# Effective U-Values for Skylights

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## INTRODUCTION

Increased interest in energy conservation, codes, and costs has prompted us to publish curves of effective U-values for skylights. Conventional U-values are used by architects and engineers to estimate heating and cooling loads of buildings. An estimate of these loads is necessary in order to properly size heating and air-conditioning equipment. Conventional U-values work well for this purpose. However, for energy computational purposes it does not work well especially for building elements that transmit light (like a skylight - for example). The reason being is that solar gain and daylighting advantages are not taken into account in establishing conventional U-values. Hence, we developed effective U-values which give a fairly good representation of the annual net energy balance through skylights.

## DEVELOPING EFFECTIVE U-VALUES

How were the effective U-values developed? The industry standard computational procedure was used. This is AAMA Standard 1602 Voluntary Standard Procedure for Calculating Skylight Annual Energy Balance. (AAMA is the Architectural Aluminum Manufacturers Association.) This procedure analyzes all the energy transfers through a skylight - not just conventional U-value losses. These are:

1. Solar Gain.
2. Dome Glazing Conduction/Convection.
3. Curb Conduction/Convection.
4. Infiltration/Exfiltration.
5. Lighting Credit.
6. Equivalent Roof Area Compensation.

We selected 15 large cities in the U.S. for analysis. We used average weather data for each city as supplied by the National Climatic Center of the National Oceanic and Atmospheric Administration. WE analyzed a typical building (110'x100'x12') in each city. We analyzed single and double domed skylights in both heated only and heated/air-conditioned buildings. We assumed each building had 70 skylights, each 49"x49". This means that the skylights comprised about 10% of the roof area. We think that 10% roof coverage represents an approximate "upper limit" for the typical skylighted roof on an inudstrial or commercial building. The percent roof coverage determines the amount of light that enters the building. The percent roof coverage does not affect the annual per square foot energy savings through the skylight. (The reason is that the positive and negative energy transfers - discussed earlier - stay in proportion to one another.) Prior technical reports (see Ref. 1 and 2) show that this is true. Obviously, the same light/solar gain and conventional U-value losses take place per square foot of skylight regardless of whether they comprise 1, 5 or 10% coverage of the roof.

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For our study, we used the typical industry standard skylight. The single domed skylights used a typical 52% transmitting white acrylic. Double domes added a clear acrylic sheet to this. All skylights had a 9" high insulated curb (U-value = 0.21 BTU/hr./ft.$^2$/°F).

ANALYZING THE ENERGY TRANSFERS

Because we examined horizontal skylighted roofs with relatively low percent roof coverage, a simple degree day approach was used. Because of the magnitude of the energy transfers, this method gave a good first approximation of the net energy transfer (savings) possible with the use of skylights. The analysis procedure involved dividing the year (by months) into a heating and cooling season. Any month with more than 100 heating degree days was considered a heating month. The remaining months were considered the cooling season for analysis purposes. We treated the energy transfers as follows.

During the Heating Season

Count as positive: solar gain, and equivalent roof area
Count as negative: curb, dome glazing, and infiltration losses

During the Cooling Season

Count as positive: lighting credit and equivalent roof area
Count as negative: solar gain, curb, dome glazing and infiltration losses.

Please note that lighting credit is taken only during the cooling season (3-5 mo./yr. in many areas of the country). Obviously, if electric lighting were displaced during the winter heating season, heat would have to be supplied by the heating plant of the building. However, the building owner is probably paying substantially less for energies used by the heating plant than those used by the electrical system of his factory or building. In other words, we performed an energy balance; not an economic analysis. That is, on a BTU basis, the cost of electricity to operate the lighting may be 3 or 4 times the cost of the coal, oil, or gas used for heating the building. In other words, the economic justification for using skylights on a building may far exceed the energy savings justification. It is even possible the net energy savings could be very small - and yet the dollar savings could be quite substantial.

Obviously, these "lighting credits" or illumination savings are a large part of the total energy savings. These are the savings that would accrue by not turning on electric lighting. For the most part, they are computed on a "conservative" basis. The illumination savings are credited only for the summer months (cooling season) and only for the hours of occupancy and the weekly usage of the building. On the other hand, energy losses are computed on a 24-hr. a day basis.

Only for air-conditioned buildings did the cooling season's negative factors affect the energy transfer analysis. (Obviously, if these energy transfers were not removed, the interior temperature of a building would increase.)

For computational purposes, energy transfers during the cooling season were divided by the coefficient of performance of the air-conditioning system. The lighting credit was higher in air-conditioned buildings. This results because the air-conditioning system does not have to handle the additional heat load from the electric lighting system. In general, daylighting is more efficient than electric lighting. That is, for a given illumination level, daylighting from skylights has less accompanying heat (solar gain) compared to the heat from electric lighting systems. The in-house engineering divisions of many electric utilities have recently been very interested in promoting the use of skylights to help reduce their customer's peak load.

The solar gain was computed for the use of both clear and overcast days. For analysis purposes, we used a weather-weighted average by factoring the percent sunshine for that specific location.

We analyzed the 15 selected cities as described above using the total-energy-transfer method. The resulting annual energy savings are shown on Table 1. These values were then converted to effective U-values using the degree day data for that particular location. The resulting effective U-values are shown in Table 2. The effective U-values are plotted on Figures 1 through 4. The data contained in Tables 3 and 4 show that the total annual energy savings (and therefore effective U-values) is relatively insensitive to the percentage roof coverage of the skylights.

An example analysis is shown in Appendix I. Typical justifications for using skylights is shown in Appendix II.

A list of references is included and a table showing conventional U-values with appropriate warnings for their use. (See Table 5)

COMMENTS AND QUESTIONS

1. Reviewer #1. Would suggest that the analysis be completed for different assumed lighting levels ranging from 30 footcandles to 120 footcandles?

   Response: As shown in Tables 3 and 4 the calculated energy savings is not affected by the percent of the roof which is covered by skylights. This is to be expected because the balance is calculated per square foot of skylight. As the area increases, U-value losses increase but so do solar heat gain and natural daylighting. Therefore, one selects the amount of skylights based on the desired internal illumination levels and takes credit for that lighting once the desired level is reached.

2. Duane S. Ellifritt Metal Building Manufacturing Association. Do you plan to submit a change to the three model building codes which gives the designer the ability to modify the required "U" values for buildings with skylights? Would the same trade-offs apply to translucent plastic panels in the plane of the roof i.e. no curb?

   Response: All three of the major building codes have been made aware of the results of these studies. The Southern Building Code Congress has exempted skylights from U-value considerations provided the roof coverage is less than ten percent and double glazed units are used in areas with more than 2500 heating degree days. The other building code bodies are still considering the issue. We would hope that they would adopt the same stance.

   The basis for the computational procedure, AAMA 1602.1, allows only domed units to be considered. As shown in Figure 6 on page 32 of that document the translucent dome acts as significant "light amplifier" at solar altitudes of ten degrees and less. Curb size can be adjusted per the procedure but flat panels cannot be used and we have not made studies on these to date.

3. Gary Gillette National Fenestration Council. Would you please explain the computer algorithms used for obtaining your available exterior daylight?

   Response: Figures 4 and 5 on pages 30 and 31 of AAMA Standard 1602.1 show the illumination on horizontal surfaces on clear and overcast days as a function of solar altitude. The solar altitude is calculated on an hour by hour basis for the 21st day of each month given the buildings locations (latitude and longitude). For clear days, clear sky luminance is added to the direct illumination. On overcast days, only the data from Figure 4 is used. A "weather weighted" average illumination is also calculated using the percent sunshine in the building locale i.e. clear data times percent sunshine plus overcast data times one minus percent sunshine.

## APPENDIX I: EXAMPLE ANALYSIS

Let us analyze a typical industrial building (100 t. x 100 ft. x 12 ft.) in Kansas City, Missouri (39°, 17 min. north latitude). Kansas City has about 5,200 heating degree days, 1,400 cooling degree days and 64% sunshine. The cooling season is generally considered to be June through September. On this building, let us assume we put forty 49-in. square double glazed skylights (commonly called 5252's) with 9-in. high, insulated curbs. The glazing is clear acrylic over white translucent acrylic (52% light transmitting.) This size and glazing combination represents the typical "industry standard skylight". These units have a "free light area" of 46¼-in. x 46¼-in. - about 14.85 ft.$^2$ per skylight. The resulting skylight coverage in this case is 5.9% of the roof area. This is a rather large coverage which results in high lighting levels inside the building. The following table shows daily averages for a typical year:

(8 a.m. to 5 p.m.) Average Annual Interior Lighting Levels

| | |
|---|---|
| clear day | 117 footcandles |
| overcast day | 26 footcandles |
| weather-weighted average day | 85 footcandles |

For lighting crediting purposes we established the necessary electric lighting system. Assuming a maintained design illumination level of 70 footcandles and typical room reflectances, this building would require approximately 276 four-ft. - 2 lamp fluorescent fixtures. The total wattage is 25,392 counting ballast consumption.

The listing below will put in persepctive the magnitude of the energy transfers through the skylighted portion of the roof of this building. For simplicity, all values shown are for the entire season and are in thousands of Btu's per ft.$^2$ of skylight per year.

| Factor | Thousands of Btu's of Energy Transfer During: Cooling Season | Heating Season |
|---|---|---|
| Average solar gain | -39 | 104 |
| Dome glazing losses | - 3 | -87 |
| Curb losses | - 1 | -21 |
| Equivalent roof gains | 1 | 10 |
| Infiltration losses* | - 1 | - 7 |

| | Thousands of Btu's Credited If Building Is: Non Air-Conditioned | Air-Conditioned |
|---|---|---|
| Lighting Credit | 99 | 144 |

*These losses are based on a skylight that is tightly sealed. Infiltration coefficient = .05 Btu/Hr./°F/perimeter foot. Obviously, greater amounts of air infiltration could have an effect on the total building net energy balance.

The net result is that a building without air conditioning will save annually about 98,000 Btu's per ft.$^2$ of skylight. A building with air conditioning will save a little more - about 100,000 Btu's per ft.$^2$ of skylight. (For an air-conditioned building the higher lighting credit is offset by the large summer solar heat gain that must be removed. Otherwise, the savings would be much greater.)

The result is that a building of this type would save about 59 million Btu's annually by using skylights. Remember, we are taking lighting credit only at the design level. If credit was taken for all the light that enters the building, the energy savings would be approximately double.

## APPENDIX II: JUSTIFICATIONS FOR USING SKYLIGHTS MOST FREQUENTLY MENTIONED BY ARCHITECTS, OWNERS, ENGINEERS, ENERGY CONSULTANTS, CODE OFFICIALS & FEDERAL ADMINISTRATORS

Skylights are the premier application of passive solar energy known today. Skylights are the most energy efficient and cost effective of all passive solar applications, because of several key reasons:

(1) Skylights are used specifically as daylighting elements (hlaf the solar spectrum is visible light which skylights use directly with no conversion inefficiencies). Skylight systems are often designed to provide a general overall illumination level throughout most of the year with task lighting added by electric fixtures where needed.

(2) Unit skylights are used at relatively low percentages of roof coverage. The relatively low percentage coverage removes much of the "design" aspect necessary to insure significant energy conservation.

(3) Larger skylights (commonly called enclosures) are highly engineered structures used to provide a daylighted environment for the interiors of buildings. Daylighting is widely recognized to be much more efficient than electric lighting. Therefore, large amounts of energy are saved by the use of these large skylights.

(4) Skylights are extremely effective passive solar collectors and unlike flat plate collectors they:

* Have been in use for many years;
* Do not depend on sophisticated valving and voluminous storage systems;
* Require little or no maintenance;
* Have wide commercial acceptance;
* Offset the more expensive electrical energy for fast return on investment;
* Can be "managed" for even greater energy gains;
* Have "sold themselves" without the benefit of outside subsidy;
* Can be installed on most existing buildings.

(5) Skylights are more efficient than vertical fenestration (windows) because:

* Horizontal illumination is about twice the illumination on the "average" vertical surface;
* The projecting domed configuration of white translucent skylights acts as a "light amplifier" at low sun angles when lighting levels are lowest;
* There is little disability glare because skylight curbs keep the luminous panel from one's field of view;
* The soft diffused light from white translucent skylights means high ESI (equivalent sphere illumination) footcandles;
* Skylights present no compass orientation problems.

(6) Skylights are classified as a "Renewable Resource Energy Measure" by the Federal Government. (See Federal Register, Vol. No. 142, Monday July 25, 1977, (p. 37, 802 Section 450.33.)

(7) The "full spectrum" color rendering lighting and the important psychological and physiological benefits of skylights are added benefits.

(8) Engineering calculations and testimonial letters indicate reasonable payback periods.

## USEFUL REFERENCES FOR FURTHER RESEARCH

"Solar U-Number (S-U-N) Modifiers for Skylights", W. C. Burkhardt (ASHRAE) Annual Technical Conference, June 27, 1979, Detroit, MI, ASHRAE Transactions 1979, Vol. 85, Part 2.

Skylights and Energy Conservation by W. C. Burkhardt, Rohm and Haas Co., presented at the Second National Conference on Technology for Energy Conservation in Albuquerque, NM, Jan. 24-27, 1978.

Voluntary Standard Procedure for Calculating Skylight Annual Energy Balance, Publication No. AAMA 1602.1 - 1977 AAMA, 35 E. Wacker Drive, Chicago, IL 60601, (312) 782-8256

A Procedure for Calculating the Saving in Lighting Energy from the Use of Skylights, b6 Joseph B. Murdock, Professor and Chairman, Electrical Engineering Dept., Univ. of New Hampshire, Durham, NH

System Analysis for Skylight Energy Performance by the Center for Industrial and Institutional Development, Univ. of New Hampshire, Durham, NH

"Solar Heat Gains Through Domes Skylights", by L. F. Schutrum and N. Ozisik, ASHRAE Journal, August 1961

Acrylics for the Architectural Control of Solar Energy by O. L. Pierson, Rohm and Haas Co., Philadelphia, PA

Climatic Atlas of the United States, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Center, Federal Building, Asheville, NC 28801, Attn.: "Publications"

Recommended Practice of Daylighting prepared by the Daylighting Committee of the Illuminating Engineering Society, 345 East 47th St., New York, NY 10017

"Solar Optical Properties of Gray and Bronze Solar Control Series Transparent Acrylic Sheet", by W. C. Burkhardt, ASHRAE Transactions, 1975 Vol. 81, Pt. 1, P. 384

## TABLE 1

## ANNUAL ENERGY SAVINGS AND METEOROLOGICAL DATA FOR VARIOUS CITIES

| | North Latitude | | Degree Days | | | Annual Energy Savings (Thousands of BTU's/Ft.$^2$ of Skylight) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Single Dome | | Double Dome | |
| Location | Deg. | Min. | Heating | Cooling | Percent Sunshine | Heated Only | Heated Plus Air-Conditioned | Heated Only | Heated Plus Air-Conditioned |
| Atlanta, GA | 33 | 39 | 3095 | 1589 | 61 | 133 | 121 | 156 | 157 |
| Charlotte, NC | 35 | 13 | 3218 | 1596 | 66 | 141 | 128 | 158 | 156 |
| Concord, NH | 43 | 12 | 7360 | 346 | 54 | -46 | -48 | 26 | 30 |
| Dallas, TX | 32 | 54 | 2382 | 2587 | 71 | 186 | 161 | 200 | 193 |
| Denver, CO | 39 | 45 | 6016 | 630 | 70 | 32 | 23 | 83 | 81 |
| Hartford, CT | 41 | 56 | 6350 | 584 | 57 | -7 | -11 | 53 | 55 |
| Jacksonville, FL | 30 | 30 | 1327 | 2596 | 61 | 205 | 188 | 207 | 206 |
| Kansas City, MO | 39 | 17 | 5161 | 1421 | 64 | 60 | 48 | 98 | 94 |
| Philadelphia, PA | 39 | 53 | 4865 | 1104 | 58 | 59 | 55 | 102 | 108 |
| Richmond, VA | 37 | 30 | 3939 | 1353 | 60 | 103 | 95 | 133 | 136 |
| Sacramento, CA | 38 | 31 | 2843 | 1159 | 79 | 162 | 145 | 171 | 163 |
| San Diego, CA | 32 | 44 | 1507 | 727 | 67 | 203 | 199 | 205 | 211 |
| Seattle, WA | 47 | 27 | 5185 | 129 | 49 | 12 | 14 | 53 | 58 |
| St. Louis, MO | 38 | 45 | 4750 | 1475 | 58 | 65 | 56 | 107 | 107 |

Note: The above analysis was based on our "standard building" (100' x 100' x 12') and had 70 49" x 49" skylights for a 10.4% coverage. Single domes were a typical 52% transmitting white acrylic. Double domes added a clear acrylic sheet to this. Energy savings are Mode 1 type, i.e., lighting savings only at the design level.

TABLE 2

EFFECTIVE ANNUAL U-VALUES FOR SKYLIGHTS WHEN CREDIT IS GIVEN FOR SOLAR GAIN AND DAYLIGHTING

| | | | | Effective Annual U-Values (Btu/Hr./$Ft^2$/°F) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Single Domed Skylight Bldgs. | | Double Domed Skylight Bldgs. | |
| Location | Heating Degree Days | Cooling Degree Days | Total Cooling & Heating Degree Days | Heated Only | Heated & Air-Conditioned | Heated Only | Heated & Air-Conditioned |
| Atlanta, GA | 3095 | 1589 | 4684 | -1.79 | -1.08 | -2.10 | -1.39 |
| Charlotte, NC | 3218 | 1596 | 4814 | -1.83 | -1.11 | -2.05 | -1.35 |
| Concord, NH | 7360 | 346 | 7706 | +0.26 | +0.26 | -0.15 | -0.16 |
| Dallas, TX | 2382 | 2587 | 4969 | -3.25 | -1.35 | -3.50 | -1.62 |
| Denver, CO | 6016 | 630 | 6646 | -0.22 | -0.14 | -0.57 | -0.51 |
| Hartford, CT | 6350 | 584 | 6934 | +0.05 | +0.07 | -0.35 | -0.33 |
| Jacksonville, FL | 1327 | 2596 | 3923 | -6.44 | -2.00 | -6.50 | -2.19 |
| Kansas City, MO | 5161 | 1421 | 6582 | -0.48 | -0.30 | -0.79 | -0.59 |
| Little Rock, AR | 3354 | 1925 | 5279 | -1.54 | -0.84 | -1.88 | -1.17 |
| Philadelphia, PA | 4865 | 1104 | 5969 | -0.50 | -0.38 | -0.87 | -0.75 |
| Richmond, VA | 3939 | 1353 | 5292 | -1.09 | -0.75 | -1.41 | -1.07 |
| Sacramento, CA | 2843 | 1159 | 4002 | -2.37 | -1.51 | -2.50 | -1.70 |
| San Diego, CA | 1507 | 727 | 2234 | -5.61 | -3.71 | -5.67 | -3.93 |
| Seattle, WA | 5185 | 129 | 5314 | -0.10 | -0.11 | -0.43 | -0.45 |
| St. Louis, MO | 4750 | 1475 | 6225 | -0.57 | -0.37 | -0.94 | -0.72 |

Notes:

1. This table is a good approximation for well designed skylights (see text) that make up no more than 10% of the roof area ( a somewhat arbitrarily chosen upper limit). At roof coverages greater than 10%, AAMA Standard 1602 should not be used for determining the total energy transfers through a skylighted roof.

2. The above effective U-Value data was computed by doing a complete energy transfer analysis for a typical building in the cities indicated. The analysis was based on our "standard building" (100'x100'x12') and had 70 skylights 49"x49" for a 10.4% coverage. Single domes were a typical 53% transmitting white acrylic. Double domes added a clear acrylic sheet to this. Daylighting credit is taken by computing the lighting savings only at the design level.

3. A negative effective U-Value means that the energy balance for that location resulted in a net energy savings. The larger the negative effective U-Value the more energy that is saved.

4. Only heating degree day data was used in computing the values for heated only buildings. For heated and air-conditioned buildings, the sum of the heating and cooling degree days was used.

TABLE 3

SINGLE DOME SKYLIGHT SAVINGS

| CONCORD, NH | Energy Savings (Thousands of BTU's/Ft.$^2$ of Skylight/Yr.) | |
|---|---|---|
| Percent Roof Coverage | Non-Air Conditioned Building | Air Conditioned Building |
| 10.4 | -52,000 | -54,000 |
| 5.2 | -52,000 | -54,000 |
| 2.67 | -54,000 | -57,000 |
| 1.3 | -54,000 | -55,000 |
| **PHILA., PA** | | |
| Percent Roof Coverage | | |
| 10.4 | 58,000 | 53,000 |
| 5.2 | 58,000 | 53,000 |
| 2.67 | 55,000 | 49,000 |
| 1.3 | 55,000 | 49,000 |
| **SAN DIEGO, CA** | | |
| Percent Roof Coverage | | |
| 10.4 | 203,000 | 198,000 |
| 5.2 | 203,000 | 198,000 |
| 2.67 | 199,000 | 193,000 |
| 1.3 | 199,000 | 193,000 |

NOTE:

The above analysis was based on our "standard building" (100' x 100' x 12'). We used 49" x 49" skylights. The skylights used a typical 53% transmitting white acrylic dome. Energy savings are Mode 1 type, i.e., lighting savings only at the design level. The table below gives the details of the individual skylight systems.

| Number of Skylights | Percent Roof Coverage | Lighting Credit (footcandles) |
|---|---|---|
| 70 | 10.4 | 120 |
| 35 | 5.2 | 60 |
| 18 | 2.67 | 30 |
| 9 | 1.3 | 15 |

## TABLE 4

## DOUBLE DOME SKYLIGHT SAVINGS

| | Energy Savings (Thousands of BTU's/$Ft.^2$ of Skylight/Yr.) | |
|---|---|---|
| Percent Roof Coverage | Non-Air Conditioned Building | Air-Conditioned Building |
| **CONCORD, NH** | | |
| 10.4 | 20,000 | 23,000 |
| 5.2 | 20,000 | 23,000 |
| 2.67 | 18,000 | 20,000 |
| 1.34 | 18,000 | 20,000 |
| **PHILA., PA** | | |
| 10.4 | 101,000 | 106,000 |
| 5.2 | 101,000 | 106,000 |
| 2.67 | 98,000 | 101,000 |
| 1.34 | 98,000 | 101,000 |
| **SAN DIEGO, CA** | | |
| 10.4 | 205,000 | 211,000 |
| 5.2 | 205,000 | 211,000 |
| 2.67 | 201,000 | 205,000 |
| 1.34 | 198,000 | 201,000 |

NOTE:

The above analysis was based on our "standard building" (100' x 100' x 12'). We used 49" x 49" skylights. The skylights were clear acrylic domes over typical 53% transmitting white acrylic inner dome. Energy savings are Mode 1 type, i.e., lighting savings only at the design level. The table below gives the details of the individual skylight systems.

| Number of Skylights | Percent Roof Coverage | Lighting Credit (footcandles) |
|---|---|---|
| 70 | 10.4 | 120 |
| 35 | 5.2 | 60 |
| 18 | 2.67 | 30 |
| 9 | 1.3 | 15 |



## TABLE 5

## CONVENTIONAL SKYLIGHT U-VALUES

| | | Approximate Average Annual U-Values (Btu/Hr./$Ft.^2$/°F) for Load Calculation and Equipment Sizing Purposes | | |
|---|---|---|---|---|
| Period | Heat Flow | Single | Double | Triple |
| Heating | Up | 1.2 | 0.7 | 0.5 |
| Cooling | Down | 0.8 | 0.5 | 0.3 |

NOTES:

1. These values should not be used for energy computational purposes. Effective U-values based on a total-energy-transfer analysis, should be used for estimating energy transfers. (Use attached graphs.)

2. The above U-values consider only convective thermal transfers and ignore solar and daylighting advantages of skylights. Therefore, they are useful mainly for equipment sizing.

FIGURE 1

## EFFECTIVE U-VALUES FOR HEATED ONLY BUILDINGS

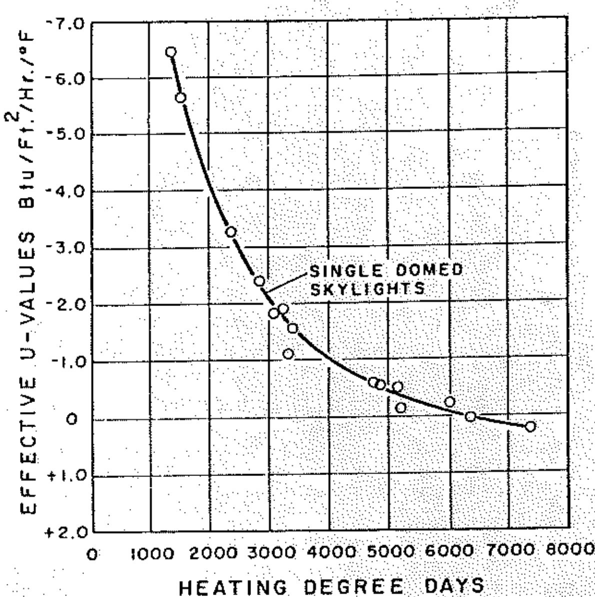


FIGURE 2

## EFFECTIVE U-VALUES FOR HEATED ONLY BUILDINGS

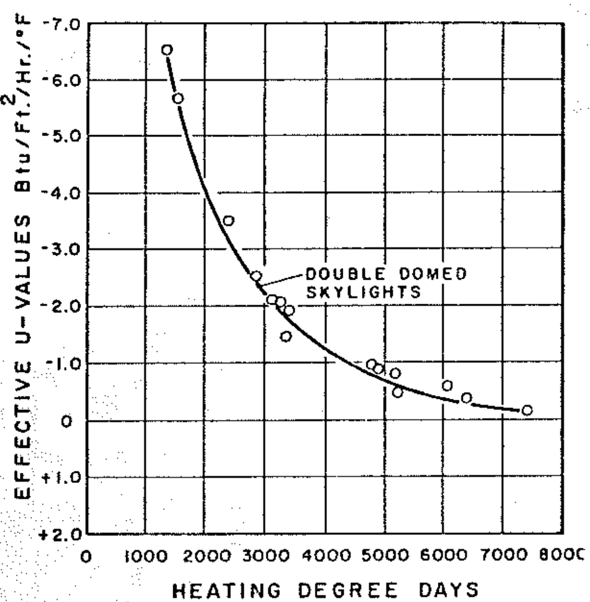


FIGURE 3

## EFFECTIVE U-VALUES FOR HEATED AND AIR-CONDITIONED BUILDINGS

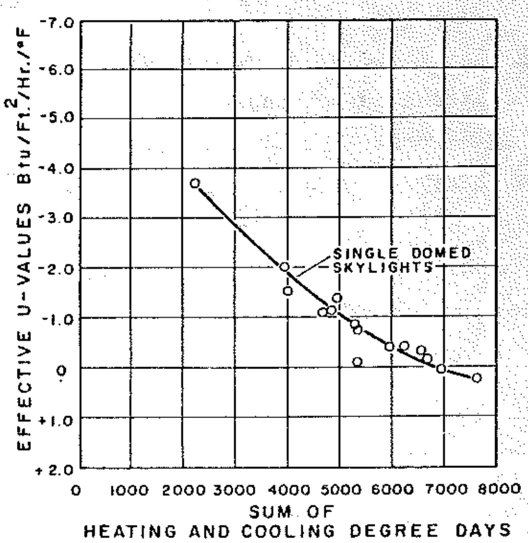


FIGURE 4

## EFFECTIVE U-VALUES FOR HEATED AND AIR-CONDITIONED BUILDINGS