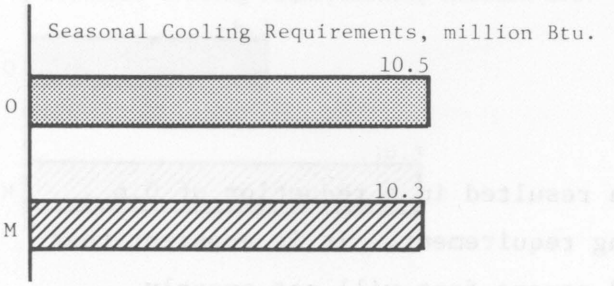
b. The seasonal cooling requirement for the Lo-Cal House in Indianapolis was about 1.61 times that for Madison; based on 10.3/6.4. There is no index for summer cooling comparable to degree-days, so that it is difficult to extend the Madison or Indianapolis experience to other climates. In all the computer tests, no provision was made for cooling by increasing ventilation when outdoor air was below 65F.

The general conclusion can be drawn that the Indianapolis location shows a smaller heating requirement, but a larger cooling requirement than the same Lo-Cal House in Madison, as would be expected from their geographic locations.

## Analysis O. (Indianapolis). ALL TRIPLE GLASS ON SOUTH, 122 SQ. FT.

In Analysis M of the basic Lo-Cal House, 101 square feet of triple glass and 21 square foot of quadruple glass (for the picture window) were used on the south wall. In Test O the 21 square foot picture window was made of triple glazing, so that the entire 122 square foot of south window was triple-glazed.





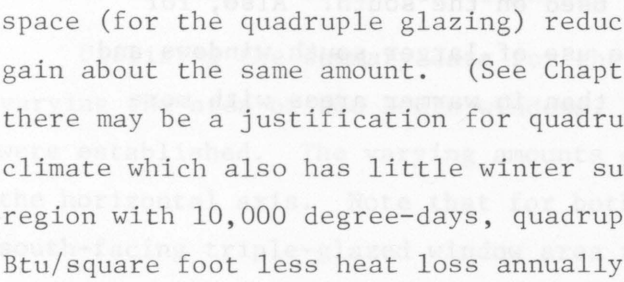
The differences between Tests O and M were less than 2% for both heating and cooling and were not considered significant.

Except for a very cold climate with little winter sunlight, the net heat gain of a south window (solar gain minus heat loss) is about the same for quadruple and triple glazing. The extra layer of glass and air space (for the quadruple glazing) reduces the heat loss and the solar gain about the same amount. (See Chapter IV). As will be shown later, there may be a justification for quadruple glazing in an extremely cold climate which also has little winter sunshine. For example, in a region with 10,000 degree-days, quadruple glass would show about 20,000 Btu/square foot less heat loss annually than triple glazing.

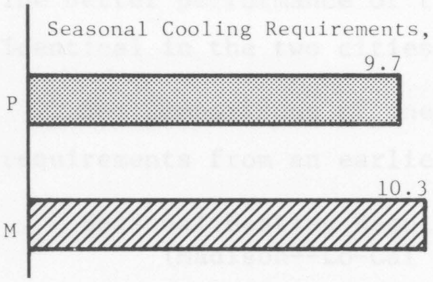
Quadruple glazing may also prove to be cost-effective on east, north, and west windows in extremely cold climates.

Analysis P. (Indianapolis). 100 SQ. FT. OF SOUTH TRIPLE GLASS

The effect of using 18% less glass area on the south is shown in this test. The reduction in area was from 122 to 100 square feet.



The 18% reduction in south glass area resulted in a 4% increase in the seasonal heating requirement.

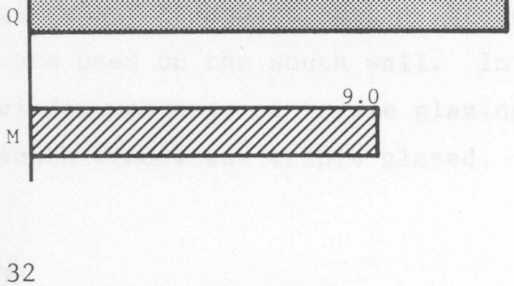


The 18% reduction in south glass area resulted in a reduction of 0.6 million Btu or about 6% in the cooling requirement. It is apparent that south glass areas between 100 and 122 square feet will not greatly change the heating and cooling requirements for the Lo-Cal House.

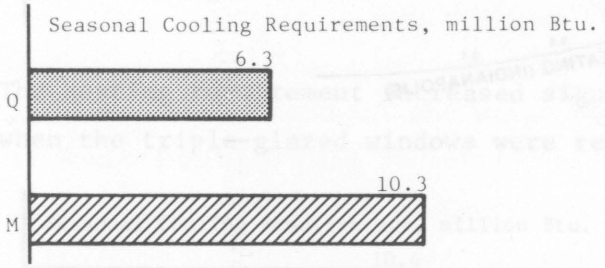
In this connection, Analysis D (Madison) showed that when the south glass area was increased about 25% (from 122 square feet to 153 square feet) the heating requirement was reduced about 7% and the cooling requirement increased about 14%. It can be concluded that considerable leeway exists in the amount of glass used on the south. Also, for cloudy areas and for colder areas the use of larger south windows and glass doors might be more beneficial than in warmer areas with more sunshine.

Analysis Q. (Indianapolis). NO SOUTH WINDOWS, BUT R-33 WALL INSTEAD

In this test the 22 square feet of triple-glazed windows on the north were retained, but the 122 square feet of south windows were replaced with an R-33 wall. While this would violate code requirements for window areas, it was intended to show the energy effect of using south windows.



The heating requirement was increased by 3.3 million Btu when the windows were omitted on the south. Each square foot of south triple-glazing reduced the annual heating requirement about 27,000 Btu from that of a heavily insulated R-33 wall.



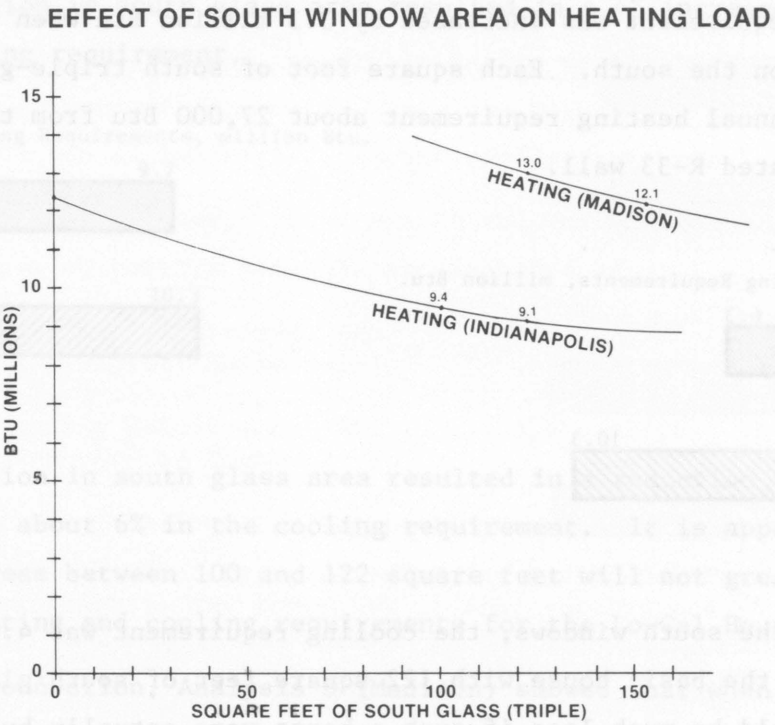
Without the south windows, the cooling requirement was 4.0 million less than for the basic house with 122 square feet of south glass. This difference would be much less if such a house were actually built, because the house would be almost like a cave and would require more lighting during the day, with consequent need for more energy used for lighting and for cooling to offset the lighting load.

Utilizing the summary data for the tests showing the effect of varying the area of the south windows, the curves in Figures 2-1 and 2-2 were established. The varying amounts of south window area are shown on the horizontal axis. Note that for both cities, any increase in the south-facing triple-glazed window area resulted in a decreased heating requirement. Both curves showed a tendency to level off at some larger window area. The Indianapolis data in particular showed relatively little change in heating requirement for window areas between about 100 and 150 square feet.

On the other hand, the cooling requirement increased steadily with the window area, and showed no signs of levelling off.

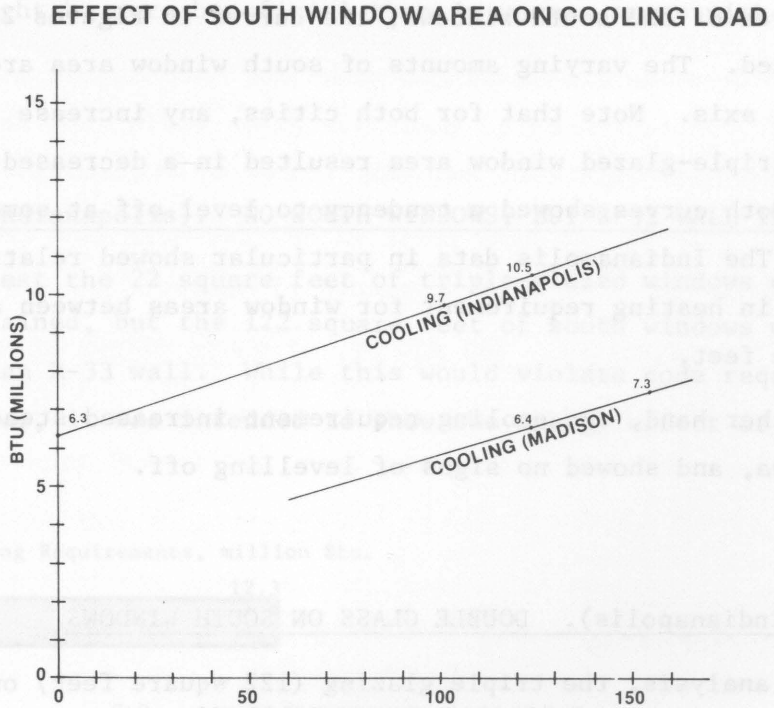
## Analysis R. (Indianapolis). DOUBLE GLASS ON SOUTH WINDOWS

For this analysis, the triple glazing (122 square feet) on the south was replaced with double glazing, while the triple glazing on the north (22 square feet) remained the same.



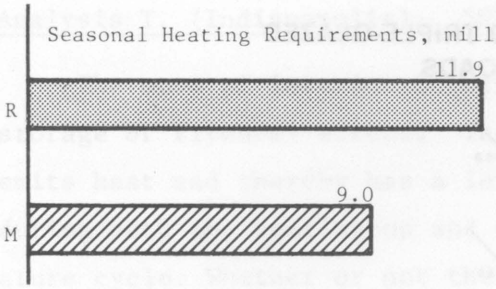
EFFECT OF SOUTH WINDOW AREA ON HEATING LOAD

Figure 2-1

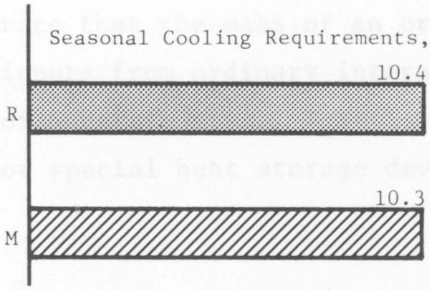


EFFECT OF SOUTH WINDOW AREA ON COOLING LOAD

Figure 2-2



The heating requirement increased significantly, 2.9 million Btu or 32%, when the triple-glazed windows were replaced with double glazing.

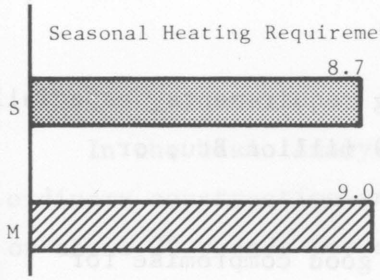


The cooling load was scarcely affected; only 0.1 million Btu or about 1% more than the 10.3 million Btu for triple glazing.

By using the data for the two cities, the graphs in Figure 2-3 show the differences between double- and triple-glazed windows for two different degree-day totals. The advantage of using triple glazing instead of double glazing in reducing the heating requirement is clearly indicated.

Analysis S. (Indianapolis). OVERHANG REDUCED FROM 30" to 24"

The 30/16 overhang specified for the Lo-Cal House is an integral part of the solar design. This test was to determine the effect of reducing the overhang by 6 inches.



With a 24-inch roof overhang the heating load was reduced from 9.0 to 8.7 million Btu, or about 3%. With the shorter overhang, the solar

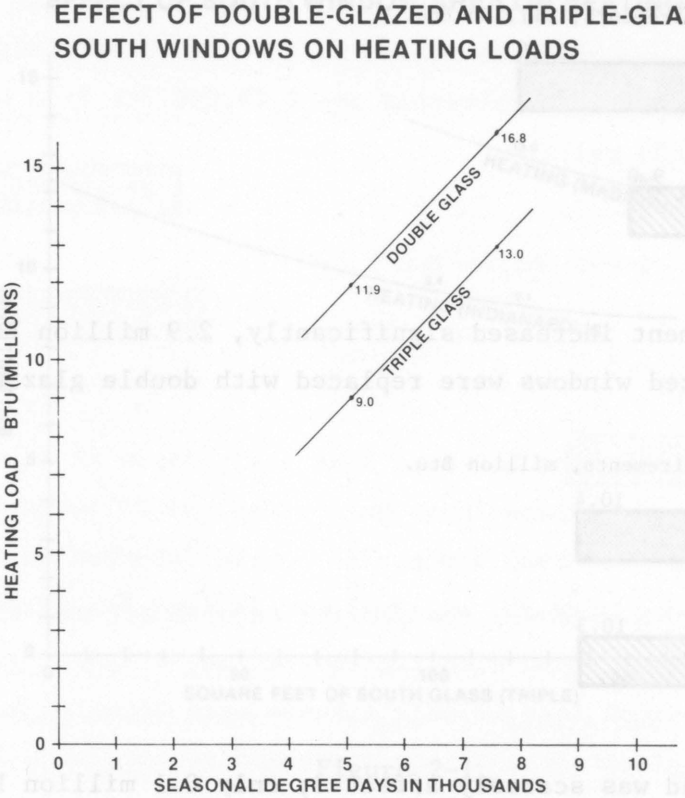
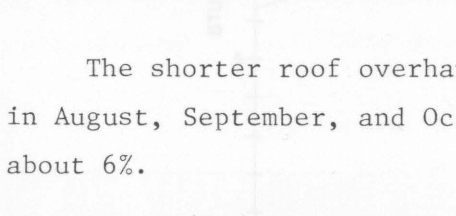

EFFECT OF DOUBLE-GLAZED AND TRIPLE-GLAZED SOUTH WINDOWS ON HEATING LOADS

Figure 2-3

gain was larger during the spring and fall months, resulting in a slightly reduced heating requirement.

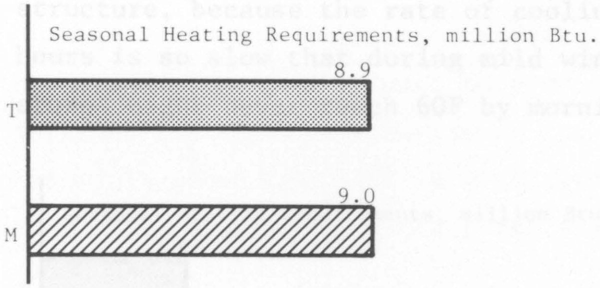


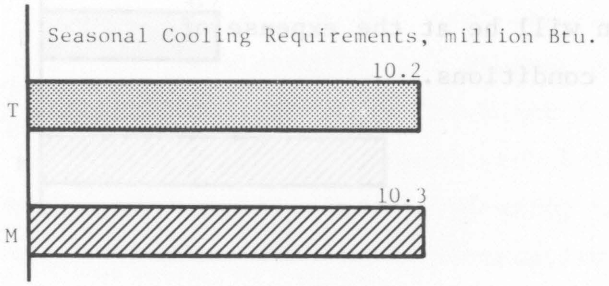
The shorter roof overhang increased the cooling requirements, especially in August, September, and October, from 10.3 to 10.9 million Btu, or about 6%.

The 30/16 roof overhang was considered to be a good compromise for a location close to 40 degrees north latitude. This overhang functions quite well for most of the temperate zone, between 30 to 50 degrees latitude. (See Circular C3.2, "Solar Orientation").

Analysis T. (Indianapolis). 50% INCREASE IN INTERIOR MASS.

The mass of interior furnishings and house construction has a heat-storage or flywheel effect. The interior mass absorbs, stores, and emits heat and thereby has a levelling effect on room temperatures during both the heating-up and cooling-off phases of each daily temperature cycle. Whether or not the heat storage of the mass is sufficient depends upon: a. the heat loss rate of the house shell, and b. the heat inputs from internal and solar gains. The basic design of the Lo-Cal House intended that super-insulation would so reduce the heat loss rate that the mass of an ordinary house would suffice to store the heat inputs from ordinary internal gains and solar gains from south windows of moderate area. That is, it was intended that oversized solar windows or special heat storage devices would not be needed.

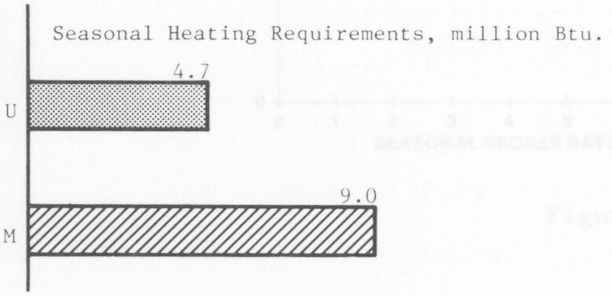




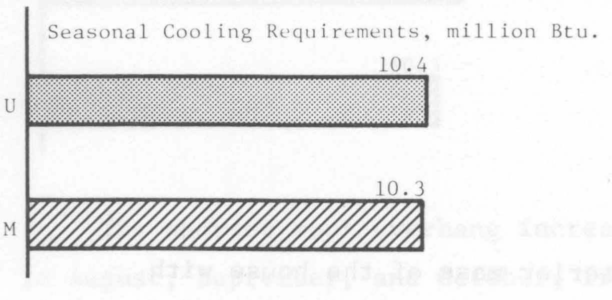
In the basic Analysis (M), the interior mass of the house with ordinary construction and furnishings was assumed to be 30,000 pounds, or about 20 pounds per square foot. For Analysis T the interior mass was assumed to be 45,000 pounds, or 30 pounds per square foot. The increase in interior mass was found to have a negligibly small effect on energy requirements for both heating and cooling seasons.

### Analysis U. (Indianapolis). INFILTRATION RATE REDUCED TO 0.3 AIR CHANGE/HR.

Discussion of the infiltration rate and its effect on the heating load, in particular, has been presented in Analysis J (Madison data) and in Chapter VI. With very tight house construction, infiltration rates as low as 0.3 air changes per hour should be obtainable. In fact, rates as low as 0.1 air change per hour have been reported for some research houses. Such low air-change rates are beneficial as far as energy savings are concerned, but can be detrimental with respect to air quality and to high humidity. The 0.5 air-change rate assumed for all analyses except J and U is equivalent to changing the indoor air once each two hours. While this is not a high rate of air-change, it has been accepted as a reasonable lower limit for ordinary family living.



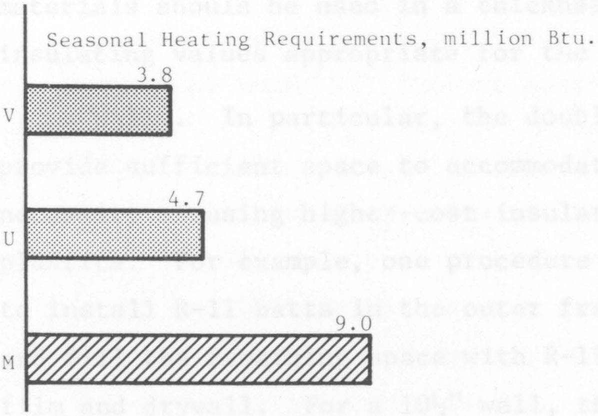
The reduction in infiltration rate from 0.5 to 0.3 air change per hour resulted in almost 50% reduction in heating requirement. As discussed in Chapter VI, this reduction will be at the expense of higher odor levels and higher humidity conditions.



The energy requirement for the cooling season was surprisingly unchanged by lower infiltration rates. This is easier to understand when the basic assumptions are examined closely. For both Analyses U and M, the assumption is made that the windows are closed during the entire summer and that ventilation air is brought in only by infiltration. With this small amount of ventilation, the house cools slowly, even when outdoor air is much cooler. It is probable that all of the cooling requirements shown by these computer analyses may be much higher than the condition when the homeowner opens the windows at night and allows a high rate of ventilation to cool the house. The cooling requirements shown are more realistic for those houses where night-air cooling (by open windows or exhaust fans) is not feasible because of environmental factors such as security, dusty outdoor air, pollen or other allergens, or high humidity.

### Analysis V. (Indianapolis). 0.3 AIR CHANGE PLUS 60F NIGHT SETBACK

Night setback of the room thermostat during the heating season is commonly advocated as an energy conservation measure. The question arises whether night setback would be effective in a super-insulated structure, because the rate of cooling of the house during the night hours is so slow that during mild winter weather the house air temperatures might never reach 60F by morning.



By comparing Test U with the preceding Test V, the night setback reduced energy requirements an additional 0.9 million Btu, or almost 20%. The annual savings amounted to only 100,000 Btu for each degree of setback. No evaluation was made for night setback with the normal 0.5 air change rate.

Values for seasonal cooling requirement would be represented by those for Test U, since a night setback to 60F has no meaning during the cooling season.

[5] Shading coefficient is the ratio of the solar heat gain of the window to the heat gain of a single glass window. S.C. of .82 transmits 82% of the solar energy transmitted by a single glass window. An S.C. of .01 indicates a window transmitting only 1% of the solar gain of a single glass window.

# CHAPTER III. HOUSE PLANS AND CONSTRUCTION DETAILS

These drawings serve as examples of the broad diversity of plans and elevations which can incorporate the Illinois Lo-Cal House principles of solar orientation, window design, and super-insulation of walls, ceilings, and floor or foundation.

The drawings consist of four floor plans, foundation plans, typical elevations, and other construction details. Basic plan dimensions are shown, but only a few notes are given. The drawings do not comprise a complete set of working drawings or specifications. However, the information on the drawings should be useful to an architect, builder, or homeowner in developing a set of drawings and specifications for a Lo-Cal House which is suitable for a particular client, building site, and climate.

## Insulation

The low-cost insulation materials, such as cellulose, mineral wool, or glass fiber, may be used to develop the high thermal resistance required for super-insulation of the walls, ceiling, and floor. The materials should be used in a thickness and density which develop insulating values appropriate for the climate.

Walls. In particular, the double-framed wall is designed to provide sufficient space to accommodate adequate insulation without the necessity of using higher-cost insulation materials, such as the foamed plastics. For example, one procedure to insulate the 8½" wall space is to install R-11 batts in the outer frame, install the electric wiring, and fill the remaining space with R-19 batts. This is covered by polyethylene film and drywall. For a 10½" wall, the procedure is similar except that two R-19 batts are used. Alternatively, the wiring can be installed and the wall enclosed with polyethylene film and drywall, and then suitable insulation material can be blown into the wall space. Note that the wall space should be filled with insulation material, as air space has little insulating value compared to the insulation material.

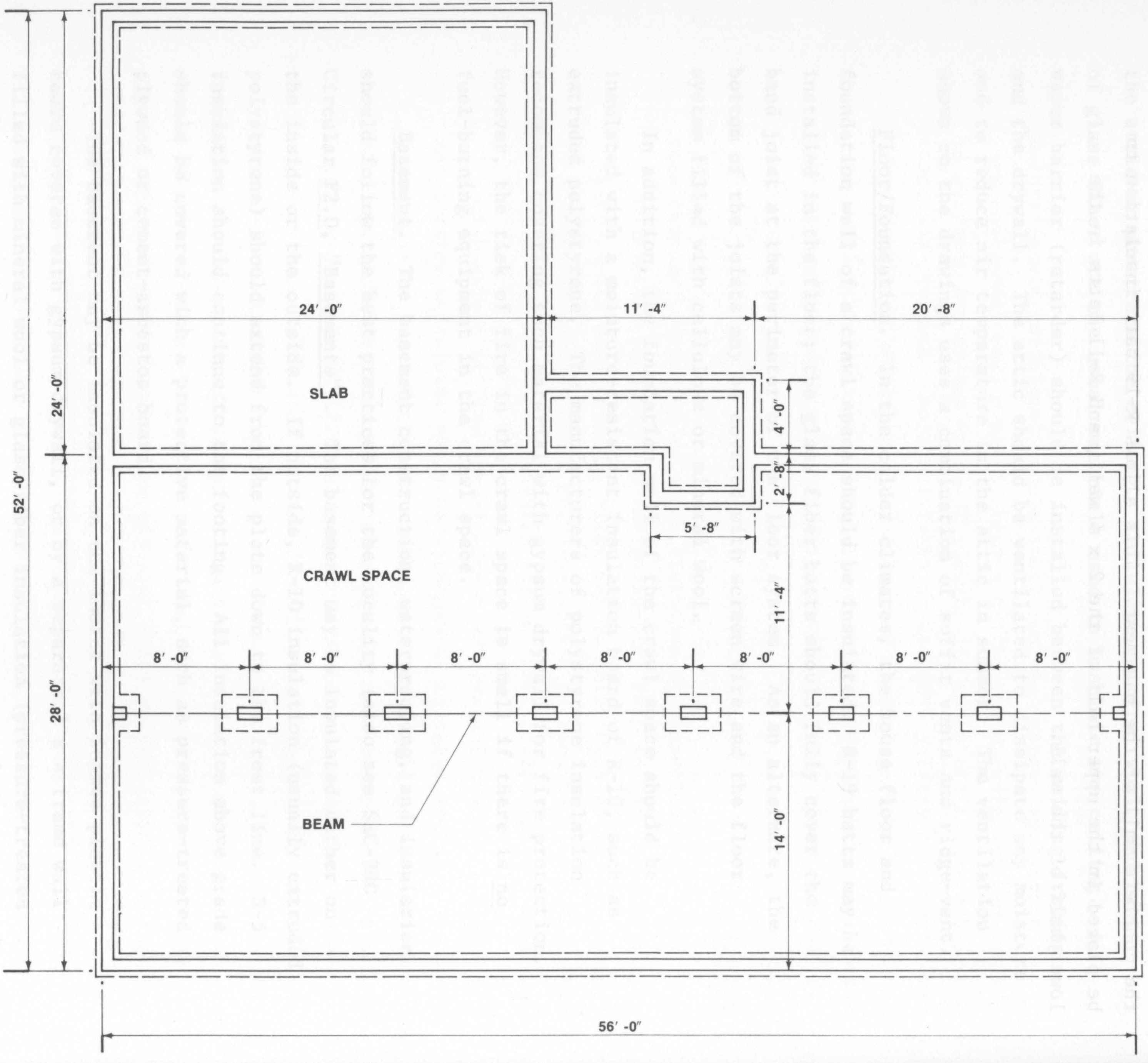
Ceiling. The special roof framing detail at the eaves is designed to permit the full thickness of insulation to extend over the outside wall. Note the retainer on Figure 3-10, which protects the insulation against wind effects in the ventilated attic. In very cold climates, the roof slope may be made steeper to withstand the heavier ice and snow load and to allow as much as 18" of ceiling insulation. For the greatest energy efficiency, no ductwork or recessed lights should be installed in the attic or penetrate the ceiling. Cellulose, mineral wool, and batts of glass fiber are the usual materials used to insulate the ceiling. A vapor barrier (retarder) should be installed between the ceiling framing and the drywall. The attic should be ventilated to dissipate any moisture and to reduce air temperature in the attic in summer. The ventilation shown on the drawings uses a combination of soffit vents and ridge-vent.

Floor/Foundation. In the colder climates, the house floor and foundation wall of a crawl space should be insulated. R-19 batts may be installed in the floor; the glass fiber batts should fully cover the band joist at the perimeter of the floor system. As an alternate, the bottom of the joists may be covered with screen wire and the floor system filled with cellulose or mineral wool.

In addition, the foundation wall of the crawl space should be insulated with a moisture-resistant insulation board of R-10, such as extruded polystyrene. The manufacturers of polystyrene insulation recommend covering such material with gypsum drywall for fire protection. However, the risk of fire in the crawl space is small if there is no fuel-burning equipment in the crawl space.

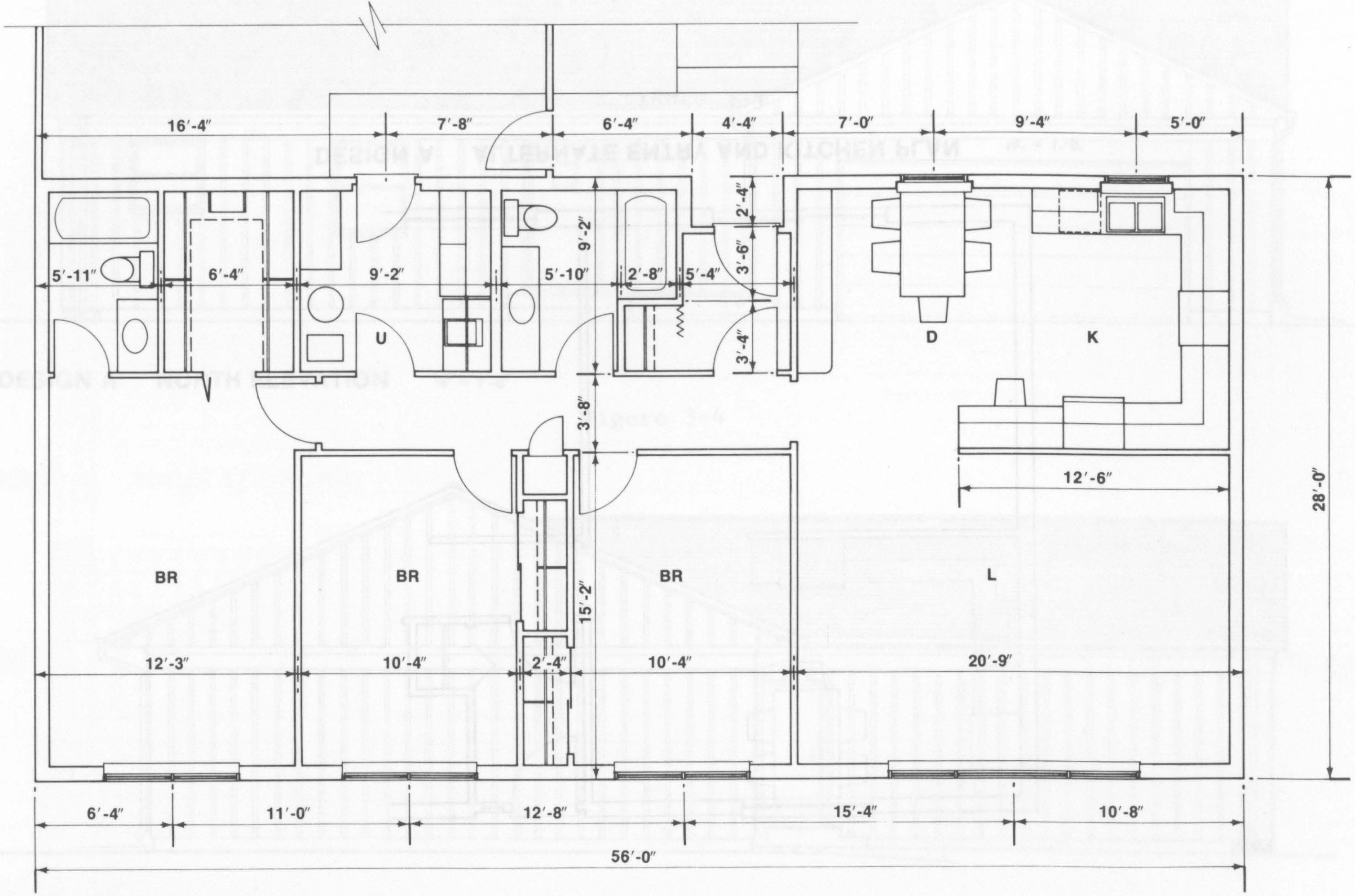
Basement. The basement construction, waterproofing, and insulation should follow the best practices for the locality (also see SHC-BRC Circular F2.0, "Basements"). The basement may be insulated either on the inside or the outside. If outside, R-10 insulation (usually extruded polystyrene) should extend from the plate down to the frost line. R-5 insulation should continue to the footing. All insulation above grade should be covered with a protective material, such as pressure-treated plywood or cement-asbestos board.

The basement may be insulated on the inside with foamed plastic board covered with gypsum drywall, or by a separate 2 x 4 frame wall filled with mineral wool or glass fiber insulation (pressure-treated lumber is recommended for the bottom plate). To prevent any wetting of the insulation through the basement wall, a polyethylene film can be installed directly over the wall. A second layer of polyethylene film is installed over the insulation and behind the interior finish. The insulated space should be vented through the top plate. A very high level of insulation can be attained by spacing the 2 x 4 wall 2½" from the concrete wall of the basement. This allows R-19 batt insulation to be placed in the upper half of the 2 x 4 wall, and R-11 batts in the lower half of the wall.



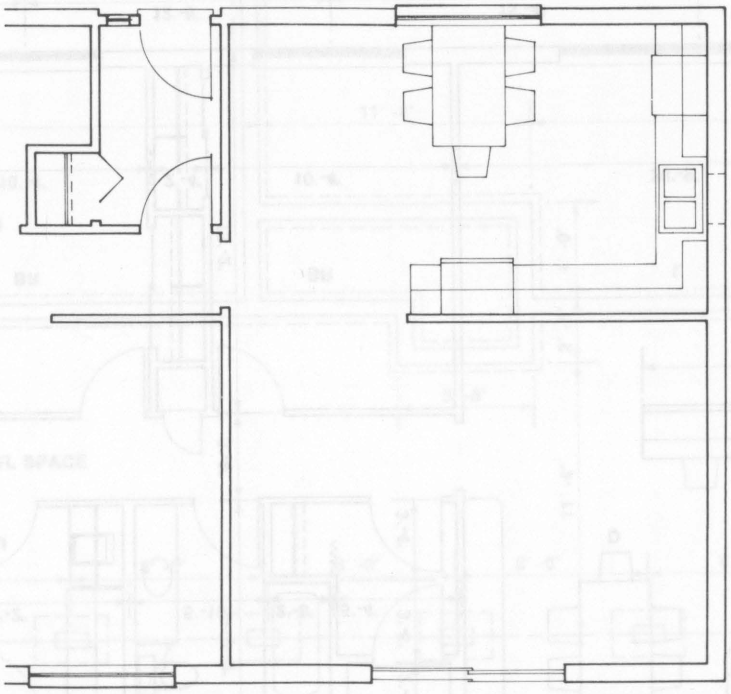
**DESIGN A FOUNDATION PLAN** 1/8″ = 1′-0″

Figure 3-1



**DESIGN A PLAN** ⅛″ = 1′-0″

Figure 3-2



**DESIGN A ALTERNATE ENTRY AND KITCHEN PLAN** ⅛" = 1'-0"

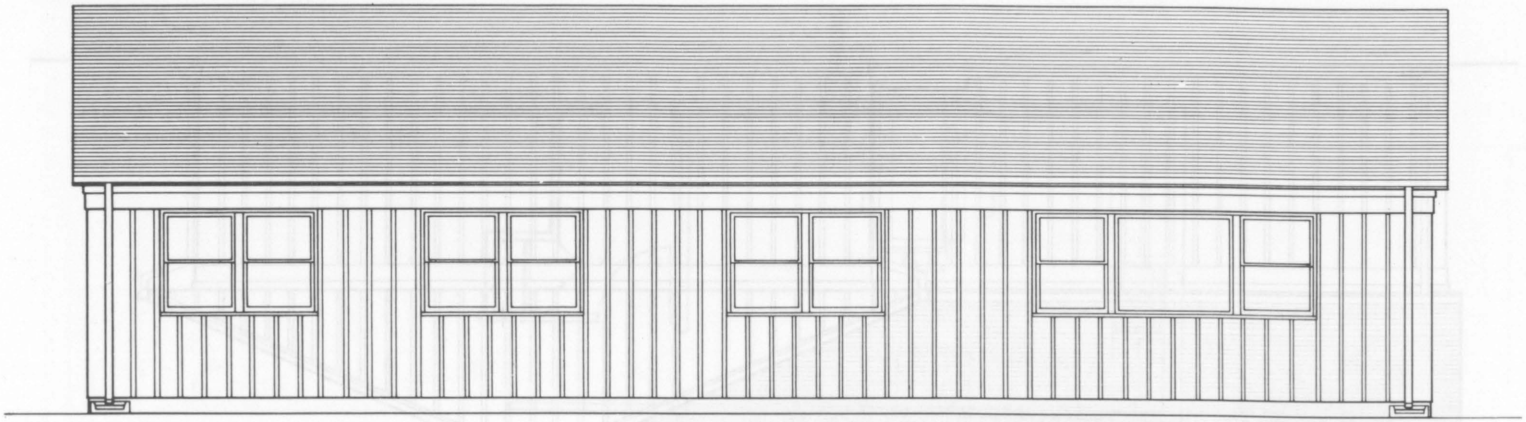
Figure 3-3

**DESIGN A NORTH ELEVATION** 1/8" = 1'-0"

Figure 3-4

**DESIGN A EAST ELEVATION** 1/8" = 1'-0"

Figure 3-5



**DESIGN A SOUTH ELEVATION** ⅛″ = 1′-0″

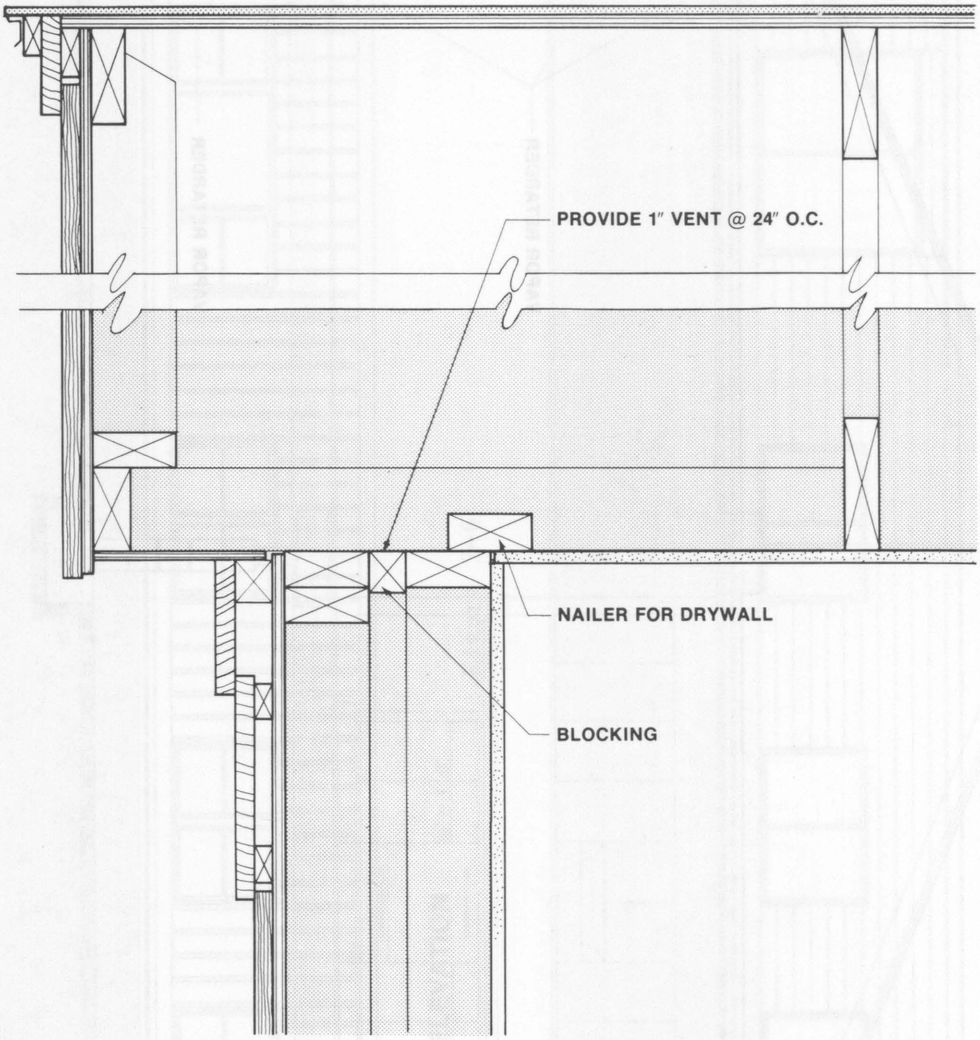
Figure 3-6

**DESIGN A ALTERNATE SOUTH ELEVATION** ⅛″ = 1′-0″

Figure 3-7

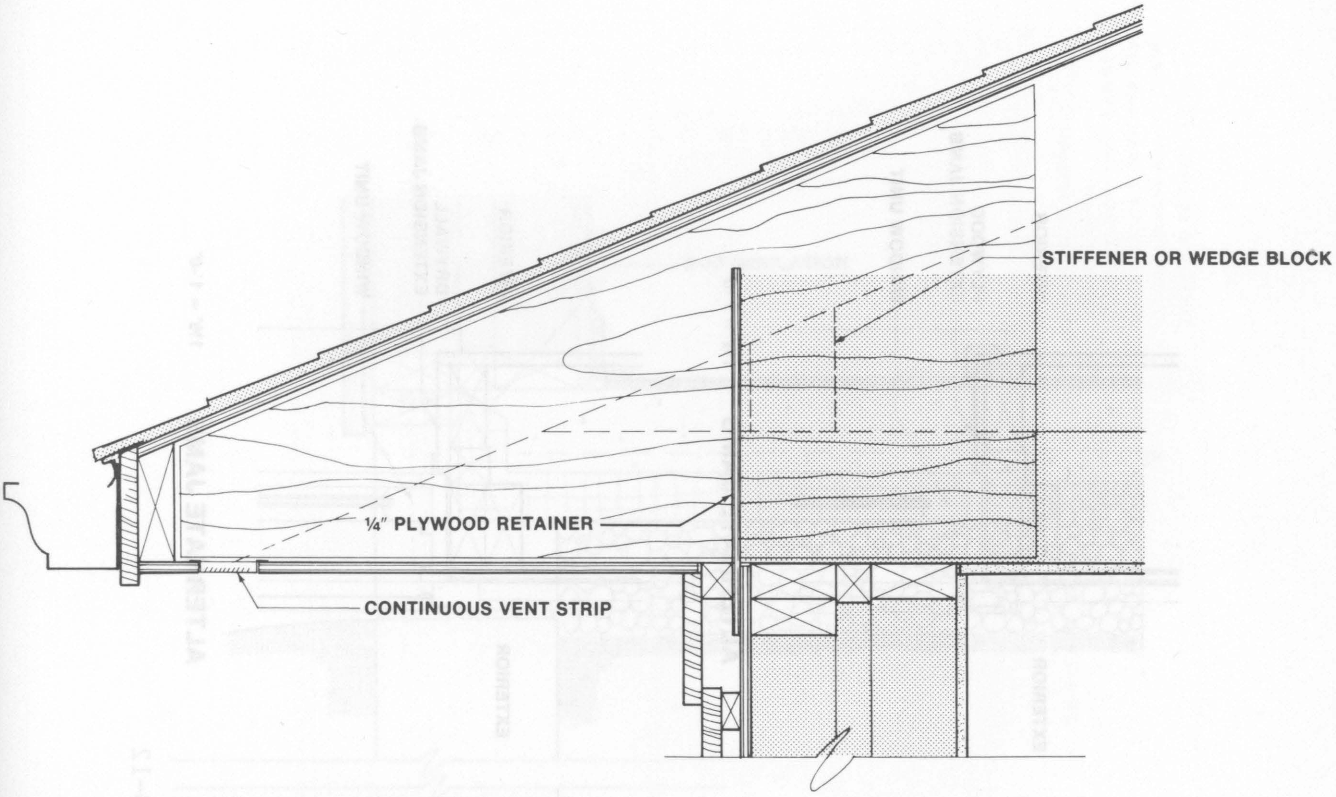
**DESIGN A SECTION** ¼" = 1'-0"

Figure 3-8



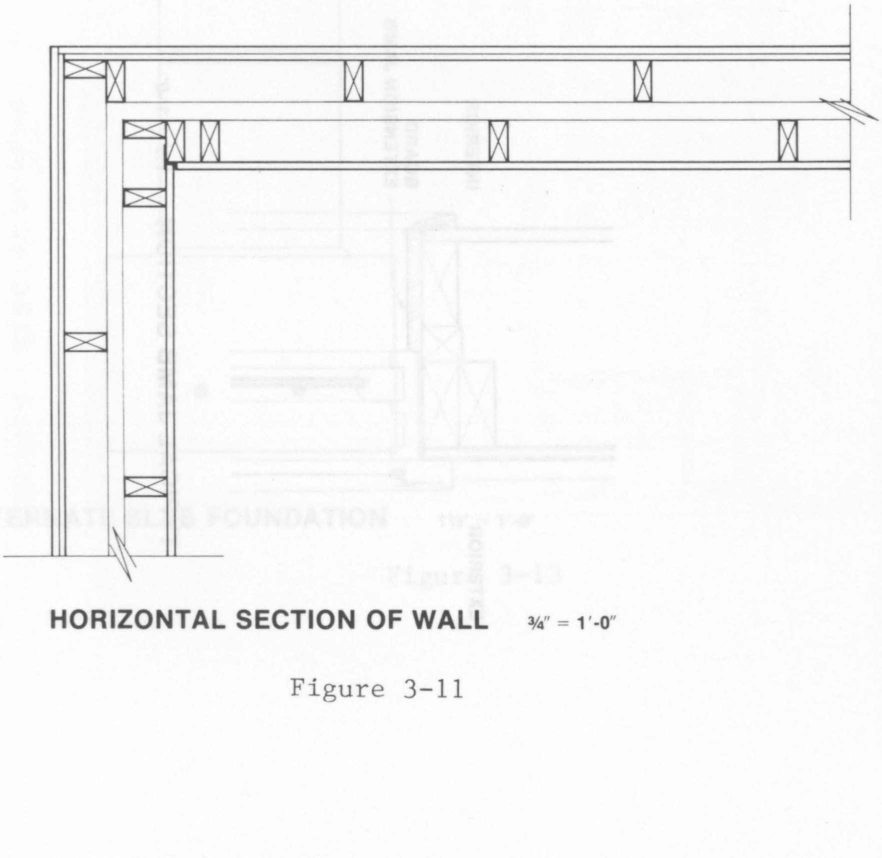
DESIGN A SECTION THROUGH GABLE END 1½″ = 1′-0″

Figure 3-9



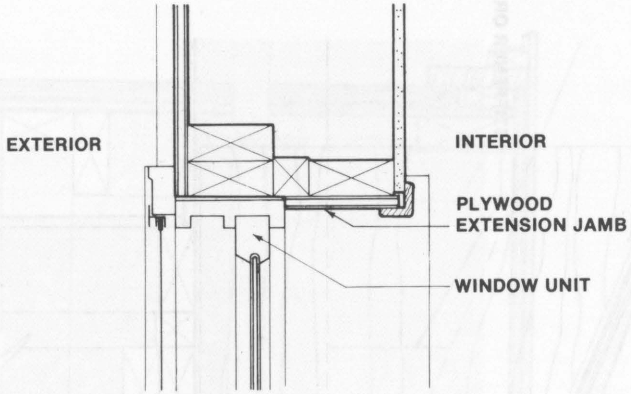
**SECTION THROUGH CORNICE** 1½″ = 1′-0″

Figure 3-10

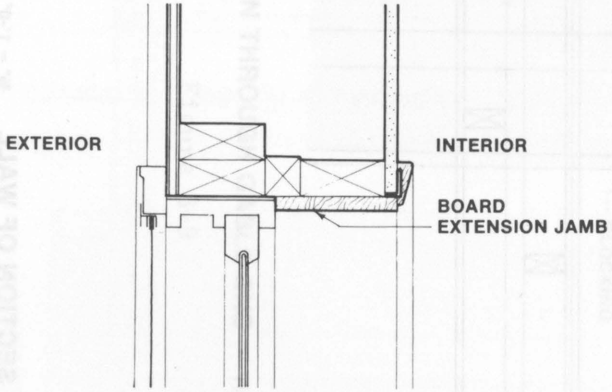


**HORIZONTAL SECTION OF WALL** ¾″ = 1′-0″

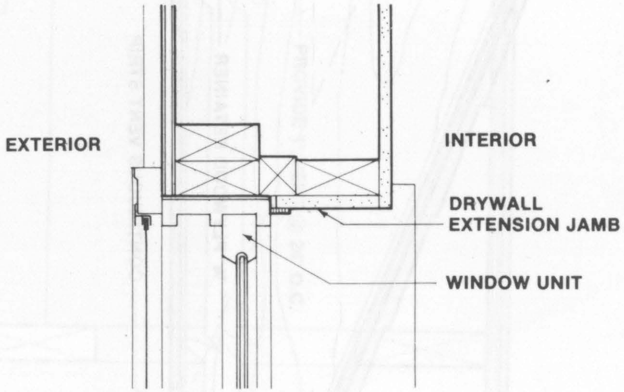
Figure 3-11



**ALTERNATE JAMB** 1½" = 1'-0"

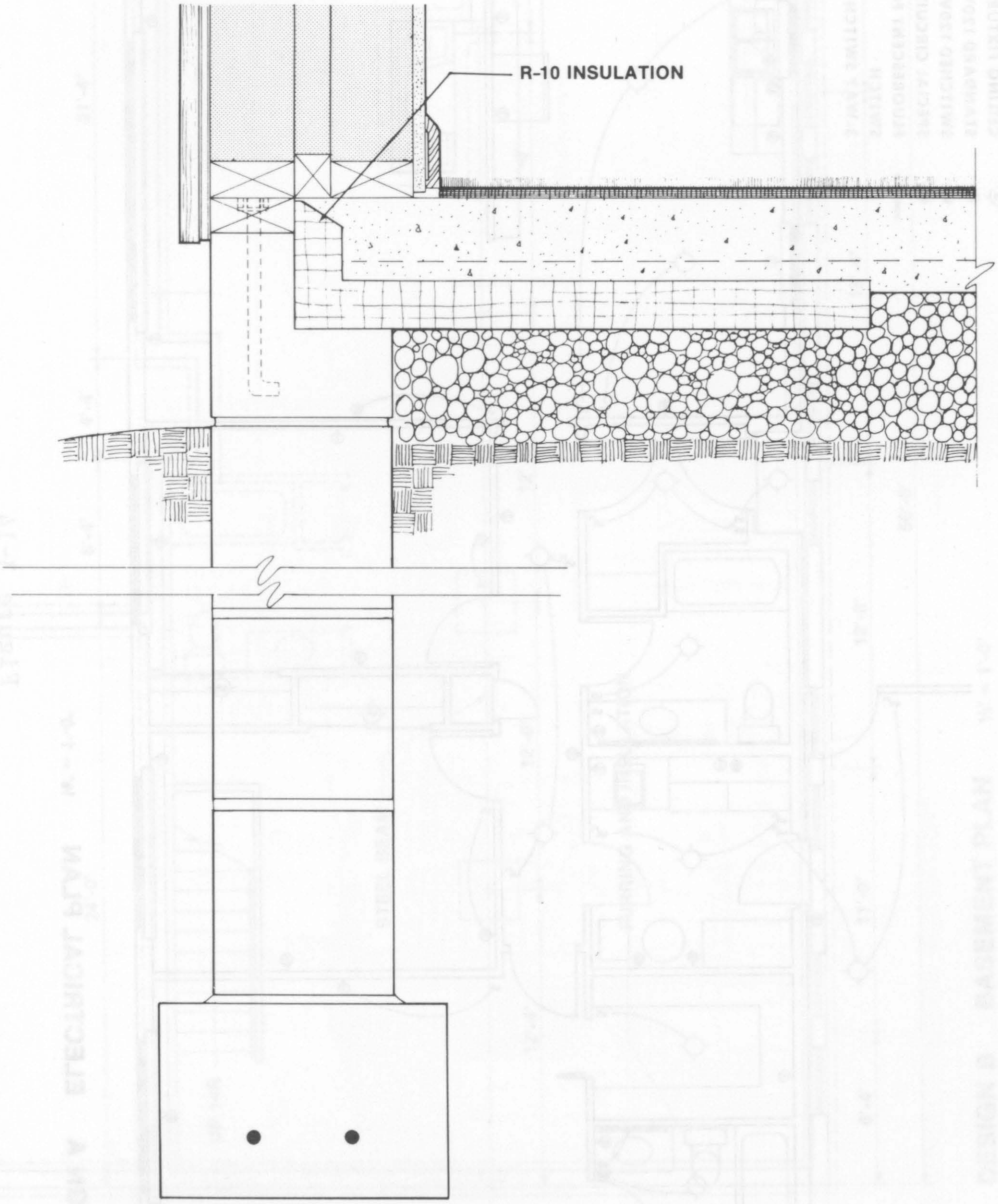


**TYPICAL JAMB SECTION** 1½" = 1'-0"



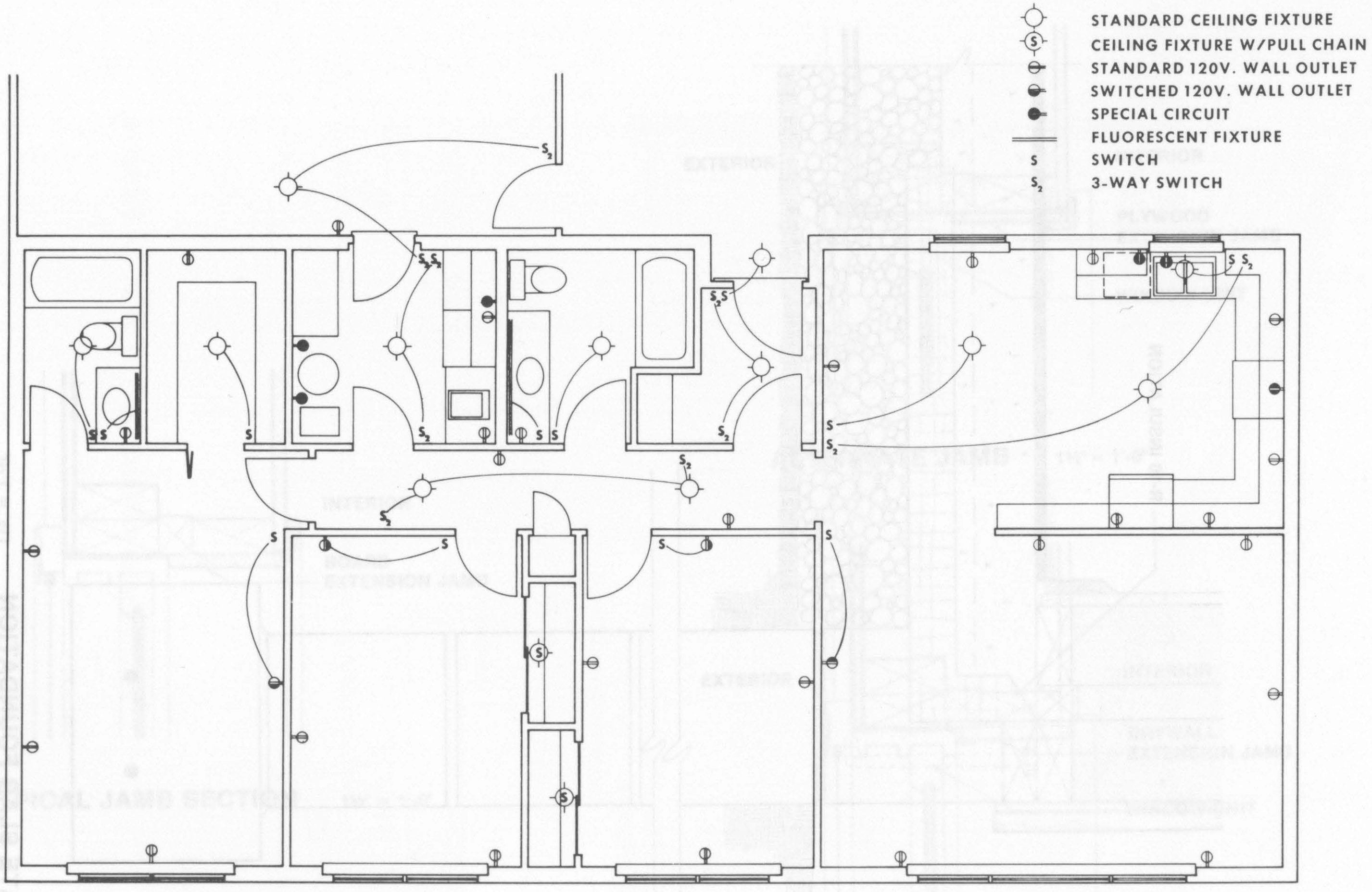
**ALTERNATE JAMB** 1½" = 1'-0"

Figure 3-12



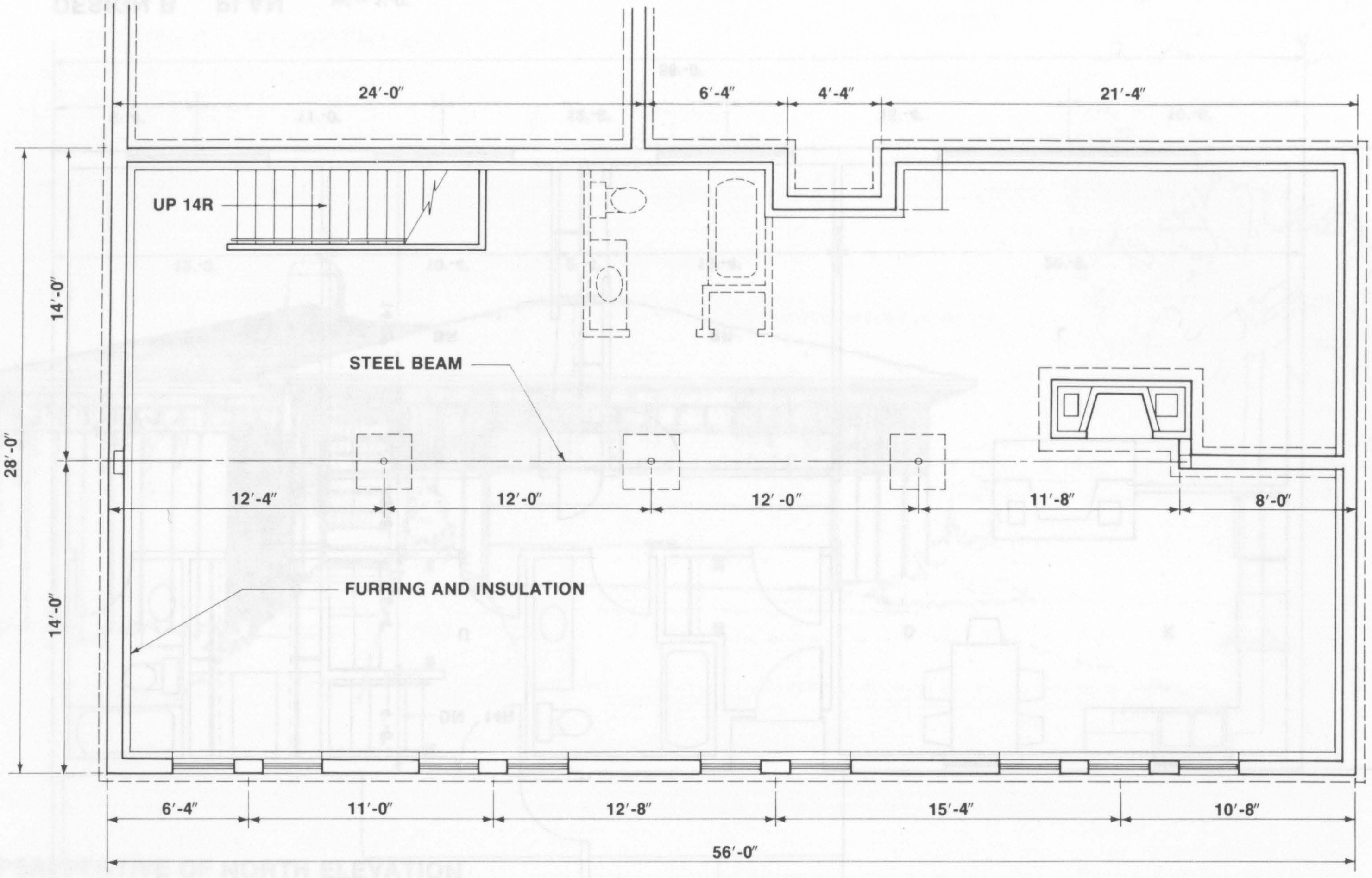
**ALTERNATE SLAB FOUNDATION** 1½" = 1'-0"

Figure 3-13



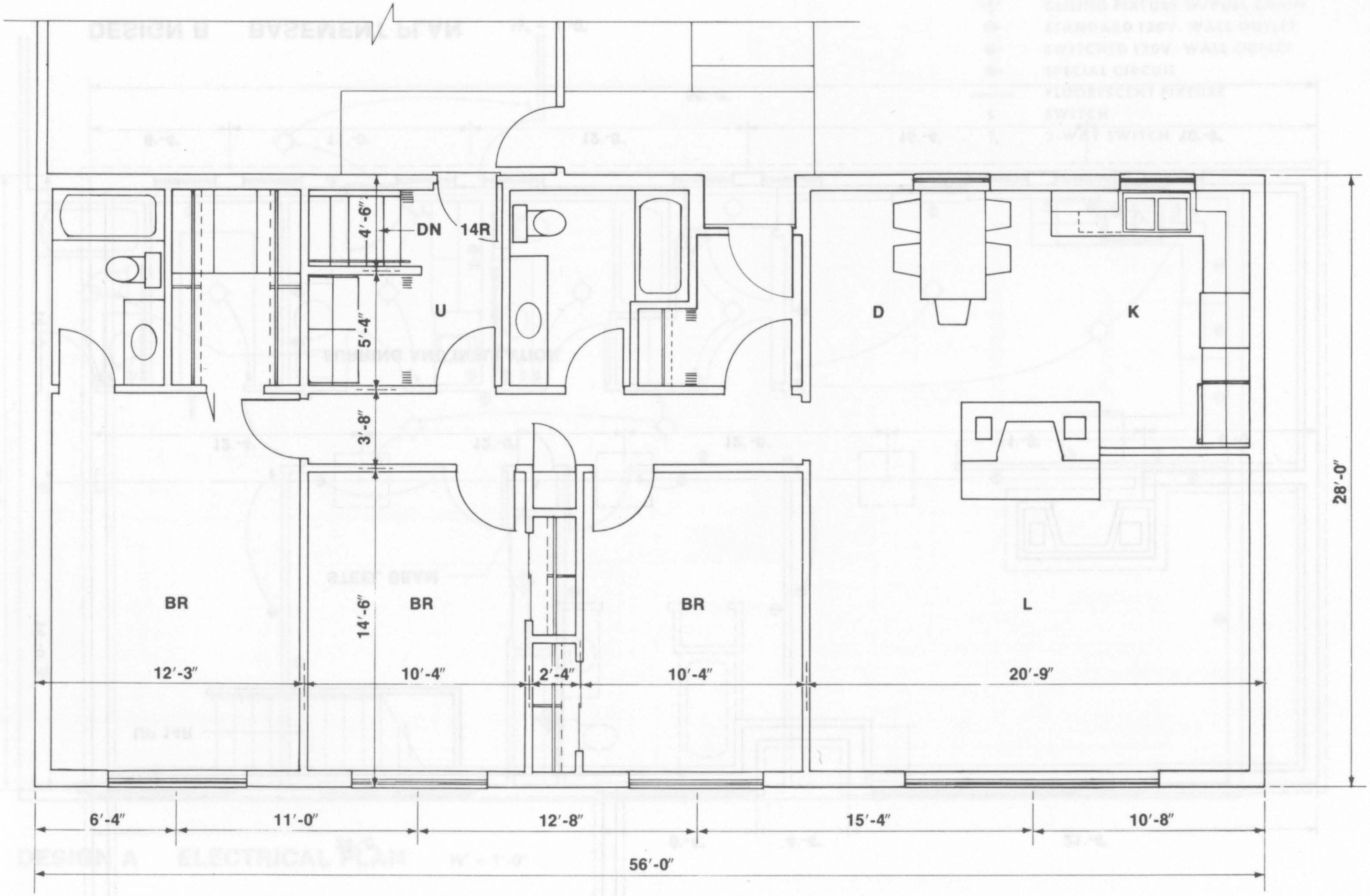
**DESIGN A ELECTRICAL PLAN** 1/8" = 1'-0"

Figure 3-14



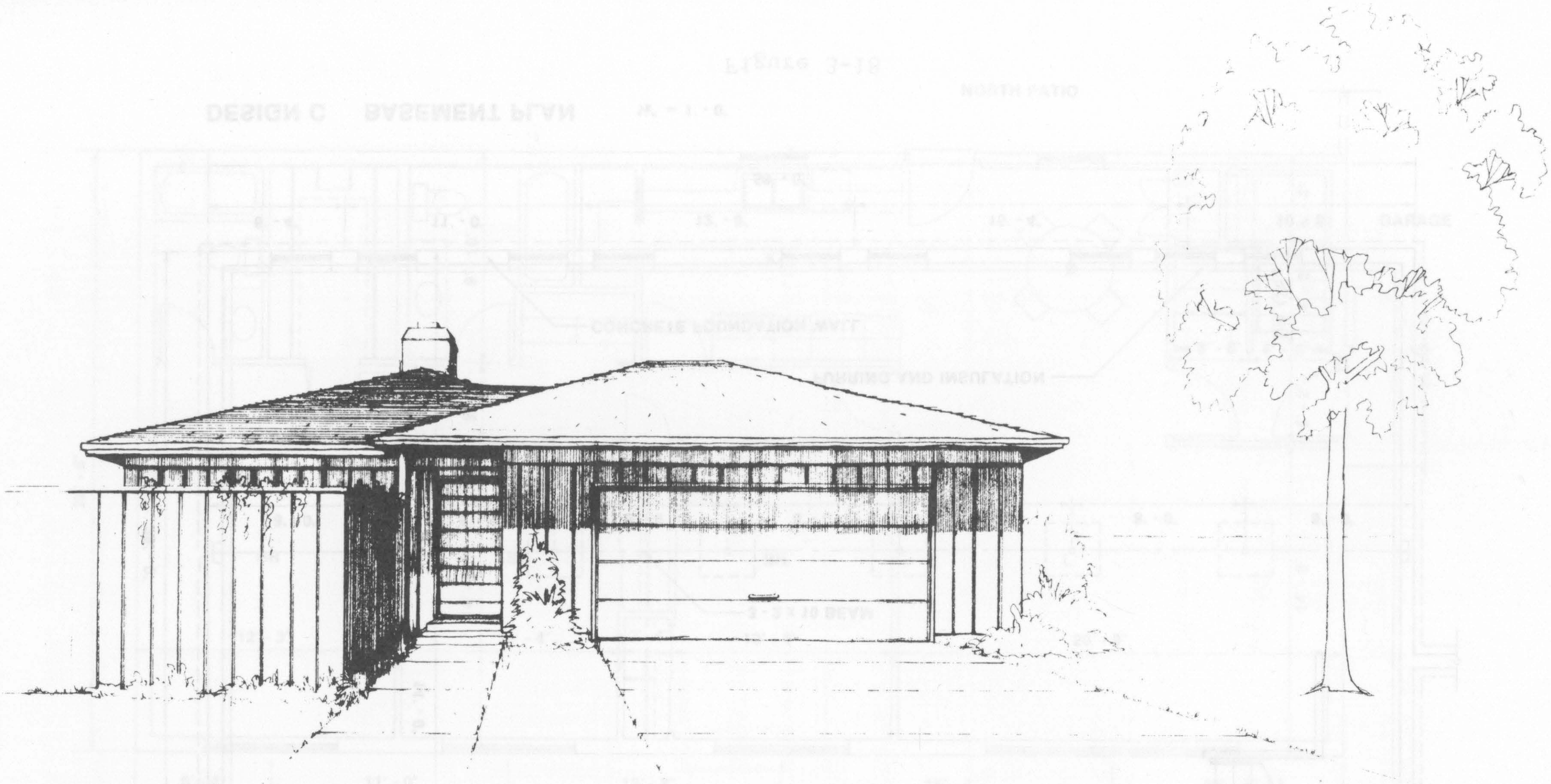
**DESIGN B BASEMENT PLAN** 1/8″ = 1′-0″

Figure 3-15



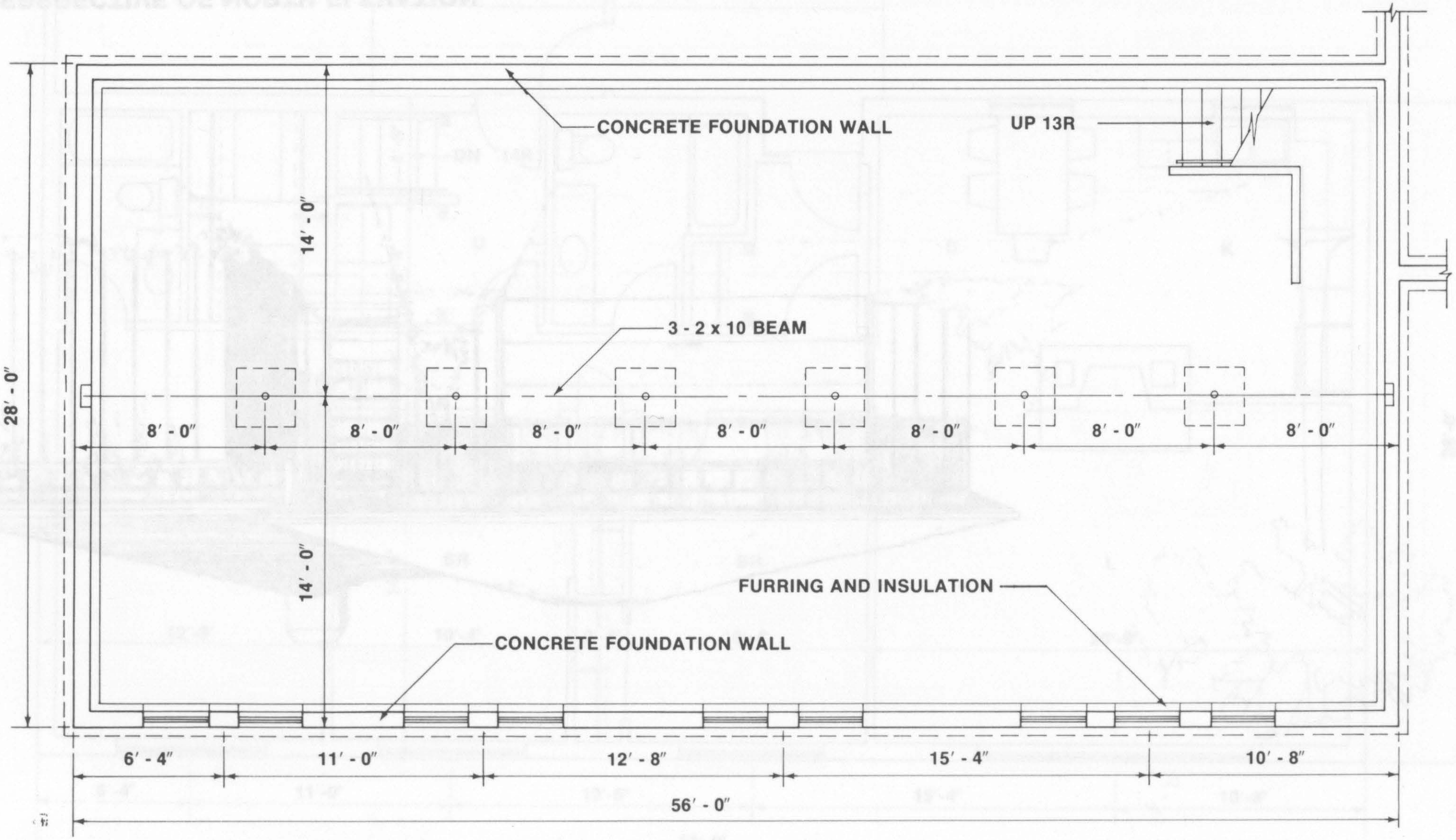
**DESIGN B PLAN** 1/8" = 1'-0"

Figure 3-16



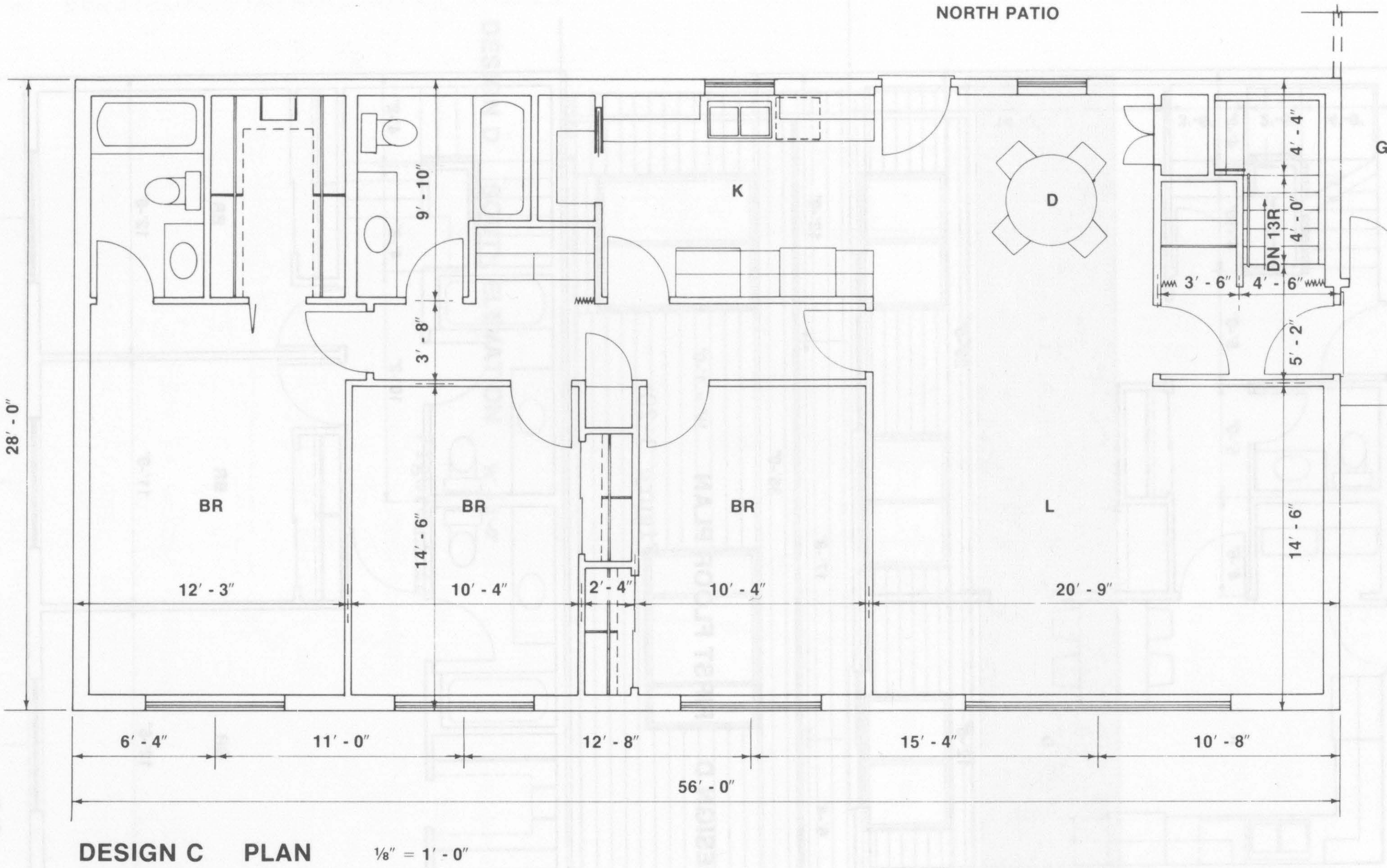
**DESIGN B PERSPECTIVE OF NORTH ELEVATION**

Figure 3-17



**DESIGN C BASEMENT PLAN** 1/8" = 1' - 0"

Figure 3-18


NORTH PATIO
GARAGE
K
D
DN 13R
BR
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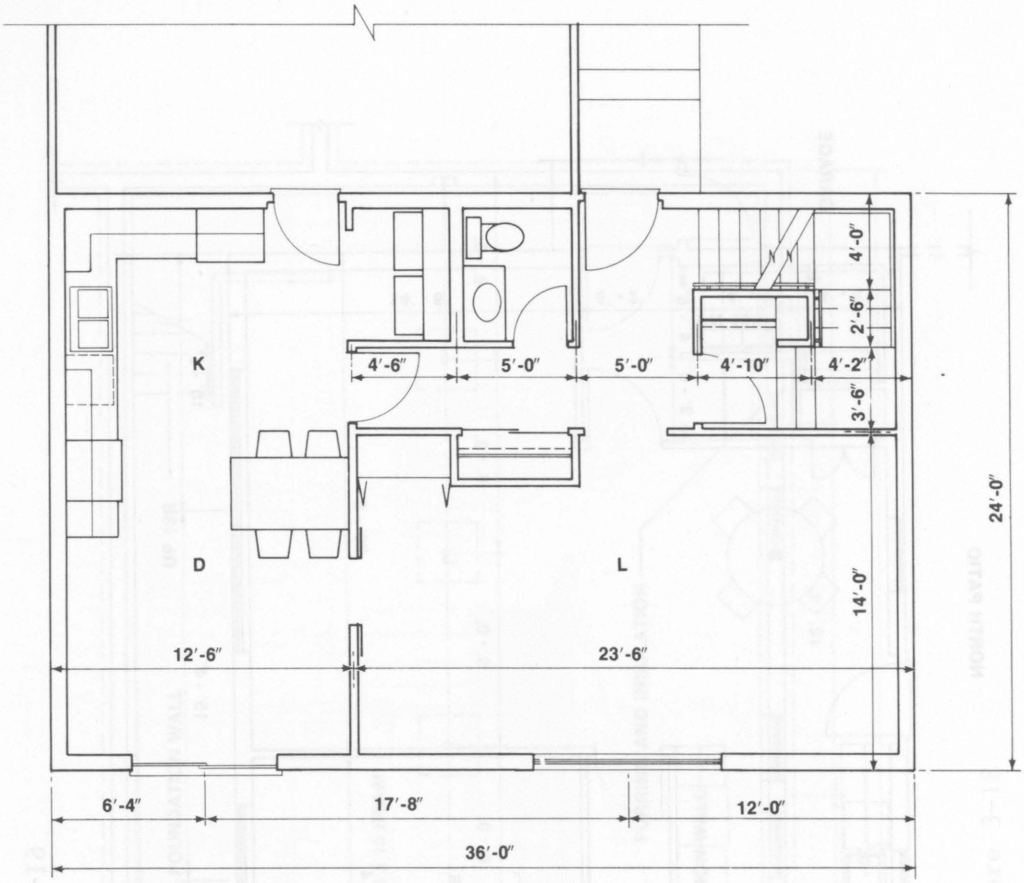
BR
L
28' - 0"
9' - 10"
3' - 8"
14' - 6"
4' - 4"
4' - 0"
4' - 0"
3' - 6"
4' - 6"
5' - 2"
14' - 6"
12' - 3"
10' - 4"
2' - 4"
10' - 4"
20' - 9"
6' - 4"
11' - 0"
12' - 8"
15' - 4"
10' - 8"
56' - 0"
DESIGN C PLAN
1/8" = 1' - 0"

Figure 3-19

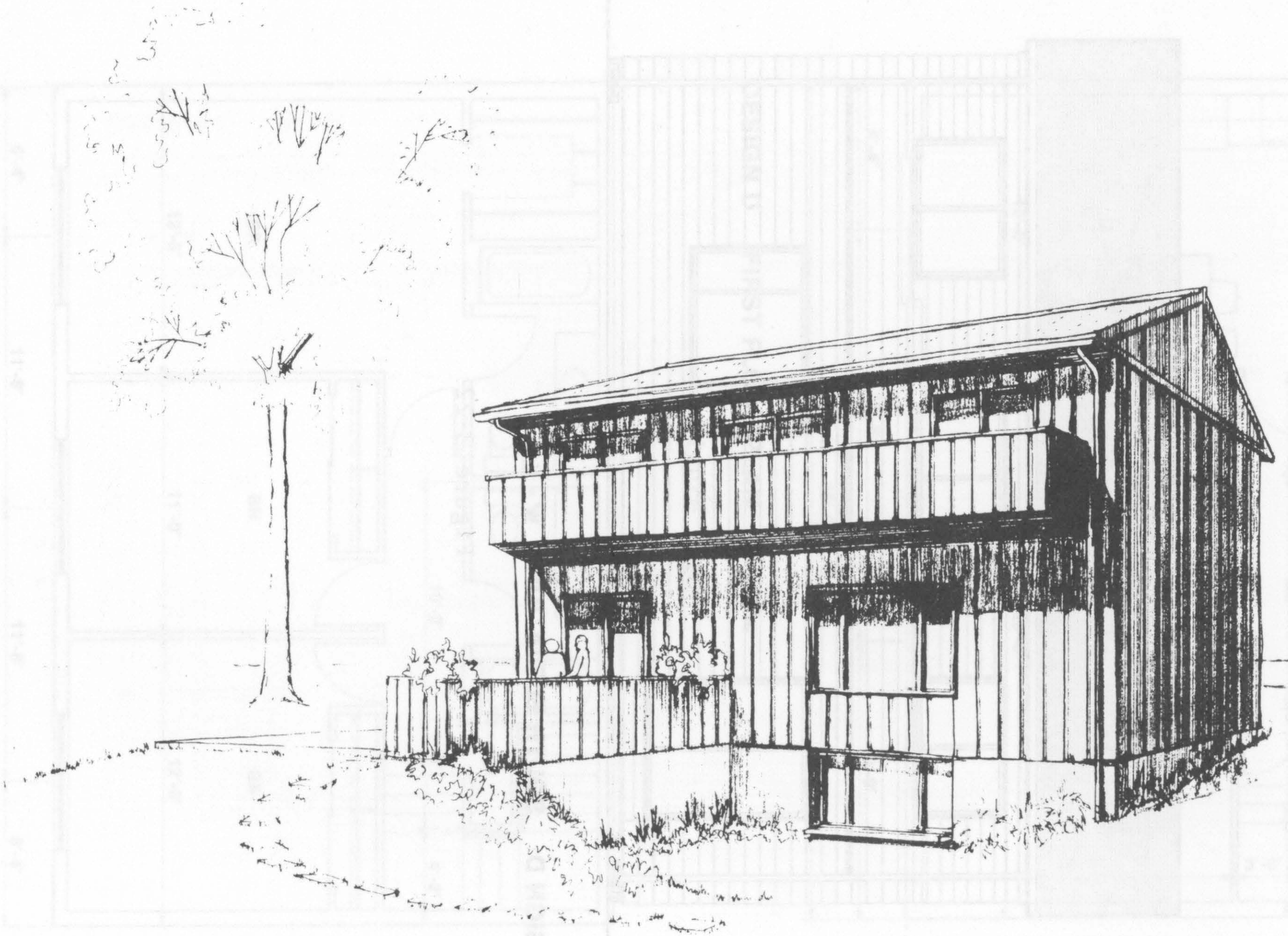


**DESIGN D FIRST FLOOR PLAN** 1/8" = 1'-0"

Figure 3-20

**DESIGN D SOUTH ELEVATION** 1/8" = 1'-0"

Figure 3-22



**DESIGN D PERSPECTIVE OF SOUTHEAST CORNER**

Figure 3-23

# CHAPTER IV. SPECIAL WINDOW STUDIES

Earlier solar houses were designed with the general concept that south windows were good. Some designers reasoned that since south windows were good, the south wall should be as large as possible and be almost entirely glass. The amount of south window area and the type of glazing (whether single, double, or triple glass) and their effects on south window solar gain, heat loss, and surface temperature were not carefully evaluated. These south window effects were not well coordinated with the heat loss rate, insulation levels, and internal heat gains of the house. The influence of the roof overhang in controlling the solar gain during the warmer months was not carefully evaluated.

As a first step in the design of the Lo-Cal House, a study was made to measure the net effect of solar heat gain and conductive heat loss of windows. Data used were for Champaign, Illinois (40 degree latitude) and for Bismark, North Dakota (48 degree latitude), using average temperatures and amount of sunlight per day. After calculating the net heating effect of windows, the windows and roof overhang could be rationally designed for a super-insulated house.

Figure 4-1 shows solar heat gains for different orientations of a single-glazed window. The values shown are maximum gains (obtained from ASHRAE FUNDAMENTALS, 1972) for a clear day at 40 degrees north latitude. The vertical scale shows the Btu transmitted through one square foot of single glass during the day, and includes 20% solar reflectance from the ground. These values are slightly smaller than the solar energy actually impinging on the window because of the reflectance and absorption of the glass. The graph has been drawn so that the heating season is in the center of the diagram. (All values for monthly divisions indicate the 21st day of each month.)

a. The south facing window is unique because the solar gain during the cold months is relatively uniform and averages about 1550 Btu/square foot/day. During the warm months, the south window shows considerably lower gains.

b. The South East facing window is exposed to solar gain primarily before noon while the South West facing window is primarily exposed after noon. The total amount, however, is the same and is relatively high (over 1000 Btu/square foot/day the year around.

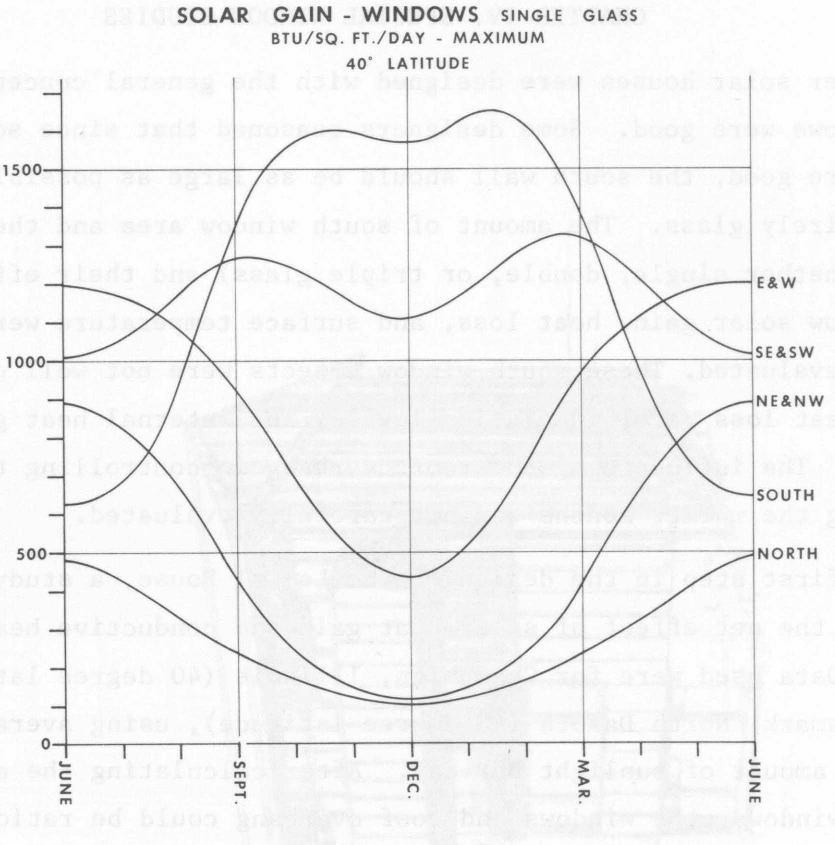


Figure 4-1

c. The North facing windows show small solar gain during the cold months and slightly higher values during the warm months, as a result of the sun shining on the north wall during early morning and late evening hours.

d. During the warm months the North East and North West facing windows show somewhat larger solar gains than the North windows.

e. The East- and West-facing windows show gains which are opposite of those for South facing windows--the solar gain is high during the warm months and low during the cold months.

Since the desirable solar characteristics are high heat gain in the winter from the standpoint of solar orientation and useful solar gain, and low heat gain in the summer, South-facing windows are the best. East- and West-facing windows show the poorest characteristics.

The following figures refer to south-facing windows only. In Figure 4-2, slight reductions in solar gain transmitted through the windows are shown for double and triple glazing, fully exposed to sunlight. The shading coefficient is defined as the ratio of solar gain transmitted through a particular glazing to that transmitted by a single piece of

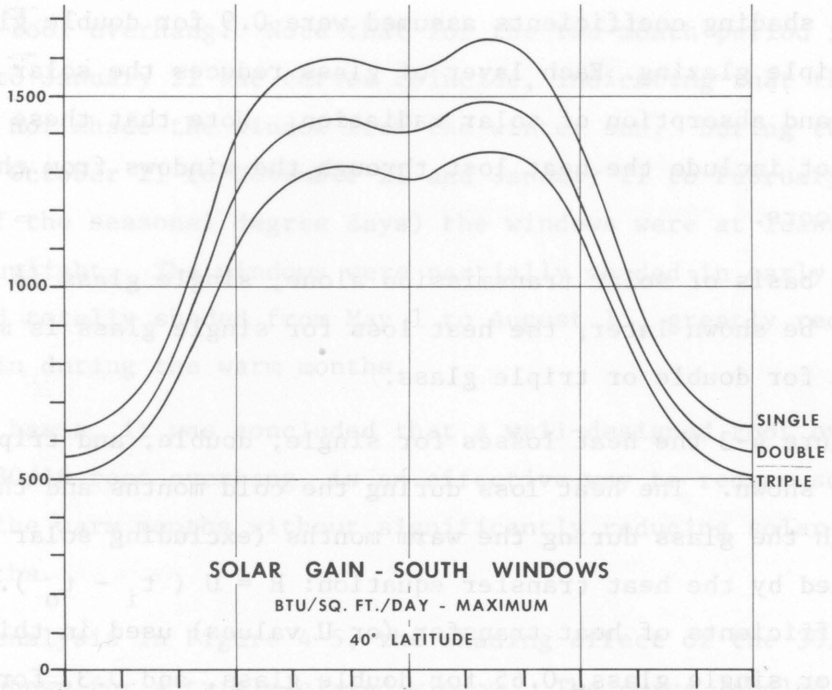


Figure 4-2

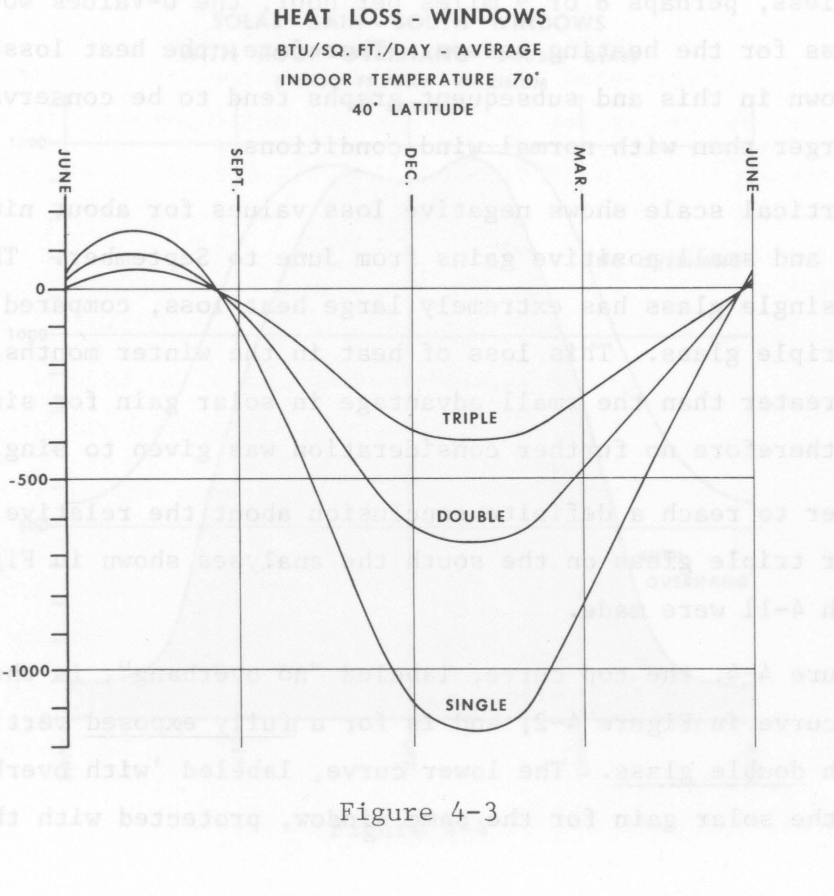


Figure 4-3

glass. The shading coefficients assumed were 0.9 for double glazing and 0.82 for triple glazing. Each layer of glass reduces the solar gain by reflection and absorption of solar radiation. Note that these heat gain values do not include the heat lost through the windows from the house to the outdoors.

On the basis of solar transmission alone, single glass is the best, but as will be shown later, the heat loss for single glass is much larger than for double or triple glass.

In Figure 4-3 the heat losses for single, double, and triple glazing are shown. The heat loss during the cold months and the heat gain through the glass during the warm months (excluding solar gain) can be determined by the heat transfer equation: $H = U ( t_i - t_o )$. The overall coefficients of heat transfer (or U values) used in this equation were 1.15 for single glass, 0.65 for double glass, and 0.37 for triple glass. The indoor temperature ($t_i$) was 70F, and the average outdoor air temperature ($t_o$) was for Champaign, Illinois.

The U-values used were for 15 miles per hour wind, commonly used for design heat loss calculations. However, since average wind velocity is usually less, perhaps 8 or 9 miles per hour, the U-Values would be somewhat less for the heating season. Therefore, the heat losses of windows, shown in this and subsequent graphs tend to be conservative; that is, larger than with normal wind conditions.

The vertical scale shows negative loss values for about nine months of the year and small positive gains from June to September. The graph shows that single glass has extremely large heat loss, compared with double or triple glass. This loss of heat in the winter months proved to be far greater than the small advantage in solar gain for single glass, and therefore no further consideration was given to single glass.

In order to reach a definite conclusion about the relative merits of double or triple glass on the south the analyses shown in Figures. 4-4 through 4-11 were made.

In Figure 4-4, the top curve, labeled "no overhang", is the same as the middle curve in Figure 4-2, and is for a <u>fully exposed</u> vertical window, with <u>double glass</u>. The lower curve, labeled 'with overhang", represents the solar gain for the same window, protected with the recommended 30/16 roof overhang. Note that for the two-month period from November 21 to January 21 the curves coincide, indicating that the roof overhang did not shade the window from the winter sun. During the periods from October 21 to November 21 and January 21 to February 21 (about 70% of the seasonal degree days) the windows were at least 85% exposed to sunlight. The windows were partially shaded in early spring and fall, and totally shaded from May 1 to August 15, greatly reducing the solar gain during the warm months.

On this basis, it was concluded that a well-designed roof overhang, such as the 30/16 roof overhang, is an effective way to reduce solar gain during the warm months without significantly reducing solar gain in the cold months.

In the analysis in Figure 4-5, the shading effect of the 30/16 roof overhang is shown for a triple-glazed window. The curve labeled "no overhang" is similar to the bottom curve in Figure 4-4 and showed peak values of about 1300 Btu per square foot per day.

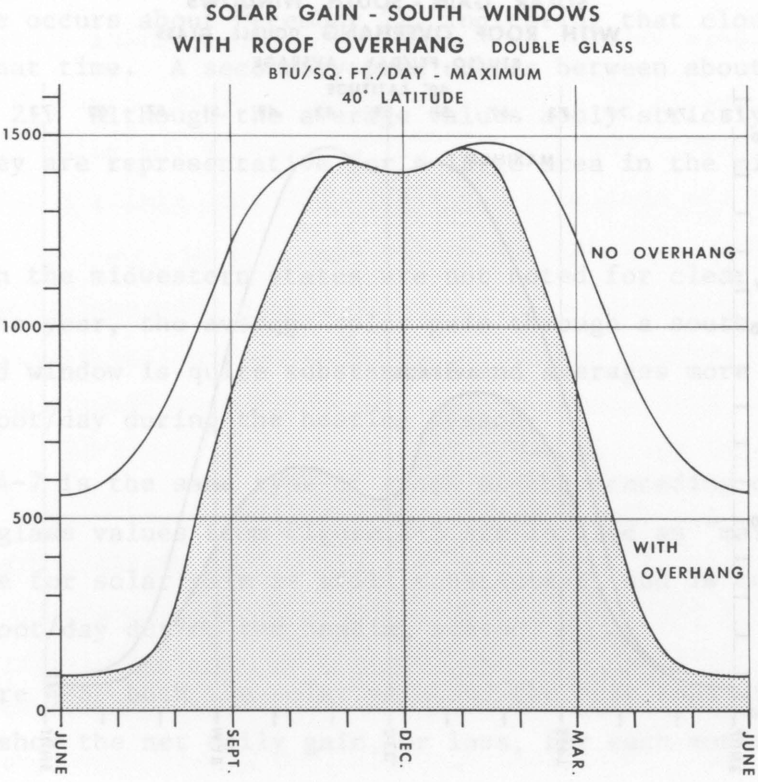


Figure 4-4

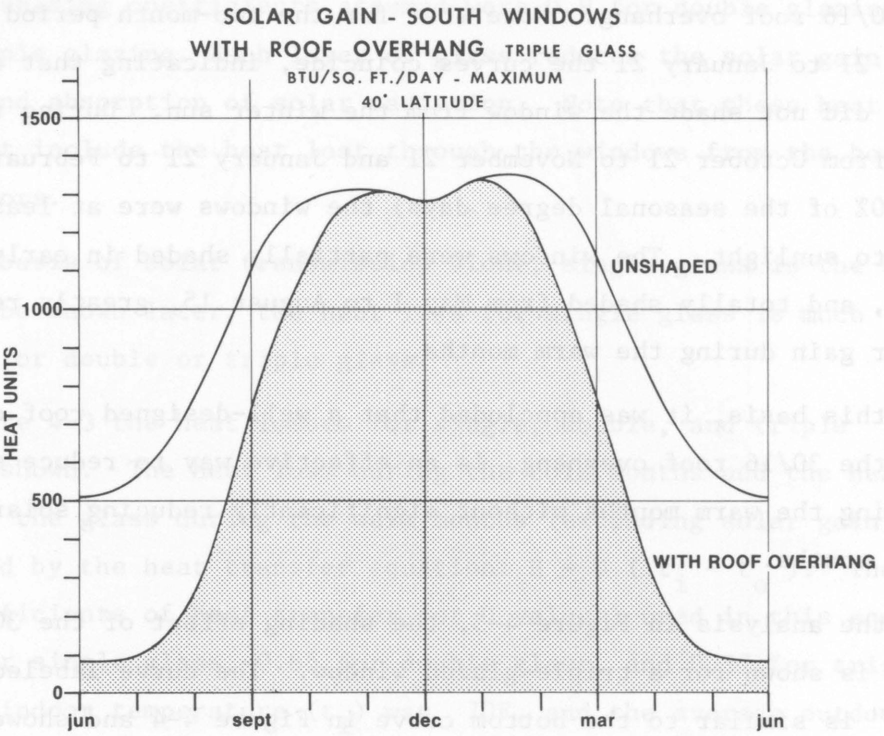


Figure 4-5

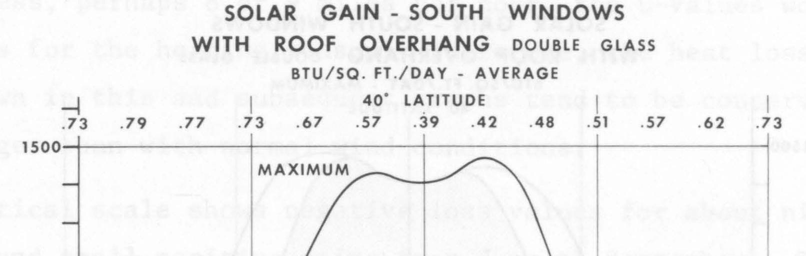


Figure 4-6

Essentially the results were similar to those for the double-glazed window in Figure 4-4, with a reduction in solar gain of about 10%. The data represented by these Figures did not provide a sufficient basis to make a clear-cut decision between double-glazed and triple-glazed windows, since the transmission heat loss from indoors to outdoors had not yet been considered.

Up to this point, the solar gains were maximum values for clear sky conditions throughout the year. Each locality will show varying degrees of cloudiness; the ratios of actual sunshine hours to the maximum hours are shown at the top of Figure 4-6. For example, the ratio of 0.73 for June indicates that the actual sunshine hours, based on weather data accumulated for several years, was 73% of the maximum possible for the locality. Strictly speaking, the ratios shown apply to Urbana-Champaign, Illinois. Similar ratios are available for all major weather stations.

The curve labeled "maximum" is the same as the curve labeled "with overhang" in Figure 4-4, and applies to double-glazed windows. When the values shown by the maximum curve are multiplied by the sunshine ratios, the lower curve is obtained. For example, the peak solar gain in Urbana-Champaign occurs between October 21 and November 21. A dip in the average curve occurs about December 21, indicating that cloudy conditions prevail at that time. A secondary peak occurs between about January 21 and February 21. Although the average values apply strictly to one locality, they are representative for a large area in the midwestern states.

Although the midwestern states are not noted for clear, sunny days throughout the year, the average solar gain through a south-facing double-glazed window is quite substantial and averages more than 600 Btu/square foot/day during the heating season.

Figure 4-7 is the same type of graph as the preceding one except that triple-glass values from Figure 4-5 are labeled as "maximum". The average value for solar gain is still substantial, and is more than 500 Btu/square foot/day during the heating season.

In Figure 4-8, both the solar gain and the heat loss effects are combined to show the net daily gain, or loss, for each month of the year.

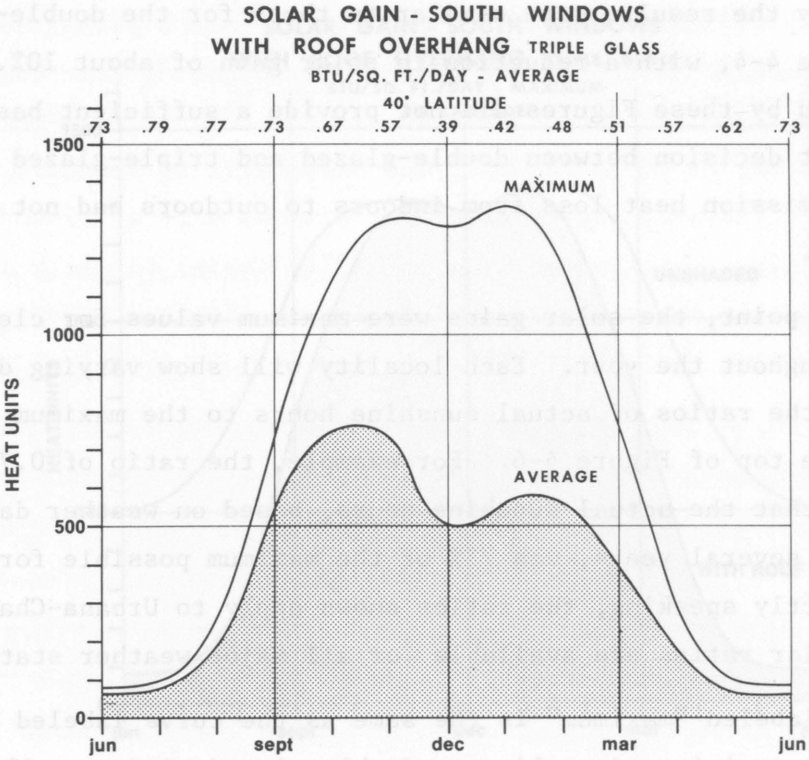


Figure 4-7

The top curve, labeled "solar gain", is the same as the "average" curve shown in Figure 4-6 for double-glazed windows facing south.

The "net" curve is an arithmetical average of the curves for "solar gain" and "heat loss". For example, on December 21 the solar gain was about 555 Btu and the heat loss was about -630 Btu, giving a net loss of about -75 Btu/square foot/day (of 24 hours).

The double-glazed south-facing window showed substantial net gains from about August through November, but did show some net losses between December and May. With snow cover on the ground to reflect sunlight, the solar gain would be somewhat increased.

Figure 4-9 is the same, except that a triple-glazed window is shown. The most striking difference compared to the previous Figure, is the extremely <u>small net loss</u>, and this occurs during the spring months from April 21 to the first of June, when such losses are of little consequence. Otherwise, the solar gain exceeds the heat loss for the entire heating season. Reflected sunlight from ground snow cover would increase the average gain more than 100 Btu/square foot/day.

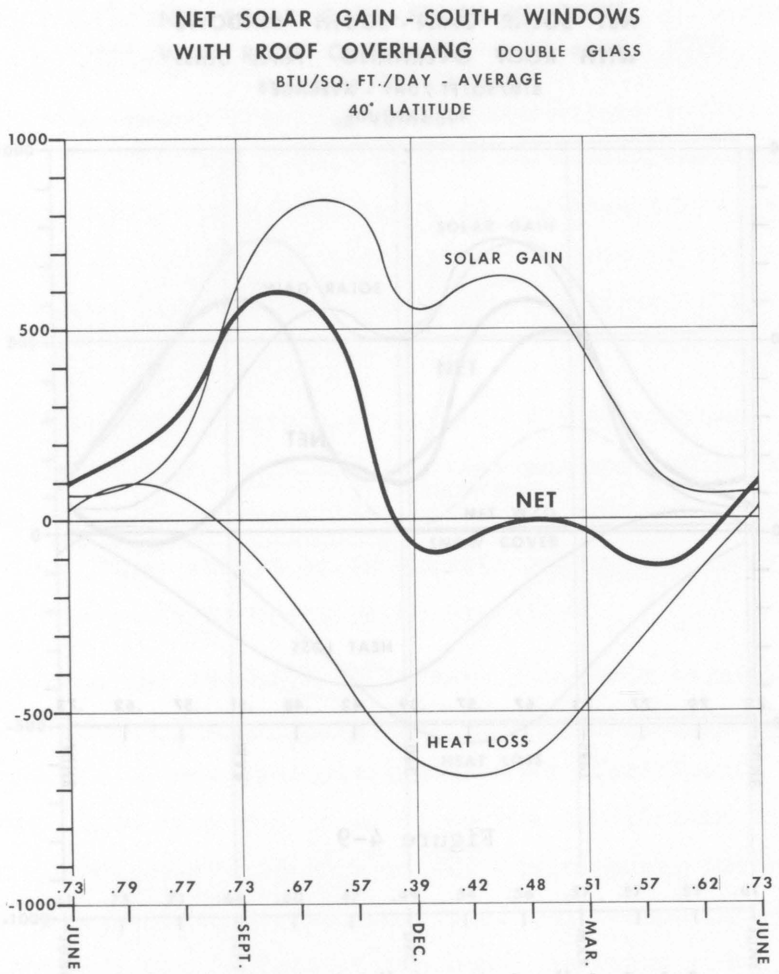


Figure 4-8

Based upon a comparison of Figure 4-8 and 4-9 it was concluded that for the sunshine conditions encountered in Urbana-Champaign the triple-glazed window facing south provided a greater net heat gain than the double-glazed window. Subsequent analyses showed that this benefit of triple glazing is less pronounced for mild climates (less than 4500 degree-days). The merits of double vs. triple glazing in a mild climate are discussed later.

In Figure 4-10, two different conditions were imposed on triple-glazed, south-facing windows:

a. The solar data were for 48 degrees latitude and the weather data for Bismark, North Dakota, close to the Canadian border.

b. The effect of snow cover on the ground is shown for a period of 110 days.

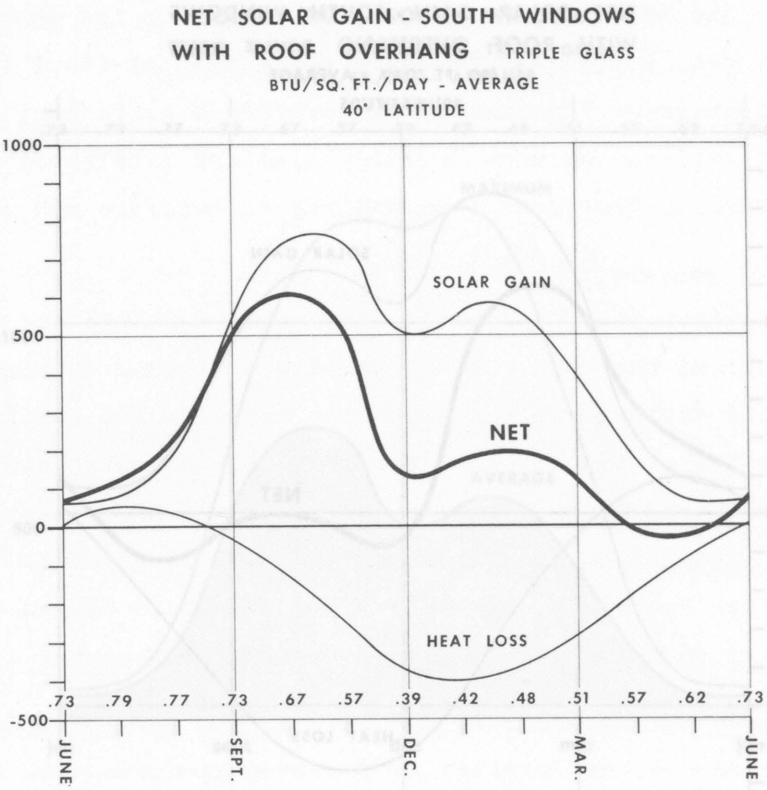


Figure 4-9

The top curve, labeled "solar gain", is without snow cover. Note two distinct peaks of over 750 Btu/square foot/day gain. The ratios of actual sunshine to maximum are listed at the bottom of the graph. Small differences can be noted between the ratios for Urbana-Champaign from May to November, but lower from December to March. That is, Bismark shows slightly more sunshine in the extremely cold months of December through March.

The bottom curve for "heat loss" reaches a value of about -550 Btu, which is greater than the -400 Btu for Champaign. The larger heat loss correlates with the colder weather in Bismark.

Two "net" curves are shown: the solid line shows the net gain with direct solar gain augmented by sunlight reflected from snow cover for a period of 110 days; the broken line shows the net gain with direct solar gain without the reflectance from the snow cover.

Even with large heat losses, the south-facing, triple-glazed windows show a net heat gain for Bismark for every month of the year. The heat

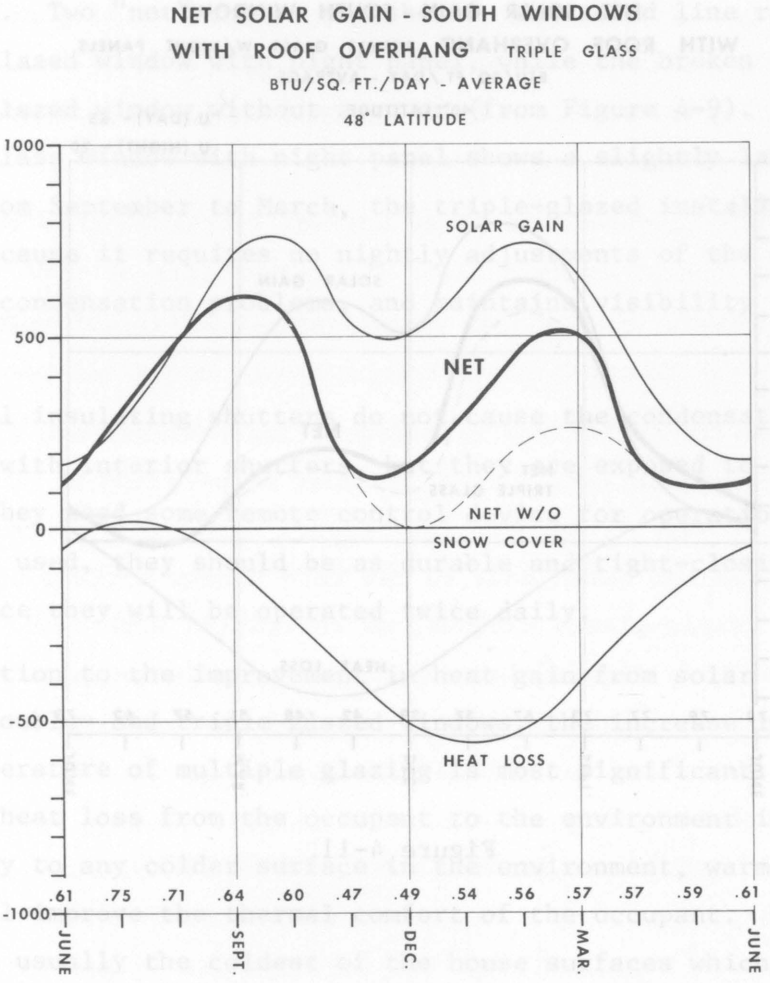


Figure 4-10

gain during August and September could be further reduced by shade trees or reflecting drapery.

A study was made to evaluate the performance of a double-glazed window equipped with an insulating cover which is closed at night compared to the triple-glazed window. The insulating panel was assumed to consist of some lightweight insulating material with an R-value of R-2.5. With this panel covering the double-glazed window (R-1.5), and counting R-1.0 for air space, the total thermal resistance at night was R-5.0. The panel was assumed to cover the window from about 5 p.m. to 7 a.m. Unless an interior insulating cover is absolutely air tight, water vapor in the room air will condense as water or ice over the window surface, which is much cooler because of the insulating cover.

The 24 hour-heat loss (bottom curve) in Figure 4-11 was reduced from about -650 Btu (from Figure 4-8) to about -400 Btu by the addition

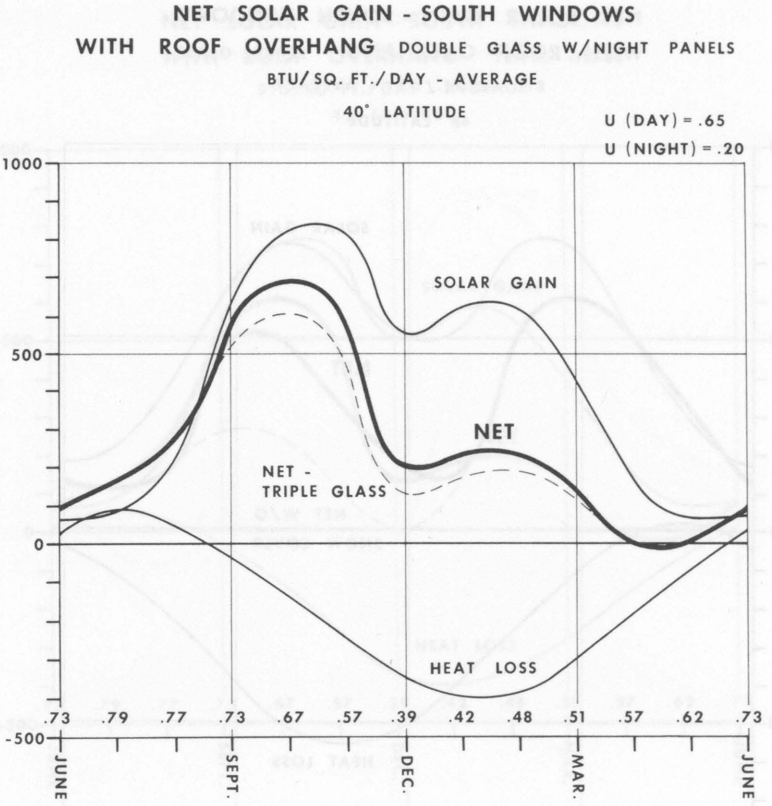


Figure 4-11

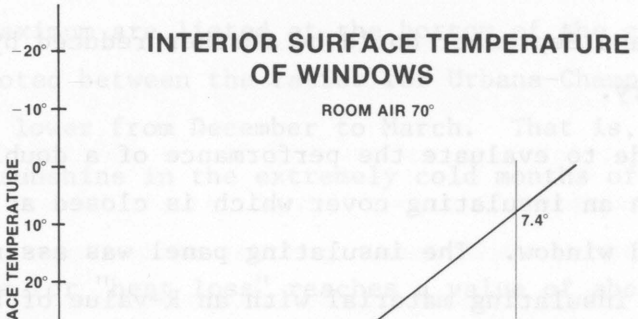


Figure 4-12

of the panel. Two "net" curves are shown: the solid line represents the double-glazed window with night panel, while the broken line shows the triple-glazed window without a cover (from Figure 4-9). Although the double-glass window with night panel shows a slightly larger net heat gain from September to March, the triple-glazed installation is preferred because it requires no nightly adjustments of the opening, presents no condensation problems, and maintains visibility through the window.

External insulating shutters do not cause the condensation problem encountered with interior shutters, but they are exposed to ice, snow, and wind. They need some remote control device for operation. If shutters are used, they should be as durable and tight-closing as prime windows, since they will be operated twice daily.

In addition to the improvement in heat gain from solar effects by the use of double- and triple-glazed windows, the increase in interior surface temperature of multiple glazing is most significant. Since part of the body heat loss from the occupant to the environment is by radiation from the body to any colder surface in the environment, warmer surrounding surfaces will improve the thermal comfort of the occupant. Window surfaces are usually the coldest of the house surfaces which surround the occupant, and they produce a sensation of discomfort, especially when the occupant is near the windows. (Radiation intensity varies inversely as the square of the distance.)

The calculated interior surface temperatures of four different glazings are shown in Figure 4-12 as they vary with the outdoor air temperature. These curves are based on the assumption that the outside air film layer corresponds to that for a 15-mile per hour wind. Note that for an outdoor temperature of -10F and room air temperature of 70F, the surface temperature of a single-glass window facing the occupant is only 7.4F. This is almost 25F colder than the temperature of melting ice and will result in ice on the windows from the condensation of moisture in the room air for any relative humidity in excess of about 10%. The convection currents rushing downwards from the cold surfaces have sufficient velocity and are so much cooler than room air temperature that the cool air flow splashes off the floor and extends far out into the room.

This convection flow occurs both day and night, as long as the window surface is cooler than room air. Thus, the occupant of a room with single-glazing encounters not only a cold radiation surface, but also strong cool drafts at ankle level.

A noticeable improvement in glass surface temperature is obtainable with double glass (34.6F at an outdoor air temperature of -10F). Even in this case, however, the surface temperature is only 2.6F warmer than melting ice, so that downward convection currents are still pronounced.

Optimum benefits in surface temperature improvements are shown with the triple-glazed window (49.3F at an outdoor temperature of -10F). Quadruple glass is only 4F warmer. It becomes apparent that the radiation heat loss from the human body to the cold window surface is greatly diminished with triple-glazed windows, as contrasted with those for single glazed and even double-glazed windows. (Radiation heat transfer occurs as the difference of the fourth powers of the absolute temperatures.

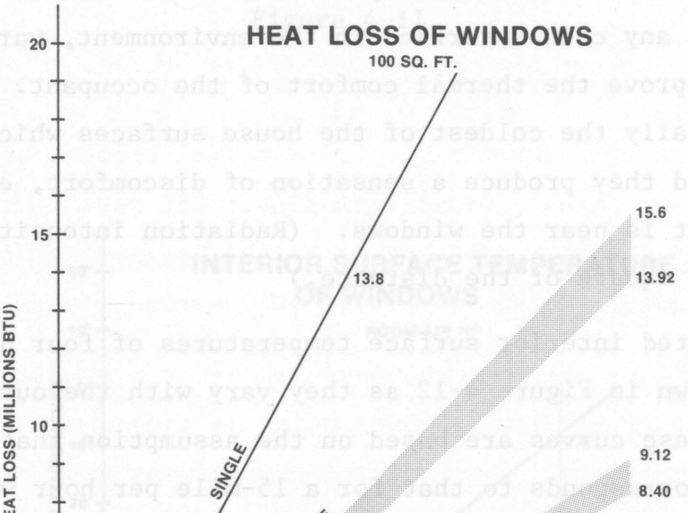


Figure 4-13

In simpler terms, this means that the radiation heat losses increase extremely rapidly, and not linearly, when the temperature difference is increased.) Also, the window surface is warm enough so that moisture from room air will not condense until the relative humidity is about 48% (at -10F outdoors), which is well above the level considered desirable during the winter.

Figure 4-13 shows the seasonal heat loss of 100 square feet of window area for varying seasonal degree days. The actual heat loss for the windows of a particular house can be obtained by multiplying the heat loss values shown by the square feet of window area, divided by 100. As mentioned earlier, the U-values used in the derivation of the curves are for 15 miles per hour wind, not average wind. The values shown are conservative and on the high side.

The main purpose in presenting the four distinct window types is to show the extremely large heat loss of single-glazed windows and the diminishing returns as successive layers of glass are added. The shaded areas for double, triple, and quadruple glazed windows show the variations introduced by the air space between the layers of glass. In general, air spaces of 1/4 inch between panes are represented by heat losses near the top of the shaded area, and larger air spaces are near the bottom of the shaded area.

Triple-glazed windows show considerable improvement over the double-glazed window. However, the improvement resulting from the quadruple-glazed windows is considerably smaller, and in many cases may not prove cost-effective. It is also apparent that the actual differences in heat loss are increased in cold-climate conditions. Triple- and quadruple-glazing may not be cost-effective in mild climates, but their benefits are most apparent in extremely cold climates.

Figures 4-15 through 4-20 show six sets of comparative studies of single- and multiple-glazed windows that indicate when a multi-glazed window is more advantageous than a window with lesser glazing. Each Figure contains four pairs of curves, one each for climates providing 600, 800, 1000, and 1200 Btu/square foot/day solar heat gain through single glass. The interior house temperature is assumed to be 70F, regardless of comfort conditions with the various multi-glazings.

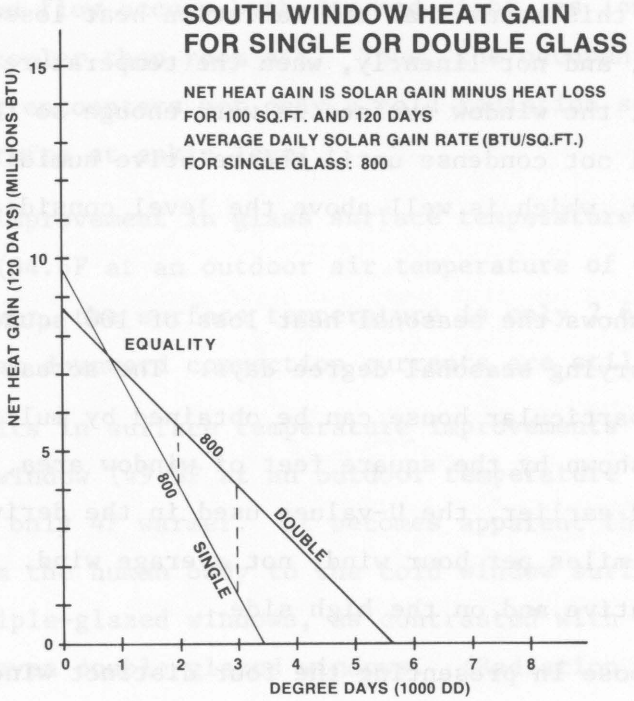


Figure 4-14

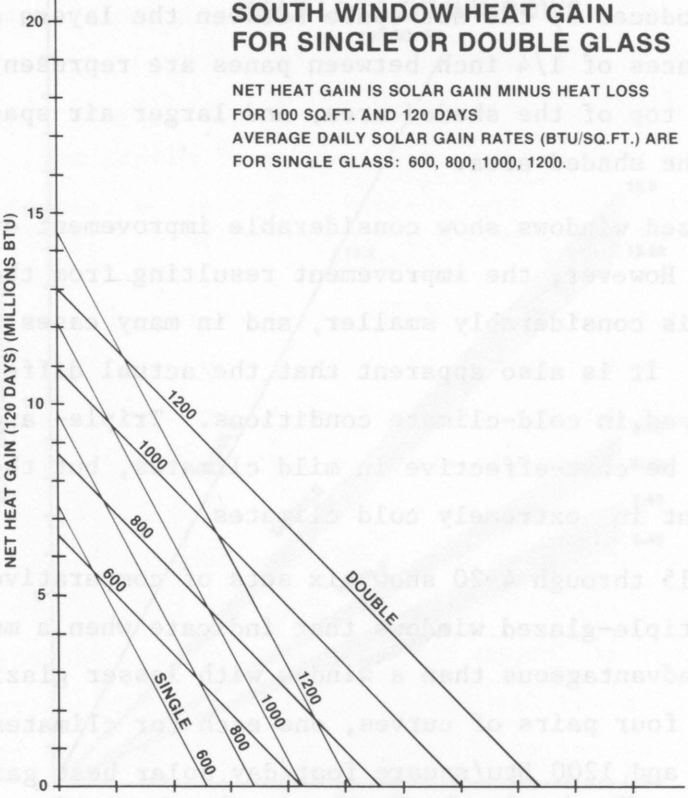


Figure 4-15

Figures 4-15, 4-16, and 4-17 are suitable for locations with a shorter heating season (120 days), whereas Figures 4-18, 4-19, and 4-20 are for longer heating seasons (180 days).

In order to explain the trends shown by the curves, Figure 4-14 is a simplified version of one situation with each factor described in detail:

Degree-days show a range from 0 to 10,000. For Figures 4-15, 4-16, and 4-17 (shorter heating season) the values from 0 to about 4000 degree-days are most applicable.

Net Heat Gain is the solar gain minus the conduction heat loss from indoors to outdoors during the heating season of about 120 days.

Single refers to the net heat gain for single glazing. Note that the net heat gain approaches zero for colder weather.

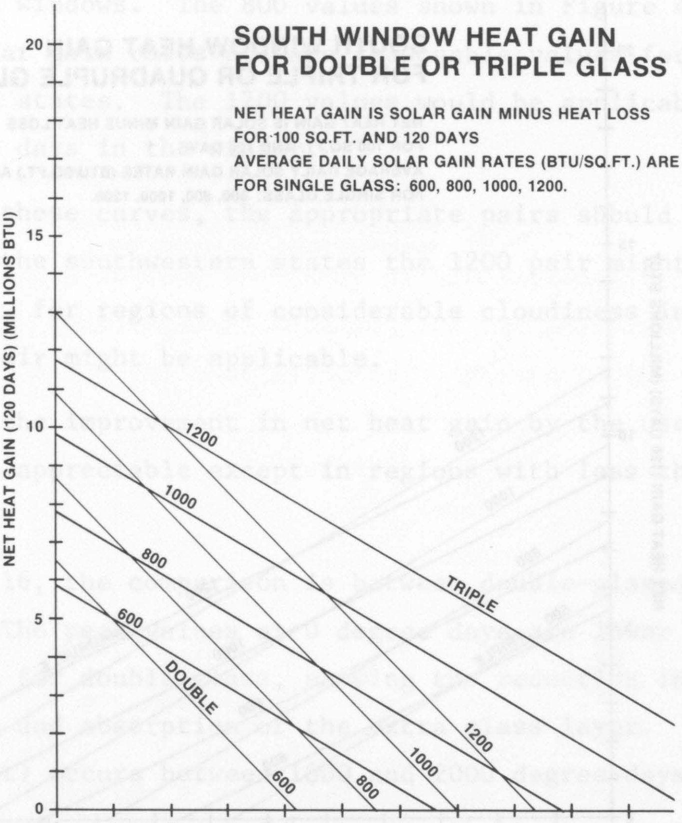


Figure 4-16

Double is the net heat gain for double-glazing. The slope is less steep, indicating that the zero heat gain occurs during colder weather.

800 refers to the climate where the average daily solar gain for a single-glazed window is 800 Btu/square foot/day. For example, with a solar gain of 800 Btu for single glass, double glass would have a solar gain of 720 Btu/square foot/day, (0.9 x 800), where 0.9 is the shading coefficient for double glass.

Daily solar gain values of 600 are applicable to regions of considerable cloudiness, 800 for average cloudiness, 1000 for light cloudiness, and 1200 for regions with little cloudiness.

Equality is attained when the curves for net heat gain rates cross. For example, the crossing point in this example occurs at about 1000 degree-days. This would indicate that for a very mild climate the single-window would be as effective as a double-glazed window for a south-facing window.

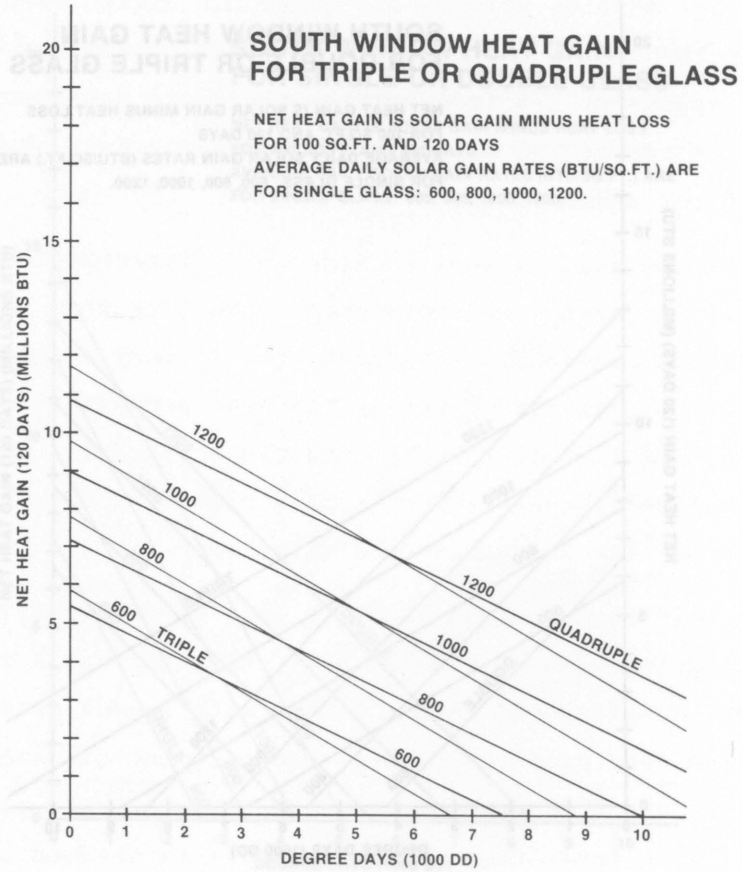


Figure 4-17

Improvement is shown for a region with 2000 degree-days, amounting to about 1.5 million Btu per season. That is, the double-window shows more net heat gain than the single window. An improvement of about 3 million Btu per season is shown for a region having 3000 degree-days. The double-window is considerably more cost effective in a colder climate than a single window.

In Figures 4-14 to 4-20, the shading coefficients and U-values used were:

| Glazing | Shading Coefficient | U-Value |
|---|---|---|
| Single | 1.0 | 1.18 |
| Double | 0.9 | 0.65 |
| Triple | 0.82 | 0.37 |
| Quadruple | 0.75 | 0.30 |

In Figure 4-15, families of curves are shown for both single-glazed and double-glazed windows. The 800 values shown in Figure 4-15 represent average daily solar gain rates and are reasonable values for large areas of the midwestern states. The 1200 values would be applicable to regions of many cloudless days in the winter.

In applying these curves, the appropriate pairs should be chosen. For example, for the southwestern states the 1200 pair might be selected. On the other hand, for regions of considerable cloudiness in the winter months, the 600 pair might be applicable.

In general, the improvement in net heat gain by the use of double-glazed windows is appreciable except in regions with less than about 2000 degree-days.

In Figure 4-16, the comparison is between double-glazed and triple-glazed windows. The peak values at 0 degree days are lower for the triple glass than for double glass, showing the reduction in solar gain by the reflection and absorption of the extra glass layer. The equality (or crossing point) occurs between 1000 and 2000 degree-days.

For any given pair of daily solar gain rates (such as 800), the advantage of using triple glazing instead of double glazing does not become noticeable until the degree-days are in excess of about 3500 DD.

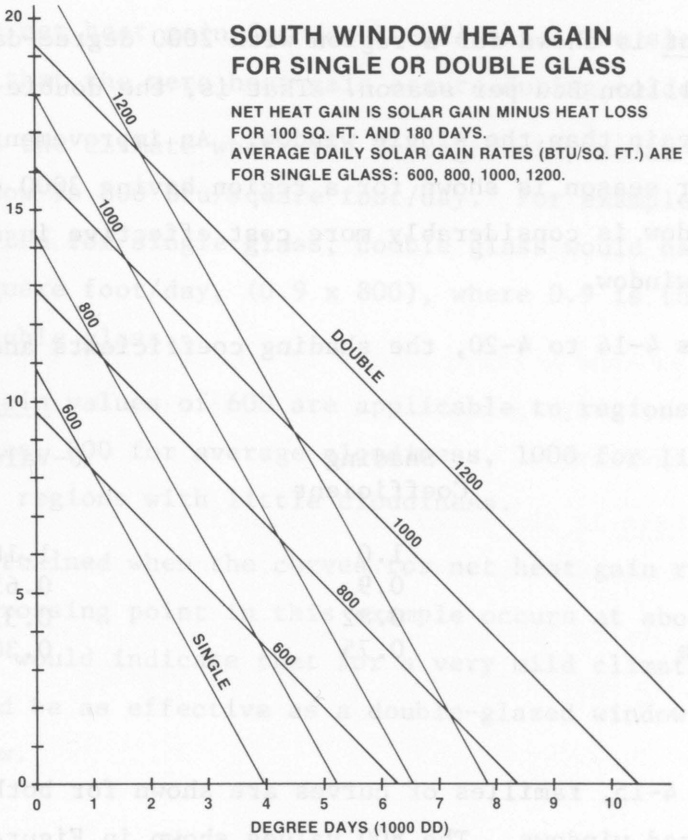


Figure 4-18

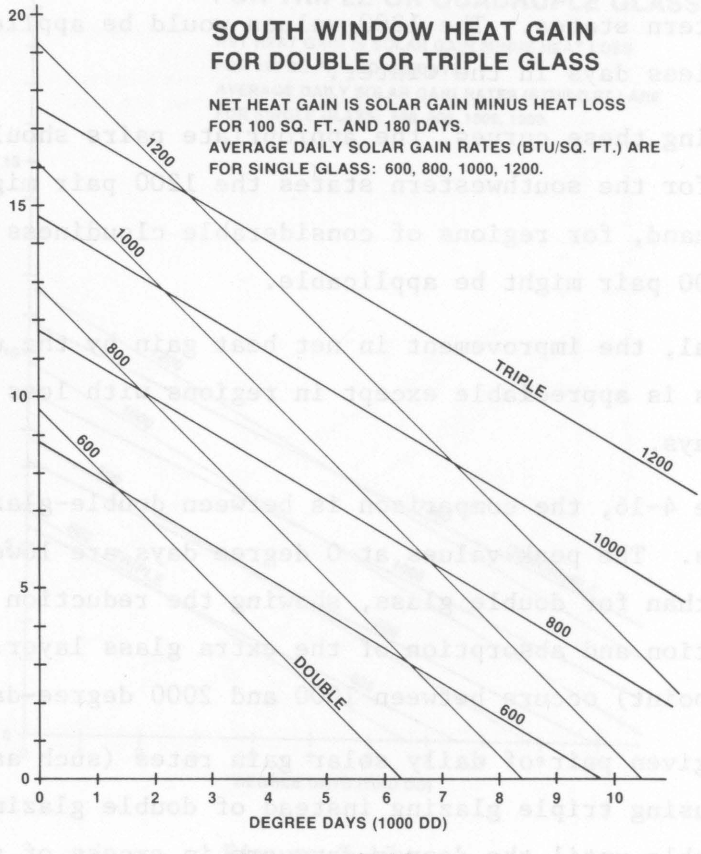


Figure 4-19

In mild climate areas the use of triple-glazed south windows may not prove cost effective.

Figure 4-17 makes the comparison between triple-glazed and quadruple-glazed windows. The performance of the two window types is nearly equal. The equality (crossing point) extends further to the right for each pair of curves, indicating that for mild climates the quadruple-glazed windows may provide slightly less net heat gain than do triple-glazed windows. It can be concluded that quadruple-glazed windows are suitable for south-facing windows only in the extremely cold regions with a heating season much longer than 120 days.

Figures 4-18, 4-19, and 4-20 are extensions of Figures 4-15, 4-16, and 4-17. The only difference is that the heating season is 180 days instead of 120, so that the data are more applicable to those regions having heating seasons of 5000 degree-days or more. The trends shown are similar to those for the milder climates.

In general, the following conclusions can be drawn:

Double-glazed windows show a much greater net heat gain than do single-glazed windows. (Figure 4-18).

Triple-glazed windows show greater net heat gains than do double-glazed windows. (Figure 4-19).

Quadruple-glazed windows show very little increase in net heat gain when compared with triple-glazed windows, and the performance of the two windows is nearly equal for most climates. (Figure 4-20).

The data in Figure 4-19 can be used to compare window performance with the computer analyses for the Lo-Cal House, using double- or triple-glazing of the south windows in climates of about 7500 degree-days (Madison), and about 5000 degree-days (Indianapolis). According to Figure 4-19, the net heat gain of triple glazing for the 7500 degree-day climate is about 4.0 million Btu/year more than for double glazing of 122 square feet of south-facing windows, while in the computer analyses A and E, the advantage was 3.8 million Btu/year. For 5000 degree-days, the Figure shows an advantage for triple-glazing of 2.5 million Btu/year, while in computer analyses M and R, the advantage was 2.9 million Btu/year. The agreement between the analyses was considered to be good.

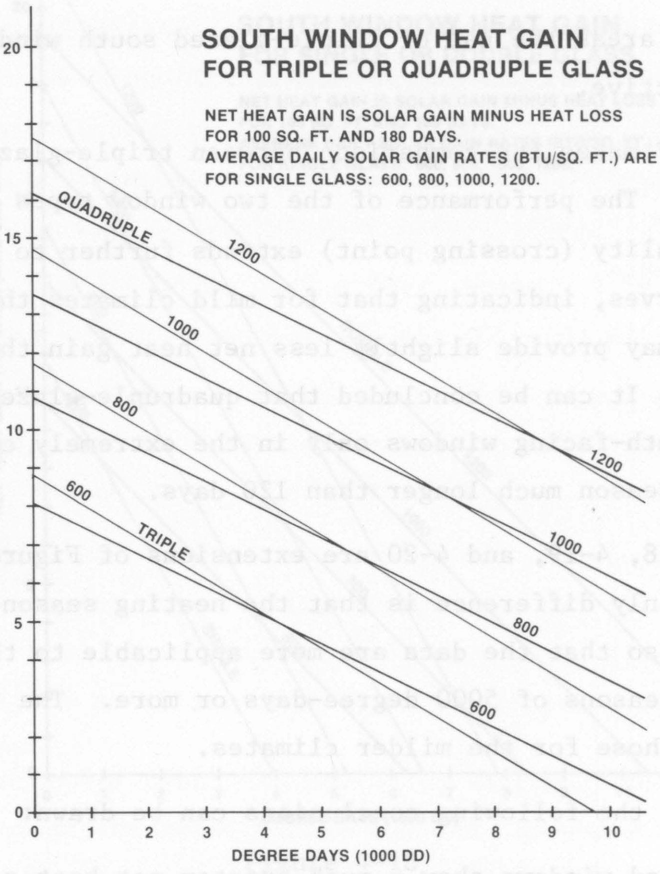


Figure 4-20

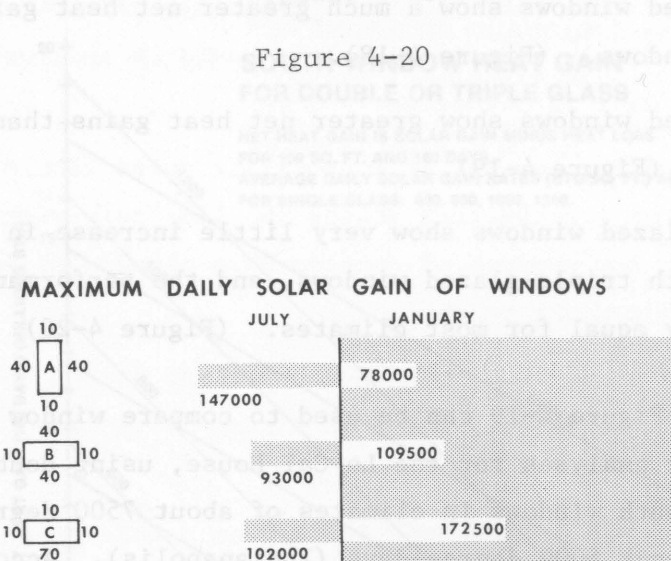


Figure 4-21

Figure 4-21 shows five different combinations of window placements and the resultant effects on daily solar gain of all windows of a house having a total window area of 150 square feet. Data are for double-glazed windows at 40 degrees latitude; triple-glazed values would be about 10% less.

House A. The house faces east or west, and the percentages of window areas on each wall are indicated. For example, 40% (60 square foot) of window area is on the west and east facing walls, while 10% (15 square foot) is on the north and south walls.

The maximum solar gain in January is only 78,000 Btu at a time when such gain would be helpful in reducing energy requirements for heating. This would save only about 1 therm of gas burned in the heating system.

House B. The house is rotated so that the house faces south, but 40% of the window area is on each of the north and the south walls. In Houses A, B, and C no roof overhang is provided for the south walls.

In comparison with House A, improvements were noted in both July and January solar heat gains.

House C. The south window area is increased to 70% of the total. The main change is in the large increase in the January solar gain.

House D. The window distribution of House C is retained, but a roof overhang is provided for the south wall. The single greatest improvement is in the reduction of the July heat gain, amounting to 51% from the 102,000 Btu shown for the house without overhang.

House E. The final arrangement shows the best case, with 80% of the windows on the south and no windows on east or west walls. The most noticeable change is in the small July solar heat gain and the large January gain; both trends are most favorable from the standpoint of minimum energy usage. For example, the 24,000 Btu of July solar gain represents only 3 kwh of house cooling, and the maximum January day solar gain (183,000 Btu) would save about 2.5 therms of gas burned in the heating system.

The study illustrates the basic requirements for good solar orientation of a house: a. a large proportion of window area on the south wall, and b. the need for properly designed roof overhang for the south wall. These basic solar requirements were integrated with superinsulation of the house structure in the design of the Illinois Lo-Cal House.

# CHAPTER V. HEATING AND COOLING SYSTEMS

The Lo-Cal House has several features that affect the heating and cooling requirements:

a. The design heat loss, excluding internal heat or solar heat gain, is extremely small. For example, in a Lo-Cal house of 1500 square feet the design heat loss for a temperature difference of 80F amounts to about 20,000 Btuh. This corresponds to about 13 Btuh per square foot, or about half that for a house of conventional good construction. With such small design loss, the house will cool very slowly. Internal and solar gains may provide more than two-thirds of the annual heat requirements.

b. On a sunny winter day, the solar gain from the south-facing windows can exceed the heat loss of the house. The heating system must shut down quickly when the solar gain is sufficient to heat the house. For this reason, a heating system with quick response and with minimum heat storage in the system itself is desirable. Conversely, a system with slow response, such as a heated floor slab, is less suitable.

c. The house will be tightly built, with triple glazing and a complete vapor barrier (retarder) applied to the walls, ceiling, and floor. Outside air must be brought into the house to control odors and humidity, and to provide combustion air for any fuel-burning equipment, such as furnace, water heater, or fireplace. Since infiltration is minimized, an adjustable vent from the outside into the return air system is the best way to introduce the outside air. The vent can be set to control the air flow at the lowest level consistent with ventilation needs and energy conservation.

d. An air temperature above 78F can occur in the south rooms of the house on sunny afternoons. The best heating system would equalize the air temperature throughout the house, by circulating and mixing the air.

Almost any heating and cooling system can be adapted to the house with varying degrees of owner acceptance. Each of several systems will be considered on an impartial basis. Since extensive field experience with the Lo-Cal House is lacking, comments are based upon previous experience with conventional housing.

## Possible Combinations of Heating and Cooling Systems

Electric Resistance Baseboards Plus Central Cooling System. This heating system consists of baseboard resistance units in each space to be heated, controlled by individual room thermostats. The heaters are commonly made to produce 250 watts (850 Btu) per foot. For example, for a design heat loss of 20,000 Btuh, the minimum total requirement would be about 24 feet of baseboard radiation, distributed among the various spaces to be heated. This would amount to a total installed load of 6000 watts, or 6 kw. The electric resistance units are relatively inexpensive, deliver the heat at the perimeter of the house at the floor level, and can be provided with individual room control. With this system, some supplementary system would be desirable to give ventilation control and equalization of air temperatures.

The suggested supplementary system is a central cooling system with the fan-coil unit located below the ceiling of the utility room and the compressor unit located outdoors. The supply duct would be in the central hallway with registers located at the high sidewall location, and a large return-air grille would also be located at the high sidewall location. As explained in Chapter VI, a vent connection to the attic would provide for the introduction of outdoor air into the duct system. The cooling system, with its own central thermostat, would operate as a cooling system in summer, but its fan would usually be operated to provide continuous air circulation during the heating season. When not needed, the fan may be shut off. The fan operation would provide the ventilation air as well as the mixing of the room air.

Electric Terminal Heaters Plus Central Cooling System. An alternate electric resistance heating system would consist of the central cooling system, as described above, but with electric resistance coils located near the register outlets. These terminal heaters would heat the circulating air before it was discharged into the room, and would be controlled by individual room thermostats.

This heating system might be less expensive than the baseboard units, but would not provide the heated air at the perimeter of the floor. Sufficient air flow would be required for low-temperature warm-air supply; otherwise, the heated air would tend to stratify and collect near the ceiling.

Conventional Forced-Air Heating System and Cooling Coil. The conventional forced-air heating system with supplementary cooling coil can be adapted to the Lo-Cal House, with the furnace located in a furnace room either on the first floor or in the basement. The warm-air supply registers preferably should be located at the baseboard or in the floor at the perimeter of the house. This permits the warm air to be discharged upwards without producing a draft in the living space, and at the same time allows the cooled air in summer to be discharged upwards and then to be disseminated outwards as it approaches the ceiling. The furnace itself can be fired by gas, oil, or electricity (or even wood or coal). The cooling coil in the furnace bonnet is connected to an outdoor compressor. The system uses a single central thermostat for year-around temperature control, and may be set on "fan" for continuous blower operation for ventilation and mixing air without heating or cooling.

For this forced-air system, a furnace of the proper size may be difficult to find. Normally, furnace inputs of about 50,000 Btuh are the smallest available (1979). In the case of the Lo-Cal House, the required input may be half as much--25,000 to 30,000 Btuh. Some comments on this topic are given later in the section entitled "Technical Details for the Heating Industry."

Although duct and register sizing procedure is the same as for conventional houses, the Lo-Cal House could utilize a standard 6-inch diameter duct and standard size register for all the branches. This would minimize installation costs by eliminating non-standard sizes of ducts, elbows, take-offs, dampers, and registers.

Conventional Hydronic System-Central Cooling System. For a hot-water system with a circulation pump, the baseboard radiators would be located at the perimeter of the house and the boiler could be in the basement or in a boiler room on the first floor. Either one-pipe or two-pipe arrangements could be used, depending upon the size and configuration of the house. The energy supply could be gas, oil, or electricity (or even coal or wood). The control would be by a single room thermostat. It is best to have a separate heater for domestic hot water, rather than to have a combined space and water heating system in a single boiler.

The cooling system would consist of a separate central fan-coil system as described earlier. The fan in this system would introduce outside air through a regulated vent and recirculate room air for mixing.

Since the baseboard radiators do have a small amount of water storage within the piping system, the radiators should not be oversized. Also, the lowest possible water temperature should be maintained to reduce the heat storage capacity of the piping. This would provide for more rapid adjustment to the almost instantaneous heat gains from the sun.

Supplementary Heating Units. Any supplementary heating device can be installed and operated as is commonly done in conventional housing. For example, a fireplace, a heat-exchanger fireplace, or a stove can be installed on the first floor or in the basement of a Lo-Cal House and utilized either occasionally or on a daily basis. Usually, these are supplementary to the regular heating system. A separate system for vent control and air mixing is most desirable with a fireplace or stove, which produces a lot of heat without good temperature control. Furthermore, the convection heat of a fireplace or stove is not released at the perimeter of the house but towards the ceiling. A high-sidewall return air grille would collect the heated air at the ceiling level and mix it with the outdoor ventilation air to be distributed through the entire house. The outdoor ventilation air would also insure that a fireplace would not "smoke" or that a wood stove would be provided with sufficient air for combustion.

Individual Cooling Units. In those areas where the cooling requirement is not large, as in some northern states, the occasional cooling needs could be met with window or through-the-wall units. The cooling load would be so small with a Lo-Cal House that one such unit would easily satisfy the Btu needs. The main difficulties with such an installation are that the cooling is concentrated in one area, the unit is relatively noisy, and the fan in the unit would provide poor air mixing during the heating season. With two smaller window units, the air distribution would be somewhat improved. In the warmer climates where the cooling requirement extends over months, a central ducted cooling system is to be preferred over the window units.

Heat Pump Forced-Air System. The heat pump cooling-heating unit can be handled the same as the conventional forced-air heating system and cooling coil. Generally, the smallest unit available will be used, about 20,000 Btuh for heating and cooling. As in the case of the conventional house, the heat pump system is more attractive and yields better returns in the milder winter climates. In view of the extremely small heating requirements, however, it may be difficult to justify the increased initial cost of the heat pump above the simple electric resistance units described, especially in the mild climate regions. Warranty, maintenance, and equipment replacement costs must be considered.

## Simulation of Monthly Heating Requirements

Computer studies A and B for the Lo-Cal House exposed to Madison, Wisconsin, weather showed heating requirements of 13.0 million Btu for the Lo-Cal House and 38.1 million Btu for the HUD House. A more detailed breakdown of these totals shows the solar gain through the windows and the heat requirements for the central heating system on a monthly basis.

| | LO-CAL HOUSE | | HUD-MPS HOUSE | |
|---|---|---|---|---|
| MONTH | WINDOW SOLAR HEAT (1000 Btu) | HEATING REQUIRED (1000 Btu) | WINDOW SOLAR HEAT (1000 Btu) | HEATING REQUIRED (1000 Btu) |
| January | 3304 | 3183 | 1974 | 8839 |
| February | 2323 | 1670 | 1693 | 5311 |
| March | 1779 | 1760 | 1437 | 4979 |
| April | 845 | 1492 | 1052 | 3356 |
| May | 315 | 270 | 571 | 879 |
| June, July, August | 0 | 0 | 89 | 25 |
| September | 186 | 38 | 300 | 388 |
| October | 757 | 279 | 788 | 1535 |
| November | 2037 | 1012 | 1455 | 4228 |
| December | 2751 | 3273 | 1546 | 8578 |
| | 14297 | 12977<br>or<br>13.0 million | 10905 | 38118<br>or<br>38.1 million |

Note: For both houses the internal gain was assumed as 51,000 Btu/day, consisting of 10 kwh and 2 persons.

For the Lo-Cal House, the maximum heating requirements were during December and January, the same two months that showed the largest solar gains through the windows. For the HUD House, the two maximum months were also December and January. and with November, February, and March also showing large demands.

Note that the solar gain for the HUD House was reasonably large (10.9 million), compared with the 14.3 million Btu for the Lo-Cal House. That is, although a substantial part of the reduction in heating requirement (3.4 million Btu) could be attributed to solar gain, the total difference in heat required of 25.1 million Btu was largely the result of the super-insulated construction of the Lo-Cal House.

Daily Temperature Variations on a Cold Winter Day. In a separate study, utilizing data from the computer analysis, an estimate was made of the manner in which the indoor air temperature of the house would vary during a 24-hour period. For this study, data for an average cold January day (Dry Bulb Average of 17.2F) were selected. Heat gains and heat losses were then accounted for on an hourly basis and predictions made of the resulting indoor air temperatures. The graph of the predicted temperatures and the demand on the heating system are shown in Figure 5-1. The sub-totals for the heat inputs to the house for the 24-hour period were:

| | |
|---|---|
| Solar gain, south windows | 110,000 Btu |
| Solar gain, walls and ceiling | 50,000 |
| Internal gains | 52,000 |
| Heat input from heating system | 105,000 |
| | 317,000 |

The outdoor temperature varied from a minimum of 11F to a maximum of 24F, with an average of 17.2F. With average wind velocity of 8 mph, the heat loss rate of the house was assumed to be about 250 Btuh/F.

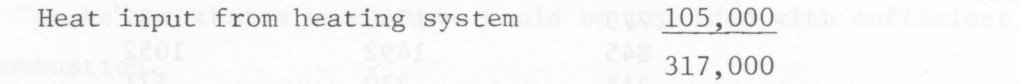


Figure 5-1

The rapid rise in indoor air temperature from 10 a.m. to 3:00 p.m., at a rate of almost 2F per hour, shows the effect of the solar gain. The room cool-down rate between 4 p.m. and midnight was about 1¼F per hour, and depended upon the rate of heat loss from the house, of heat release from the mass of the house, and of internal heat gain.

## TECHNICAL DETAILS FOR THE HEATING INDUSTRY

The following items are directed towards the profession and discuss some of the trends represented by the Lo-Cal House and their impact on the sizing and selection of equipment. While the discussion focuses on central air heating and cooling systems, the principles apply to all systems.

### Furnace Capacity Requirements

The furnace industry is faced with a challenge to produce equipment to meet the needs for the low design heat loss of super-insulated homes, such as the Lo-Cal House. Some anticipated requirements for low-capacity furnace units may not be satisfied with available equipment.

### Capacity for Different Areas

Based upon a 20,000 Btuh design heat loss for an indoor-outdoor temperature difference of 80F, the modifications for other temperature differences would be as follows:

TABLE 5-1

| | For Indoor-Outdoor Temperature Difference of: | | | | | |
|---|---|---|---|---|---|---|
| | 50F | 60F | 70F | 80F | 90F | 100F |
| Design Outdoor Temperature | 20F | 10F | 0F | -10F | -20F | -30F |
| Design Heat Loss, Btuh | 12,500 | 15,000 | 17,500 | 20,000 | 22,500 | 25,000 |
| Register Delivery, Btuh | 12,500 | 15,000 | 17,500 | 20,000 | 22,500 | 25,000 |
| Bonnet Capacity, Btuh | 14,700 | 17,650 | 20,600 | 23,530 | 26,470 | 29,400 |
| Input, minimum, Btuh | 19,600 | 23,530 | 27,470 | 31,370 | 35,290 | 39,200 |

The items in Table 5-1 show the "conventional" approach, and as will be indicated later, may lead towards oversizing of equipment for a super-insulated house, such as the Lo-Cal House.

Explanation of Terminology

Design Heat Loss. The design heat loss for heating systems is based on near-maximum conditions, in this case at -10F outdoor temperature and 15 miles per hour wind velocity. No heat gain from either internal sources or from solar gain is credited. Hence, the design heat loss would occur at night with no occupancy. The net result is that practically all heating systems so-designed will show some degree of over-capacity. The extent of this over-capacity will be large for the Lo-Cal House because the solar gain will be larger than that of most houses of conventional design. The over-capacity provided by this assumption has usually been considered as a "factor of safety" and as a reserve for unexpected weather demands.

Register Delivery. The heat delivered at the registers and diffusers in the forced-air heating system is considered to be equal to the design heat loss.

Bonnet Capacity. The heat loss in the duct system between the furnace casing and the registers depends upon the size and length of the duct system. A commonly assumed loss is 15% of the heat delivered to the bonnet, corresponding to a transmission efficiency of 85%. If the duct system is contained within the occupied portion of the house, as in a basement, the duct heat loss contributes to the heat delivered to the house. Normally, heating dealers have ignored the heat loss from the basement space and have assumed that the duct heat loss will handle the basement heating requirements.

In this connection, the correct way of making design heat loss calculations for a house with basement is to include the basement heat loss in the total for the upper story heat losses and then to provide a furnace whose bonnet capacity is equal to this total design heat loss.

Input Rating. A combustion efficiency of 75% has been assumed; that is, 25% of the heat generated in the furnace escapes as hot flue gases up the chimney.

If an inside chimney is provided, and the furnace is located in the basement, much of the heat escaping from the vent-pipe and the chimney is recovered by the house. This vagrant heat is never considered in the selection of the furnace, but serves to provide for some excess capacity.

In the case of electrical resistance coils placed close to the duct outlet of a forced-air heating system, the efficiency will be close to 100%. In this case, the input to any room is made equal to the design heat loss, and excess capacity is minimal.

## Range of Practical Furnace Sizes

In current practice, furnaces for residential service are commonly available with inputs of about 75,000 Btuh to 150,000 Btuh, with a few models showing inputs as low as 50,000 Btuh.

The values in the table show that a still lower level of inputs should be considered by the furnace manufacturers for future markets, perhaps between 20,000 and 40,000 Btuh.

With a super-insulated house, the internal heat gain from appliances and occupants provides a large part of the total heat requirements. In the example, the 52,000 Btu for internal gain is 16% of the total. Since this amount is not considered in the design heat loss, the table for furnace inputs will result in oversizing of the furnace by at least 16%. One method of correcting for this oversizing would be to omit the item for "duct transmission loss" and to arbitrarily assume that the "bonnet capacity" is the same as the "register delivery".

In any case, it can be concluded that the physical size and capacity output of heating equipment for a Lo-Cal House, and similar super-insulated houses, will be considerably smaller than conventional equipment. Also, because of inertia, special efforts will have to be made to convince the installers in the field that low-input furnaces will be satisfactory. The tendency always will be for the installer to "play safe" and be sure that the furnace will be big enough.

In this connection, the starting point for this new era in furnace selection consists in calculating heat loss tables that go far beyond the existing tables. For example, the U-values for super-insulated ceilings (including construction materials) can be as low as:

.029 for 9-inch-thick ceiling insulation
.022 for 12-inch
.018 for 15-inch
.015 for 18-inch.

The U-values for super-insulated double walls specified for the Illinois Lo-Cal House can be as low as:

.03 for 8½-inch wall insulation

.025 for 10½-inch wall insulation

These are such low values that special instructions will have to be provided to the field installers and heating contractors because they are seldom included in working tables.

## Blower Capacity for Low-Input Furnaces

The basic equation for air-flow rate and bonnet capacity is:

$$Q = 1.08\ (\text{cfm})\ (t_b - t_r)$$

in which,

Q is the bonnet capacity in Btuh,

(cfm) is cubic feet per minute of air flow,

$t_b$ is the bonnet-air temperature, and

$t_r$ is the return air temperature to the furnace.

For a given bonnet capacity, the required air flow depends upon the desired bonnet-air temperature, since the return-air temperature, $t_r$, is commonly assumed to be the same as the room-air temperature, or 70F. For each 10,000 Btuh bonnet capacity, the required air flow would be as shown in Table 5-2.

TABLE 5-2

AIR FLOW RATE FOR EACH 10,000 Btuh CAPACITY

| Bonnet Air Temperature $t_b$ | Air Temperature Rise $(t_b - t_r)$ | Air Flow Rate Cfm |
|---|---|---|
| 170 | 100 | 92.6 |
| 160 | 90 | 102.9 |
| 150 | 80 | 115.7 |
| 140 | 70 | 132.3 |
| 130 | 60 | 154.3 |
| 120 | 50 | 185.2 |
| 110 | 40 | 231.5 |
| 100 | 30 | 308.6 |
| 90 | 20 | 463.0 |

(Based on $t_r$ of 70F, corresponding to room-air temperature).

For a bonnet capacity of 23,530 Btuh, the cfm values in the table would be multiplied by 2.353. If an air temperature rise of 100F is selected by the manufacturer, the required air-flow rate would be 2.353 x 92.6 or only 218 cfm. If one considers that the smallest cooling coil that would be combined with the furnace unit would probably be about 12,000 Btuh, it can be seen that the common cooling requirement of "400 cfm per ton" would not be met.

It becomes apparent that a bonnet air temperature of 120F, corresponding to an air temperature rise of 50F, would provide the required 400 cfm. (2.353 x 185.2 = 436 cfm). Even this rate is not going to provide for a large recirculation rate. For example, for a 1500 square feet house, the volume of living space is about 12,000 cubic feet. In order to provide for one recirculation per hour, the air-flow rate would have to be: 12,000/60 or 200 cfm. Therefore, 436 cfm would provide a recirculation rate of only 2.2 per hour, which is not large. From the standpoint of good mixing of the air in the house, an air-flow rate greater than 436 cfm would be preferable.

A balance point will be reached when the requirements for mixing must be offset by the requirements of the furnace and the cooling coil. Because of the possibility of drafts from poorly directed air streams from registers and diffusers at bonnet-air temperatures of 120F (or lower), the careful selection of register locations is advised. The best location and type are the registers and diffusers designed for baseboard or floor perimeter locations, in which the circulating air is discharged vertically upwards so that the air stream does not strike an occupant. Any other register type or location can be considered as less desirable.

Required Control

The optimum system operation would consist of the following control of burner and blower:

a. Continuous Blower. The room thermostat control should provide for continuous operation of the blower, both winter and summer.

b. Intermittent Burner. The room thermostat should provide cyclical operation of the burner.

With this operation in winter, the register-air temperature will vary from room temperature to a maximum not to exceed the design bonnet-air temperature indicated in Table 5-2. This corresponds to the particular combination of blower speed and burner input selected by the furnace manufacturer. In general, the register-air temperatures will be low, providing for most efficient heat transfer. However, these low air temperatures require that the air issuing from the register or diffuser should never strike an occupant.

During the summer months, the blower is again operating continuously and the temperature control is obtained by operating the compressor cyclically. This means that the indoor relative humidity will increase sharply when the compressor is not operating, because the water droplets that collect on the cooling coil will re-evaporate during the off-period of the compressor. However, the continuous air circulation in the room will tend to give some cooling effect so that the increased relative humidity will be partly counteracted.

While a means of obtaining continuous blower operation is provided, it may not be necessary in all seasons or when the house is not occupied.

The recommended use of continuous air circulation will increase the electrical consumption, compared with intermittent blower operation, but the increase in furnace heat transfer as well as the improvements in ventilation and air mixing will more than pay for the electrical increase. Furthermore, the life of the motor is enhanced by continuous operation as compared with intermittent starts.

## REFERENCES:

C1.5 Living With the Energy Crisis
F7.0 Chimneys and Fireplaces
G3.1 Heating the Home
G3.5 Fuels and Burners
G6.1 Cooling Systems for the Home
TN #10 Home Heating and Cooling with Electricity

## CHAPTER VI. INFILTRATION RATES AND AIR CHANGES

As the heat losses through ceiling, walls, and glass are reduced by super-insulation techniques, the heat loss due to infiltration (air leakage) into a building assumes a larger proportion of the total. For example, the heat loss summary sheet in Circular C2.3 shows the following design heat-loss values:

| Component | Design Heat Loss | Percent of Total |
|---|---|---|
| Ceiling | 2,980 Btuh | 15.0% |
| Wall | 2,670 | 13.4 |
| Floor | 1,570 | 7.9 |
| Windows | 4,000 | 20.1 |
| Doors | 200 | 1.0 |
| Infiltration | 8,470 | 42.6 |
| Total | 19,890 | 100.0 |

These estimates were based on an infiltration rate of 0.5 air changes per hour. Note that the infiltration component is 42.6% of the total design heat loss. The question arises whether this large loss should be reduced.

If the house is made tighter and the actual infiltration rate is reduced 0.25 air changes per hour, the design heat-loss is significantly reduced.

Measurement of infiltration Rates. Infiltration around windows and doors and through the wall construction are estimated values only. There is no simple method of measuring actual infiltration rates.

The original measurements of air leakage were made over half a century ago under controlled laboratory conditions in which air pressure was applied to the external side of window and wall sections, corresponding to the stagnation pressure of the wind velocity, usually 15 miles per hour, impinging normally to the wall. The relatively small air leakages were measured by careful laboratory techniques involving low-velocity air flow through orifices. The results were stated in units of "cubic feet of air per hour for each linear foot of crackage," and working values were presented in design tables for windows, doors, etc.

In the calculations for design heat-loss the "leakage rate per foot of crack" was multiplied by the crackage of windows and doors in each space to be heated, taking into account the number of exposed walls in the space. This was a tedious process, but has prevailed to this date. This method is referred to as the "crackage" method for determining the infiltration rate in the design process and is considered to be the most accurate method available. Note that this estimate is for a good quality of construction and for a wind velocity of 15 miles per hour. Furthermore, the assumption is made that the windows are closed and locked. If the family has a large number of children, who may be opening and closing the doors frequently, the actual infiltration rates may be far in excess of the assumed rates. That is, actual rates of infiltration depend upon the living habits of the occupants, which are almost impossible to predict.

Later, a much simpler method was devised especially for homes, referred to as the "air change method" for estimating the infiltration rate. Experience had shown that in houses of ordinary construction of the 1930-1940 period a design air change rate of 1.0 per hour resulted in heating systems which were adequate in capacity. A value of 0.75 air changes per hour was considered as suitable for a house with "good construction", and 0.5 for a "tightly constructed" house. (Incidentally, the air change method is not suitable for buildings with high ceilings or large spaces with relatively few windows and doors.)

Some field tests were conducted in research homes, in which a tracer gas was released inside the house and the decay rate of gas concentration measured at intervals over several hours. The dilution of the tracer gas by air leakage was measured and the infiltration rate calculated from the field data. There is always a possibility that any tracer gas will be partly absorbed by the interior furnishings and give a false reading of actual infiltration. In any case, these tests, which are affected by wind direction and intensity and by neighboring structures, showed that values of from 0.5 to 0.75 air changes per hour were not unreasonable for well-constructed houses.

This detailed explanation of the basis behind the infiltration figures, and the difficulty in actually measuring the leakage, is presented to explain the reasons for some of the assumptions made in this study.

Problems Due to Lack of Infiltration. A building can be built with currently available materials and construction methods so that the house is almost "air tight". For example, if a continuous layer of polyethylene sheet is placed between the interior finish and the studs or ceiling joists, as well as below the finish flooring, and if close fitting or weather-stripped window sash and doors are used, it should be possible to reduce air infiltration to extremely low levels, perhaps to as low as 0.1 air change per hour.

A number of problems would arise that would be traceable to such low infiltration rates.

a. any moisture released within the structure would not escape readily, causing indoor relative humidities to become excessively high.

b. the lack of air change would result in an accumulation of odors that would not be tolerated by the occupants.

Precise values for an acceptable air-change rate are not possible since the living habits of the occupants affect such numbers. For example, in the ASHRAE Guide the acceptable design levels for outdoor ventilation air for commercial buildings vary from as low as 10 cfm per person for some conditions to values as high as 50 cfm per person where smoking is permitted. If these values are applied to residential structures, some interesting numbers arise. For example, a house with 1,500 square feet of floor area shows a total volume of 12,000 cubic feet. For one air change per hour, this 12,000 cubic feet would be replaced in one hour. Assuming a family of four people, each requiring a minimum of 10 cfm, the fresh air requirement would be 40 cfm, or 2,400 cubic feet per hour. The minimum design conditions would be met with 2,400/12,000 or 0.2 air changes per hour. The maximum design conditions would be met with an air change that is five times greater, or 1.0 air change per hour. If the design values for commercial applications have any significance for residential conditions, it would appear that air change rates between about 0.2 to 1.0 per hour should give acceptable indoor air quality conditions.

There exists no single value for an acceptable air-change rate because living habits of families are not the same, and no reliable measurements have been made on the day-by-day variations in release of odors and moisture from kitchen and bathroom, and the dilution effect resulting from frequent door openings.

From purely subjective impressions of research engineers in charge of the Research Homes, where actual infiltration measurements were made, an air-change rate of 0.75 per hour was considered as acceptable for <u>average</u> conditions and that a minimum rate of about 0.5 per hour might be tolerated from an air quality standpoint. A number of conflicting statements and claims have been made that should be clarified:

a. Infiltration rates as low as 0.1 air change per hour have been reported in some test houses. It is probably possible, with carefully applied polyethylene vapor retarders on every exposed surface, combined with weatherstripped windows and doors, omission of a fireplace, and the use of a heat source not involving combustion, that such extremely low rates of infiltration could be attained. It is also probable that excessively high humidities would be maintained in the house even without a humidifier in operation. The odor problem also may be unacceptable to many occupants.

b. Some builders have contended that because of the humidity build-up from tight construction, the polyethylene vapor barrier for the ceiling should be omitted. The omission of the vapor barrier allows the moisture to travel freely into the attic space and condense moisture on all cold surfaces, such as the sheathing and the nails protruding through the sheathing.

c. Some have questioned the basic approach for the Lo-Cal House of making an almost air-tight structure and then installing an outside air duct to permit forced ventilation into the house. The argument has been that the house should be loosely constructed so that 0.5 to 0.75 air changes per hour would naturally result without forced ventilation. The main difficulty with this argument is that there is <u>no way to guarantee a definite amount of air leakage into the structure</u>. If the house is loosely built, the infiltration could easily exceed 1.0 air change per hour. Such houses might provide for odor-free conditions, but at the expense of high energy costs and undesirable drafts in the living zone.

d. The following basic conditions are assumed for Lo-Cal House, and similar well-constructed tight structures:

   1. A vapor retarder should be carefully installed at <u>all</u> exposed surfaces, such as ceiling, wall, and floor.

   2. By means of weatherstripped windows and doors and caulking of window frames, a low infiltration rate should be maintained. There is no way of measuring this, but a rate of 0.25 per hour or less might be attainable.

   3. Ventilating fans are installed at bathroom and kitchen, and these are operated either by a door switch or manually.

4. A duct is installed that brings outdoor air into the return-air side of the heating or cooling system. (Details are given later).

In other words, the basic design assumes that the structure is made as near air-tight as possible, and then provided with just enough outdoor air to meet the specific needs of the family. These specific needs include enough air: to supply combustion needs for furnace, water heater, and stove; to keep the fireplace from smoking; to maintain an acceptable relative humidity, and to maintain the desired air quality. No two families have the same needs, nor does the same family show the same needs at all times.

Duct for Outside Air. the sizing of the duct for carrying outside air into the return-air duct system can be determined as follows:

a. One Air Change. One air change per hour can be determined by:

(Floor Area, x (Ceiling Height)
Sq. ft.) ft.

For example, if the floor area is 1,500 square feet and the ceiling height is 8 feet the total house volume is (1,500) (8) or 12,000 cubic feet. For one air change per hour this volume of air would be moved through the house in one hour's time.

b. CFM. One air change per hour expressed in terms of Cubic Feet for Minute, would be: 12,000/60 or 200 cfm.

c. Natural Infiltration. Whether forced ventilation is used or not, some amount of natural infiltration will occur around windows and doors and by door openings. (Evidence from Research Residence tests indicate that with small build-ups in internal pressure by fans, the forced ventilation is superimposed on natural infiltration. In other words, forced ventilation does not stop natural infiltration, except in cases where unusually high internal pressures are created.)

If the assumption is made that in a tightly constructed Lo-Cal House, a natural infiltration of 0.25 air change per hour would occur, then the remaining 0.25 air changes per hour would be supplied from the forced ventilation duct. In the example, this would be: (0.25) (200) or 50 cfm.

d. Duct Diameter. If a 5-inch diameter duct is used between the outside air intake grille and the internal return air duct of a warm air heating system, the air velocity in the duct would be 367 feet per minute. The friction loss per 100 feet of 5" diameter straight duct is 0.06 inches water gage. Assuming an equivalent duct length of 150 feet, for straight duct, elbows, and grille, the total head loss will be about 0.09 inches water gage. This should be within the common 0.10 inch return-air suction-head capability of the blower in the furnace casing.

Return Air Intake and Duct System. For a single-story house with crawl space, as assumed in the basic Lo-Cal House, the furnace would be of the down-flow type located in a first-story furnace room with the warm air discharged into a sub-floor plenum. The return-air plenum would be within the insulated envelope with the return-air trunk duct located at the hallway ceiling.

There are three possible locations for the outdoor intake grille. The location of the grille on a wall is the least desirable because of the wind pressure effect that will create excessive air flow when the wind direction is directly against the wall. A second location is the crawl space. However, since the crawl space is closed, the outdoor air duct would have to be carried to the outside wall to a wall grille. Also the duct would have to be heavily insulated to prevent cold outdoor air from cooling the crawl space. The third location is from the attic space. The main advantage of this location is that it is practically immune to wind effects. The admitted air would be of a constant quantity when the furnace blower is operating, regardless of wind direction or intensity. Also, the attic air is slightly warmer than outdoor air during the winter months and would not require as much energy to heat. The disadvantage is that during the shorter cooling season the attic air is considerably warmer than outdoor air during the daylight hours, so that energy requirements for cooling would be higher than those utilizing a wall grille for intake air. After sundown this temperature disadvantage may not exist.

Taking all things into consideration, the best compromise would probably be a vent duct leading from the return plenum to the attic space.

Setting of Damper. The vent duct should be provided with an adjustable butterfly damper in the 5-inch diameter duct that is exposed to the furnace room. The furnace blower should be started with the damper closed. As experience dictates, and after normal living habits have been established, the damper should be partly opened and the damper locked. If the air quality and the indoor humidity are still unsatisfactory, the damper should be re-set, again with a very small change in the damper position. the purpose is to introduce no more outdoor air into the house than is necessary for the occupant's olfactory comfort, or for maintaining proper humidity levels.

Basement Furnace Option. For a Lo-Cal House built with a basement, the furnace will be located in the basement with both the supply and return-air trunk ducts located near the ceiling of the basement space. Although an attic intake grille would be desirable, the difficulties in running a 5-inch diameter duct from the basement to the attic would make it necessary to seek an alternate location.

A short and convenient location of the vent intake duct is to locate the intake grille in a window well area, with the duct located above grade. The intake grille, which faces downwards and is provided with a coarse screen, is not provided with automatic dampers, as in the case of kitchen vent ducts, since the outdoor air is being drawn into the house. However, an adjustable butterfly damper should be placed in the vent duct and adjusted carefully after the furnace has been placed in operation.

The wall opening of the vent duct admits outdoor air without any preheating, but is greatly affected by wind direction and intensity. For example, when the wall is exposed to the wind force the kinetic energy of the wind provides a "stagnation" pressure that greatly exceeds the internal pressure of the house. At such times the outdoor air entering the intake grille may be considerably greater than is desired. On the other hand, if a strong wind blows from the opposite direction, the intake opening can be in a sub-atmospheric zone and the air can be "sucked out" of the house. The wind action would be reduced somewhat if the opening is located in a window well.

Since the outdoor air duct can carry air at extremely low temperatures at times, the duct should be insulated to prevent frost and condensate formation. The insulation should be carefully covered with a vapor barrier to prevent water vapor from reaching the cold pipe surface.

Central Cooling System. In systems having a non-duct heating arrangement, such as electric resistance heaters or hot-water baseboard radiators, the central cooling system provides the only means for circulating the house air. By operating the fan both winter and summer, the ventilation air can be taken from the attic space and passed through the air filters in the fan-coil unit located near the first story ceiling, then circulated throughout the house.

Escape of Indoor Air. The exhaust air leaving the house does not require a special exhaust opening, as in commercial buildings. The room air will leave the house through vent openings in the bathrooms and kitchen, and through cracks in window frames and door frames located on the downwind side. If there is a fireplace, air will leak past the fireplace damper. If a fuel burning furnace or boiler is used, and the furnace room is not tightly sealed from the other rooms, then indoor air can escape through the ventpipe and chimney.

Although it might be desirable to pre-heat the incoming ventilation air with heat from the air being discharged to the outdoors, it would be difficult to design heat-transfer equipment to handle all of the exhaust air at the several exit points mentioned above.

# CHAPTER VII. PASSIVE AND ACTIVE SOLAR SYSTEMS

Originally, the term "solar house" was applied to a house with predominantly south orientation and windows. In 1945, the Small Homes Council publication "Solar Orientation" featured a cover photograph of an early house of this type by architect George Fred Keck, and described the fundamentals of "solar house" design. In 1947, the book "Your Solar House" (Simon and Schuster) presented several solar houses designed by well-known architects.

In recent years, the term "active solar" has been used for a house with an applied solar hardware system, and the term "passive solar" for a house which was originally called a "solar house".

Various residential solar hardware systems have been developed for collection, storage, and utilization of solar energy. While most of these systems have been termed "active," even an elaborate solar hardware installation of collectors, transport, storage, and distribution has been called "passive" if the flow of energy is unaided by a blower, pump, or electrical controls.

The solar design of the Lo-Cal house is now referred to as a passive solar system, since there are no moving parts or even a storage system, aside from the mass of the house construction and room furnishings. The active system usually involves a separate collector of solar energy, ductwork or piping to a separate storage unit, and mechanical equipment to transfer fluids from one part of the system to another and to the rooms of the house. The two basic systems are not antagonistic; nevertheless, there are advantages and disadvantages of each system that would appear to be exclusive.

The passive system used in the Lo-Cal House is the oldest and simplest form of solar system, since the windows and the house itself provide the collection and storage of solar energy without supplementary storage devices such as a massive wall (Trombe), water tank, salt or rock chamber, and without special fans, pumps, valves, dampers, sensors, or controls.

The south windows function as solar collectors at room temperature, at which temperature collector efficiency is highest. Furthermore, the windows are a necessary and integral part of the house, and not an added component. With a super-insulated house, south windows of moderate size provide adequate solar gain, and internal gains become a large part of the heat supply.

In contrast, roof collectors are applied hardware attached to the house; they operate at much higher temperatures than windows. For example, the collector temperature must be higher than that of the heat-storage component, and the heat-storage temperature in turn must be higher than the house-air temperature. Also, more heat must be collected to allow for energy losses through the ductwork or piping from the collectors to storage and from storage to rooms. Such higher operating temperatures result in lower efficiency of collection, which is usually compensated for by an increase in the size of the roof collector. The cost of the active systems is usually considerably higher than passive systems. One advantage of the active system, with storage, is that the house temperature may be more closely controlled than with the passive system, without storage. With enough sunlight, collector area, and storage, heat can be stored for more than one day.

From an operation standpoint, the window collectors in the Lo-Cal House are vertical and provided with a 30/16" roof overhang, so that they are protected from hail, and snow does not collect on the surface; even a driving sleet storm is not likely to coat the glass surface. Roof collectors are vulnerable to hail, sleet, and snow in many parts of the country. Because of their remote location, roof collectors are difficult to clear of snow without expending heat energy for melting the accumulation.

Taking into consideration all of these factors, and especially the much lower cost of the passive system, the Lo-Cal House was designed to combine the passive solar system with the super-insulated construction.

If desired, and at additional cost, an active collector could be installed as a supplementary energy source, and especially as a means for heating domestic hot water.

Of the many forms of active collectors, the wall-mounted, air-heated solar collector appears to have many advantages, especially for the heating of a basement space. In this type, the house wall forms the back of the collector and any heat loss through the back enters the house and is not lost. The transport to storage (if any) is through the house space and is usually a short distance--even contiguous to the collector. Heat losses from the collector to storage are all within the house. The system is extremely simple and relatively cheap to build on the job site. On a new house, the cost of the exterior wall surface, which is not used, may be credited toward the collector cost. The vertical collector face receives good direct solar gain from the low-angle winter sunlight and also from sunlight reflected from snow cover on the ground.

The design of the wall collector is similar to the original invention of Edward L. Morse in 1881, except that the heated air is delivered by a thermostatically controlled fan or blower (not available in 1881) rather than convection. Note that the Trombe system is an adaptation of the Morse invention, with a massive wall rather than the heavy metal plate used by Morse.

Research is needed on the wall collector to determine optimum conditions for such items as:

a. spacings for the air passage,
b. air flow rates,
c. suitability of commercially available blowers and fans,
d. mass of any collector plate in front of the house wall,
e. thermostatic control of blower and fan, and
f. distribution of warm air into space to be heated.