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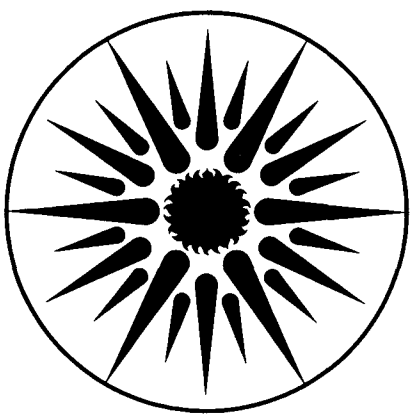
Evaluation of Solar Gain through Skylights for Inclusion in the SP53 Residential Building Loads Data Base

J.W. Hanford and Y.J. Huang

December 1993



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EVALUATION OF SOLAR GAIN THROUGH SKYLIGHTS FOR INCLUSION IN THE SP53 RESIDENTIAL BUILDING LOADS DATA BASE

James W. Hanford

and

Yu Joe Huang

Energy and Environment Division

Lawrence Berkeley Laboratory

University of California

Berkeley CA 94720

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EVALUATION OF SOLAR GAIN THROUGH SKYLIGHTS FOR INCLUSION IN THE SP53 RESIDENTIAL BUILDING LOADS DATA BASE

James W. Hanford and Y. Joe Huang

ABSTRACT

The energy performance of skylights is similar to that of windows in admitting solar heat gain, while at the same time providing a pathway for convective and conductive heat transfer through the building envelope. Since skylights are typically installed at angles ranging from 0° to 45°, and differ from windows in both their construction and operation, their conductive and convective heat gains or losses, as well as solar heat gain, will differ for the same rough opening and thermal characteristics.

The objective of this work is to quantify the impact of solar gain through skylights on building heating and cooling loads in 45 climates, and to develop a method for including these data into the SP53 residential loads data base previously developed by LBL in support of DOE's Automated Residential Energy Standard (ARES) program.

We used the DOE-2.1C program to simulate the heating and cooling loads of a prototypical residential building while varying the size and solar characteristics of skylights and windows. The results are presented as *Skylight Solar Loads*, which are the contribution of solar gains through skylights to the overall building heating and cooling loads, and as *Skylight Solar Load Ratios*, which are the ratios of skylight solar loads to those for windows with the same orientation.

The study shows that skylight solar loads are larger than those for windows in both heating and cooling. Skylight solar cooling loads are from three to four times greater than those for windows regardless of the skylight tilt, except for those facing north. These cooling loads are largest for south-facing skylights at a tilt angle of approximately 20°, and drop off at higher tilts and other orientations.

Skylight solar heating loads are approximately twice that of windows for those facing east or west, and from one to two times greater for those facing south. These loads, which represent useful solar heat gain, are highest for south-facing skylights, and increase with the tilt angle. Skylight heating loads are virtually constant for east and west orientations regardless of tilt.

This study provides a procedure for evaluating the energy performance of skylights based on their heat transfer (U-value) and solar (Shading Coefficient) characteristics. Careful reading of the assumptions used in the simulations and proper selection of the skylight characteristics are necessary for using these results in future work.

EVALUATION OF SOLAR GAIN THROUGH SKYLIGHTS FOR INCLUSION IN THE SP53 RESIDENTIAL BUILDING LOADS DATABASE

James W. Hanford and Yu Joe Huang

INTRODUCTION

Skylights are much like windows in their impacts on residential building heating and cooling loads. They provide pathways for convective and conductive heat transfer through the building envelope and admit solar gain. However, because skylights are installed at angles typically ranging from 0° to 45° from the horizontal, and because of the slightly different construction of skylights as compared to windows, skylights may provide different quantities of conductive and convective heat gains or losses as well as solar heat gain for the same rough opening.

The objective of this work is to quantify the impact of solar gain through skylights on residential heating and cooling loads. We assume that the conductive and convective properties of skylights are much the same as those of windows given appropriate assumptions about unit U-values. Therefore, we focus only on the solar gains which offset the heating loads or increase the cooling loads of a building. This work builds on a methodology previously developed under ASHRAE Special Project 53 (SP53) for estimating window solar loads in residential buildings.[1] In the SP53 project, and in this work, we use the DOE-2 building energy analysis program (Version 2.1C) and a standardized residential building prototype with varying quantities and characteristics of windows to calculate incremental changes in heating and cooling loads due to skylights and/or windows.

The results of this analysis are intended for use in the previously generated SP53 data base. The results are presented as *Skylight Solar Loads*, which are the contributions of the solar gain through skylight to the overall building heating and cooling loads, and as *Skylight Solar Load Ratios*, which are the ratios of skylight solar loads to window solar loads in the same orientation. These ratios are intended to be used as modifiers to the existing SP53 coefficients for windows. We present the data in a series of tables and show some of the data graphically.

Skylights differ from windows not only in energy performance, but also in their construction and costs. In this work we have modeled only the solar heat gain component of skylight energy performance. We did not investigate their effective U-values, nor did we attempt to evaluate their lifecycle costs as compared to typical windows. A complete energy or economic evaluation of skylights needs to be done separately from windows, and use engineering and economic data specific to skylights.

METHODOLOGY

The goal of this analysis is to estimate the solar gain impacts of skylights in residential buildings for incorporation into a building heating and cooling loads data base previously developed at LBL. We are concerned only with the solar loads, and assume that the conductive effects of skylights are the same as for windows provided that appropriate U-values are used. We have attempted to make this work as consistent as possible with the window solar loads in the previously-developed SP53 data base. In that work, window solar load coefficients for each of the four cardinal directions were developed using a one-story single family building prototype in 45 U.S. climates. In this study, we use a slightly different methodology to generate modifiers for the window solar load coefficients to characterize solar loads for skylights of various orientations and tilts.

The parameters we calculate in this analysis are defined as follows. We use the simulations to calculate the *Solar Load* on the building. The Solar Load is the amount of solar gain that either provides useful heating and reduces the overall heating load of a building, or contributes to its cooling load. The *Skylight Solar Load* (SSL) is the amount of Solar Load admitted through a skylight per unit area of aperture for a given orientation, separated into either a *Skylight Solar Heating Load* (SSHL) or a *Skylight Solar Cooling Load* (SSCL). Likewise, the *Window Solar Load* is the amount of Solar Load per unit area of window, again with a heating (WSHL) and cooling (WSCL) component. A window is defined as vertical glazing located in the wall rather than the roof of the building. Finally, we define the *Skylight Solar Load Ratio* for heating and cooling, which is the ratio of the Skylight Solar Load to the Window Solar Load for the same orientation.

To generate the original window solar loads data base, LBL performed parametric simulations for prototypical buildings varying the total window area, the fraction of window area in each orientation (north, south, east, and west) and the shading coefficient of the windows. The results of these simulations were then analyzed using regression to generate a set of coefficients (α) that are essentially the solar loads per square foot of window in each orientation. In addition, a utilizability term ($1 + \beta \times A$) was defined that is used to calculate the total solar load on the building in both heating and cooling modes according to the following equations.

$$A = \Sigma\, \alpha_i \times (\text{area}_i \times \text{shading coefficient}_i)\text{, and}$$

$$\text{Total Solar Load} = A \times (1 + \beta \times A)$$

where i = north, south, east, and west.

In this work, we generate Skylight and Window Solar Loads that are essentially equivalent to the α value for windows in the above equation. However, we use a simpler approach than that used previously, and calculate the impact on heating and cooling loads of a small incremental change in glazing area from a base case. This incremental glazing area can be either a skylight or a window. Because the original work

was done over six years ago, we also use a different version of DOE-2.1, but the models are calibrated to the original work as discussed in Appendix B.

As the base case building, we use the one-story 1540 ft^2 prototype with a window area equal to 12% of the floor area, equally distributed in the four cardinal orientations, and a window shading coefficient of 1.0. We then add one at a time a skylight with an area equal to 1% of the floor area (15.4 ft^2) in each orientation and at four different tilts. In addition, we run a window case for comparison. These runs are outlined in Table 1.

Table 1. Parametric Runs for Skylight Analysis

Case	Added Aperture Type	Tilt (Degrees)	Tilt (Slope)	Added Aperture Shading Coefficient (SC)
C14	Window	90	vertical	1.00
C15	Window	90	vertical	0.00
C16	Skylight	0	flat roof	1.00
C17	Skylight	0	flat roof	0.00
C18	Skylight	18.4	4/12	1.00
C19	Skylight	18.4	4/12	0.00
C20	Skylight	30.3	7/12	1.00
C21	Skylight	30.3	7/12	0.00
C22	Skylight	45	12/12	1.00
C23	Skylight	45	12/12	0.00

Base case house is one-story, 1540 ft^2, with window area equal to 12% of floor area. For each case, the incremental aperture area is 1% of the floor area (15.4 ft^2). Each run was performed for each cardinal direction. The difference between the SC=1 and SC=0 cases is the incremental solar load.

The solar load for the incremental aperture area is calculated as the difference between the SC=1 and SC=0 cases. This procedure removes the effect of increased conductive heat flow due to the added glazing. The results are compiled as Δ loads for heating and cooling per square foot of skylight, which we have defined as the Skylight Solar Heating and Cooling Loads, or SSHL and SSCL. We calculate the same loads for windows, and normalize the skylight loads to the window loads by calculating the SSLR for both heating and cooling.

Note that by using the shading coefficient of the glazing as a parameter, we are controlling the amount of solar gain through the glazing rather than having DOE-2.1 calculate the solar gain based on the type of glass and the angle of incidence of the solar radiation. Thus, we may be ignoring performance differences that may occur between windows and skylights due to different solar incidence angle on roofs and walls.

However, since we are primarily concerned with quantifying the solar load through an aperture with specific known properties, the use of a shading coefficient as a parameter in the model is reasonable as long as the results are used accordingly (see the next section on the modeling assumptions).

ASSUMPTIONS

An assumption in these simulations relating to the base case shading of the windows as opposed to the skylights has a major impact on the results. For the windows, we use a shading schedule of 0.80 in the winter and 0.60 in the summer to model the effects of window mullions and drapes on solar heat gain. This scheduled shading is modeled in addition to the shading coefficient of the window itself.

For the skylights, we do not use any shading schedule. We do this for two reasons. First, we assume that skylights typically do not have operable shades that can be moved by the occupants of the building. Second, the actual shading properties of the skylight assembly depend on a variety of factors. Discussions about standard, i.e., NFRC, testing procedures for rating and labeling skylights and their shading characteristics are ongoing and have yet to produce a final decision.

The simulations also include the shading effects of neighboring buildings (10 feet tall, 20 feet away) and a 2 foot roof eave overhang. These shading surfaces will further reduce solar gain through windows as compared to skylights, since the skylights are mounted on the roof, and will not "see" any obstruction from these surfaces.

The impacts of these assumptions are important when considering how these results will be used. We leave it to the user to determine the proper inputs for the shading coefficient of the skylight assembly based on the assumptions we use in the modeling and that we have stated here explicitly. Furthermore, use of these results should be made consistent with the outcome of the NFRC discussions mentioned above. Any other shading not actually modeled (e.g. from trees or other obstructions) would also need to be incorporated into the shading coefficient of the skylight or windows when using these results.

RESULTS

The results of the analysis are presented in the tables given in Appendix A. In addition, data for some locations are shown graphically. We give two sets of results. First are the Skylight Solar Loads and the Window Solar Loads, which are theoretically similar to the window solar load coefficients in the SP53 data base but which are different due to our inability to replicate the previous simulation results and the more simplified analytical approach used in this work. These solar loads are the amount of usable solar gain (useful in offsetting heating loads or contributing to the cooling load) per square foot of aperture. Second, we present the Skylight Solar Load Ratios for each

of the tilts; that is, the ratio of skylight to analogous window solar load on each of the four orientations.

Since it was impossible to fully replicate the earlier work, the SSLR values are the preferred results. These ratios can be used to modify the window solar load coefficients from the earlier work to arrive at a consistent set of solar load coefficients for skylights.

The results for 3 of the 45 climates represented are shown in Figures 1, 2, and 3. We show Albuquerque (a heating and cooling climate with substantial sunshine), Miami (a cooling-only climate), and Seattle (heating only with minimal sunshine). The figures show expected trends that can be summarized as follows:

1. Skylight Solar Cooling Loads are highest for the south orientation at a tilt of approximately 20°. Cooling loads drop slightly at increasing angles of tilt.
2. Skylight Solar Heating Loads (or useful solar gain) are highest for south-facing skylights at increasing tilt angles. Heating loads are virtually constant for the east and west orientations regardless of tilt angle.
3. Solar Cooling Loads are typically three to four times greater for skylights as compared to windows. This ratio does not vary dramatically across tilts, except on the north orientation where cooling loads for windows (the denominator in the equation) are small. These ratios are significantly higher than 1.0, meaning that skylights have a much greater cooling load impact than windows, reflecting the increasing gains at non-vertical tilts, and the shading assumptions used in the simulations.
4. Solar Heating Loads are approximately twice that of windows for east or west, and from one to two times greater than windows for south orientations. There is also a constantly increasing heating load for the south skylight orientation at increasing angles of tilt. These results also reflect the shading assumptions used in the DOE-2 model.

REFERENCES

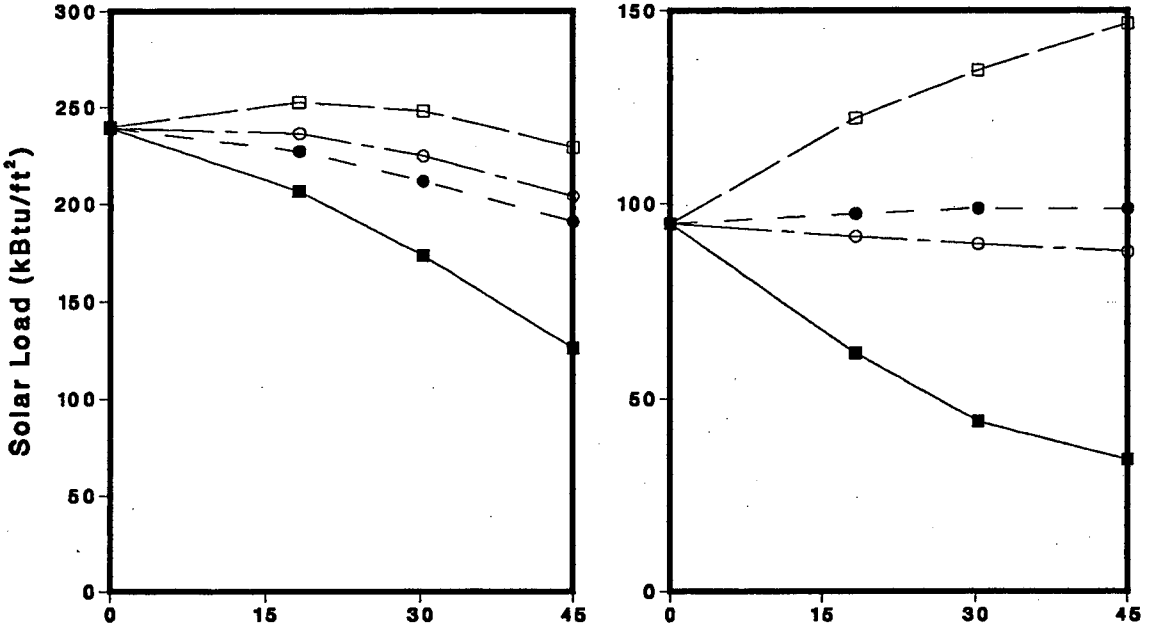
1. Huang, Y.J., R. Ritschard and J. Bull. 1987. "Technical Documentation for a Residential Energy Use Data Base Developed in Support of ASHRAE Special Project 53," LBL-24306, Lawrence Berkeley Laboratory, Berkeley, CA.

Figure 1. Skylight Solar Loads and Load Ratios for Albuquerque

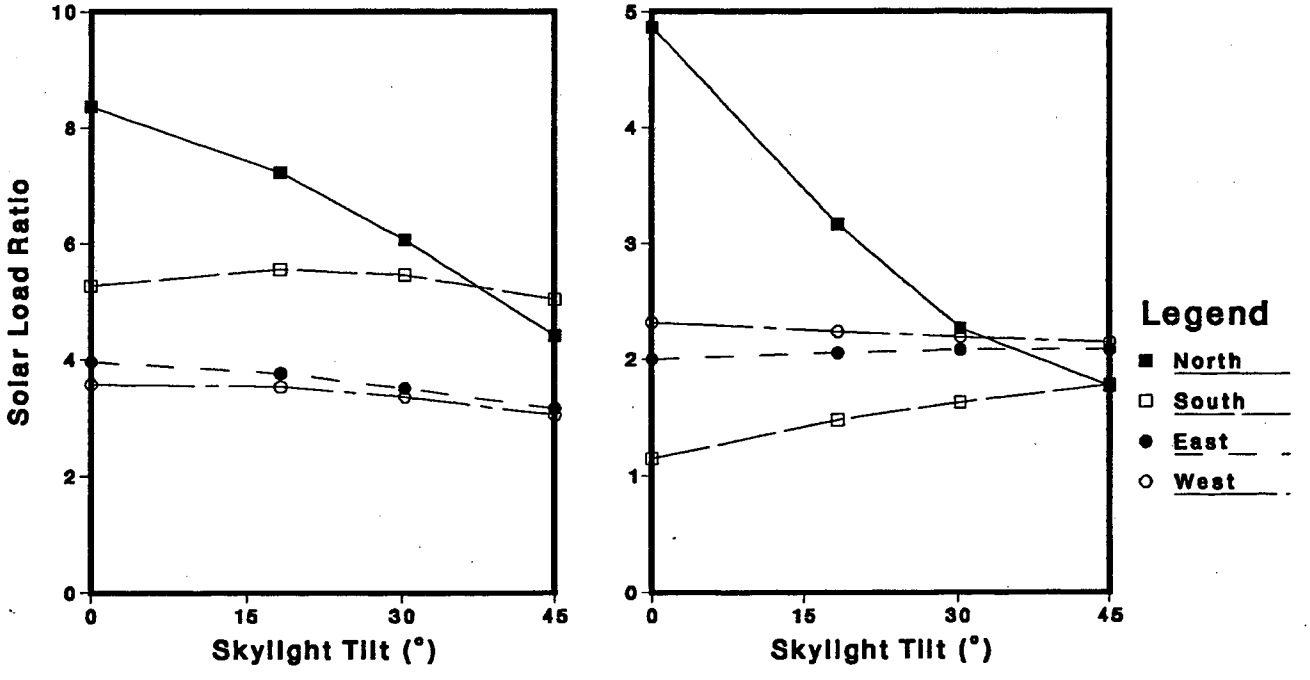
Cooling

Heating

Skylight Solar Loads are Δ heating or cooling loads per ft^2 of skylight at a SC of 1.00 .



Skylight Solar Load Ratios are the ratios of skylight to window solar loads for the same orientation.



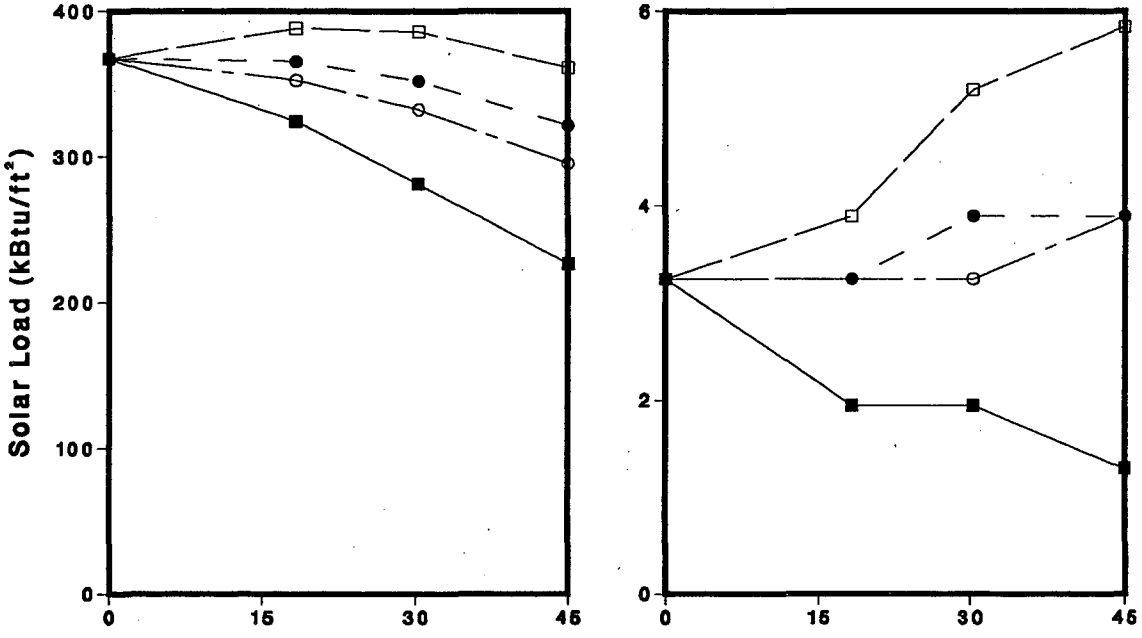
Note: Skylight loads are at a shading coefficient (SC) of 1.00, but window loads are with base SCs of 0.80 in winter and 0.60 in summer.

Figure 2. Skylight Solar Loads and Load Ratios for Miami

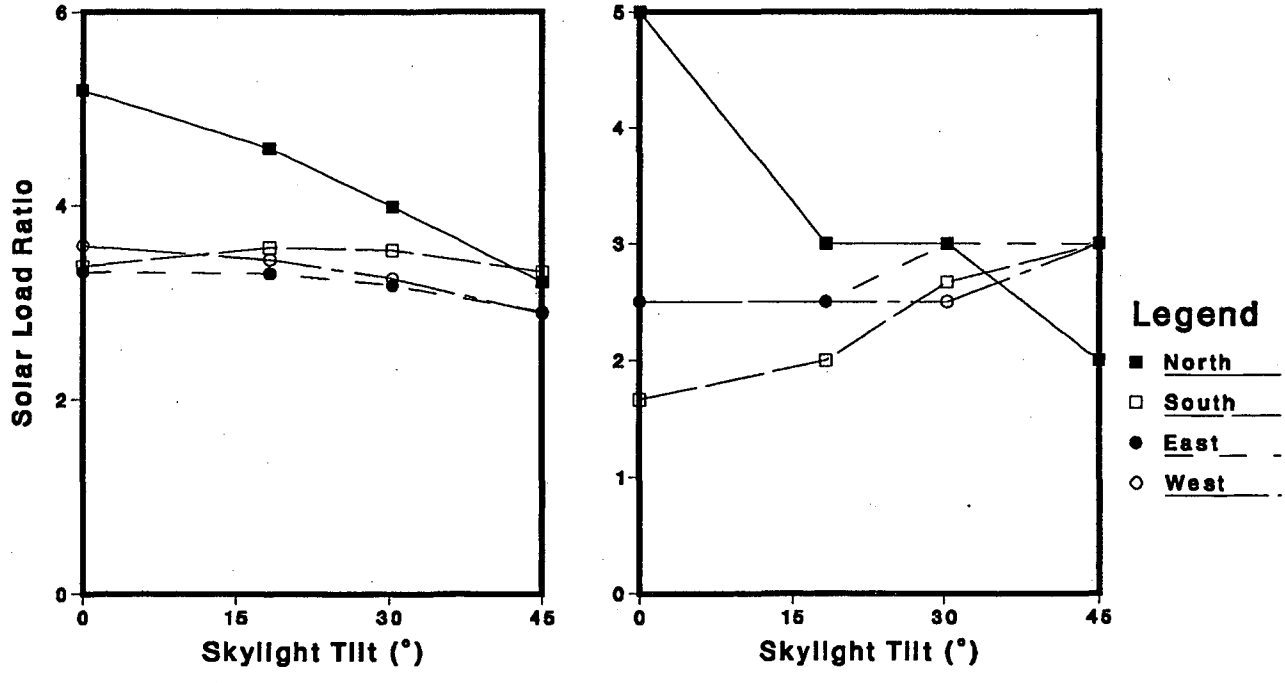
Cooling

Heating

Skylight Solar Loads are Δ heating or cooling loads per ft^2 of skylight at a SC of 1.00 .

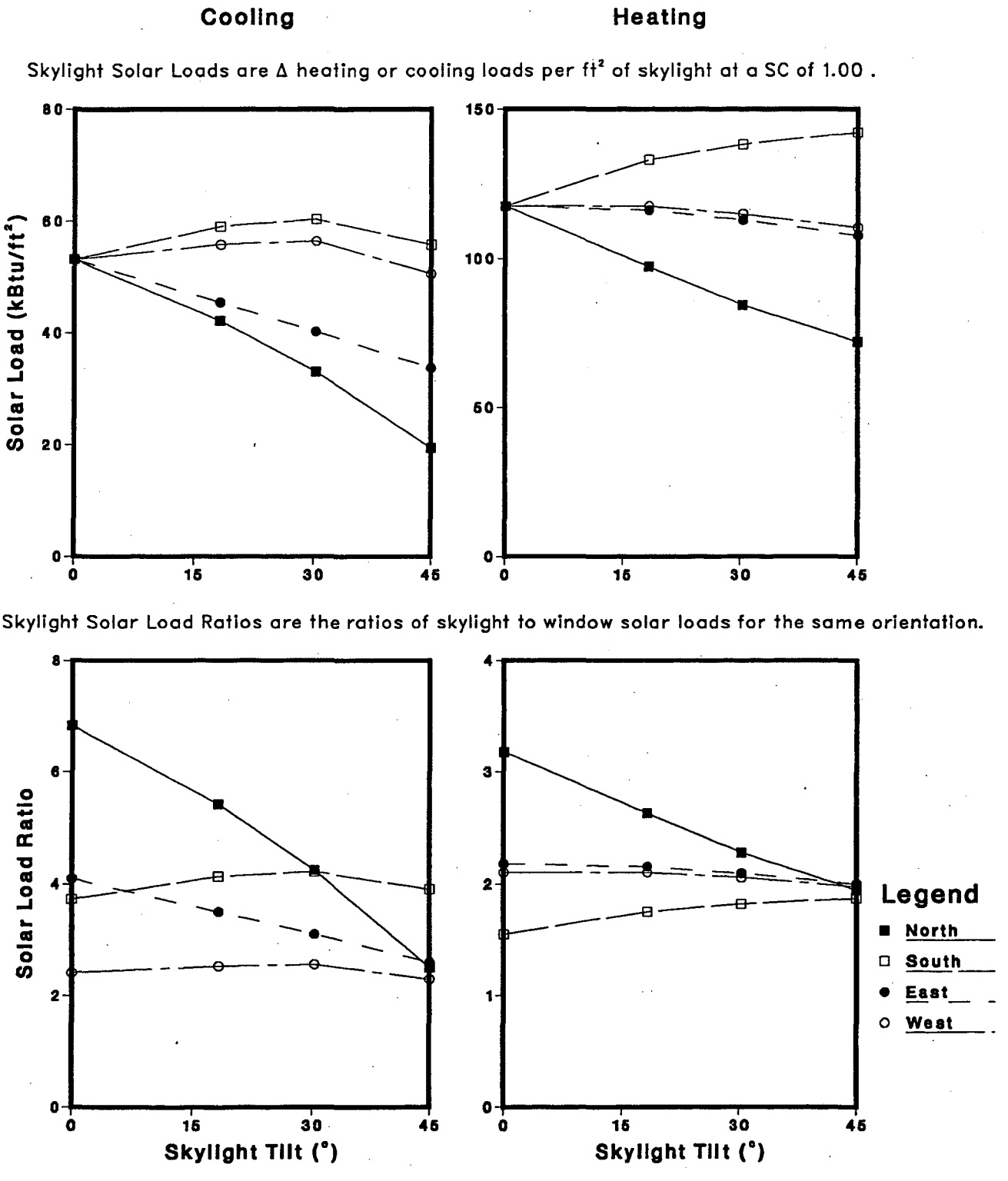


Skylight Solar Load Ratios are the ratios of skylight to window solar loads for the same orientation.



Note: Skylight loads are at a shading coefficient (SC) of 1.00, but window loads are with base SCs of 0.80 in winter and 0.60 in summer.

Figure 3. Skylight Solar Loads and Load Ratios for Seattle



Note: Skylight loads are at a shading coefficient (SC) of 1.00, but window loads are with base SCs of 0.80 in winter and 0.60 in summer.

APPENDIX A - RESULTS TABLES

Appendix A.1. Skylight Solar Loads and Load Ratios

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Albuquerque NM										
Window	*90*	*Cooling*	*28.6*	*45.5*	*60.4*	*66.9*				
Skylight	0	Cooling	239.0	239.6	239.0	239.0	8.36	5.27	3.96	3.57
"	18	"	206.5	252.6	227.3	236.4	7.23	5.56	3.76	3.53
"	30	"	173.4	248.1	211.7	224.7	6.07	5.46	3.51	3.36
"	45	"	126.0	229.2	190.9	203.9	4.41	5.04	3.16	3.05
Window	*90*	*Heating*	*-19.5*	*-82.5*	*-47.4*	*-40.9*				
Skylight	0	Heating	-94.8	-94.8	-94.8	-94.8	4.87	1.15	2.00	2.32
"	18	"	-61.7	-122.1	-97.4	-91.6	3.17	1.48	2.05	2.24
"	30	"	-44.2	-134.4	-98.7	-89.6	2.27	1.63	2.08	2.19
"	45	"	-34.4	-146.8	-98.7	-87.7	1.77	1.78	2.08	2.14
Atlanta GA										
Window	*90*	*Cooling*	*35.7*	*46.1*	*55.8*	*60.4*				
Skylight	0	Cooling	203.2	203.2	203.2	203.2	5.69	4.41	3.64	3.37
"	18	"	181.2	213.6	195.5	199.4	5.07	4.63	3.50	3.30
"	30	"	159.1	209.7	185.7	190.3	4.45	4.55	3.33	3.15
"	45	"	123.4	191.6	162.3	169.5	3.45	4.15	2.91	2.81
Window	*90*	*Heating*	*-19.5*	*-50.6*	*-33.1*	*-30.5*				
Skylight	0	Heating	-69.5	-69.5	-69.5	-69.5	3.57	1.37	2.10	2.28
"	18	"	-53.2	-82.5	-70.1	-68.2	2.73	1.63	2.12	2.23
"	30	"	-43.5	-88.3	-70.1	-66.9	2.23	1.74	2.12	2.19
"	45	"	-37.0	-92.2	-67.5	-64.3	1.90	1.82	2.04	2.11
Birmingham AL										
Window	*90*	*Cooling*	*42.9*	*53.9*	*81.2*	*51.3*				
Skylight	0	Cooling	209.1	209.7	209.1	209.1	4.88	3.89	2.58	4.08
"	18	"	189.6	217.5	220.8	189.0	4.42	4.04	2.72	3.68
"	30	"	167.5	213.6	219.5	172.7	3.91	3.96	2.70	3.37
"	45	"	135.1	198.1	207.8	150.6	3.15	3.67	2.56	2.94
Window	*90*	*Heating*	*-18.2*	*-46.1*	*-35.7*	*-23.4*				
Skylight	0	Heating	-63.6	-63.6	-63.6	-63.6	3.50	1.38	1.78	2.72
"	18	"	-48.7	-75.3	-68.2	-59.1	2.68	1.63	1.91	2.53
"	30	"	-39.6	-80.5	-70.1	-56.5	2.18	1.75	1.96	2.42
"	45	"	-33.8	-84.4	-70.8	-52.6	1.86	1.83	1.98	2.25
Bismarck ND										
Window	*90*	*Cooling*	*17.5*	*31.2*	*34.4*	*39.6*				
Skylight	0	Cooling	125.3	125.3	125.3	125.3	7.15	4.02	3.64	3.16
"	18	"	100.6	137.7	117.5	124.0	5.74	4.42	3.42	3.13
"	30	"	80.5	139.0	110.4	118.8	4.59	4.46	3.21	3.00
"	45	"	53.2	130.5	97.4	107.8	3.04	4.19	2.83	2.72
Window	*90*	*Heating*	*-39.0*	*-120.1*	*-76.6*	*-68.8*				
Skylight	0	Heating	-146.8	-147.4	-146.8	-146.8	3.77	1.23	1.92	2.13
"	18	"	-106.5	-182.5	-150.6	-144.2	2.73	1.52	1.97	2.09
"	30	"	-87.0	-197.4	-150.0	-141.6	2.23	1.64	1.96	2.06
"	45	"	-70.8	-207.8	-147.4	-135.7	1.82	1.73	1.92	1.97

Appendix A.2. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Boise ID										
Window	*90*	*Cooling*	*20.8*	*33.8*	*41.6*	*53.2*				
Skylight	0	Cooling	172.7	172.7	172.7	173.4	8.31	5.12	4.16	3.26
"	18	"	142.2	188.3	159.1	172.1	6.84	5.58	3.83	3.23
"	30	"	116.2	189.6	146.1	166.9	5.59	5.62	3.52	3.13
"	45	"	77.9	178.6	131.8	155.2	3.75	5.29	3.17	2.91
Window	*90*	*Heating*	*-32.5*	*-100.6*	*-63.0*	*-58.4*				
Skylight	0	Heating	-124.7	-125.3	-125.3	-125.3	3.84	1.25	1.99	2.14
"	18	"	-90.9	-154.5	-126.6	-122.7	2.80	1.54	2.01	2.10
"	30	"	-74.7	-166.2	-124.7	-120.8	2.30	1.65	1.98	2.07
"	45	"	-60.4	-174.7	-122.7	-115.6	1.86	1.74	1.95	1.98
Boston MA										
Window	*90*	*Cooling*	*20.8*	*29.2*	*34.4*	*35.1*				
Skylight	0	Cooling	111.7	111.7	112.3	111.7	5.38	3.82	3.26	3.19
"	18	"	94.8	120.8	107.1	109.7	4.56	4.13	3.11	3.13
"	30	"	80.5	119.5	99.4	105.8	3.88	4.09	2.89	3.02
"	45	"	61.7	113.6	90.9	96.1	2.97	3.89	2.64	2.74
Window	*90*	*Heating*	*-33.1*	*-90.9*	*-57.8*	*-54.5*				
Skylight	0	Heating	-121.4	-122.1	-121.4	-121.4	3.67	1.34	2.10	2.23
"	18	"	-91.6	-145.5	-121.4	-118.8	2.76	1.60	2.10	2.18
"	30	"	-76.0	-155.2	-119.5	-115.6	2.29	1.71	2.07	2.12
"	45	"	-62.3	-161.0	-114.3	-109.7	1.88	1.77	1.98	2.01
Brownsville TX										
Window	*90*	*Cooling*	*63.6*	*90.3*	*109.7*	*103.2*				
Skylight	0	Cooling	370.1	370.1	370.1	370.1	5.82	4.10	3.37	3.58
"	18	"	327.9	383.8	362.3	357.1	5.15	4.25	3.30	3.46
"	30	"	290.9	375.3	346.8	336.4	4.57	4.16	3.16	3.26
"	45	"	235.1	344.8	315.6	304.5	3.69	3.82	2.88	2.95
Window	*90*	*Heating*	*-3.9*	*-8.4*	*-5.8*	*-5.2*				
Skylight	0	Heating	-13.6	-13.6	-13.6	-13.6	3.50	1.62	2.33	2.62
"	18	"	-11.0	-15.6	-13.6	-13.6	2.83	1.85	2.33	2.62
"	30	"	-9.7	-16.9	-14.3	-13.6	2.50	2.00	2.44	2.62
"	45	"	-7.8	-18.2	-14.3	-13.0	2.00	2.15	2.44	2.50
Buffalo NY										
Window	*90*	*Cooling*	*17.5*	*24.0*	*27.9*	*31.8*				
Skylight	0	Cooling	94.2	94.8	94.2	94.8	5.37	3.95	3.37	2.98
"	18	"	80.5	101.3	89.0	94.8	4.59	4.22	3.19	2.98
"	30	"	67.5	100.0	82.5	90.3	3.85	4.16	2.95	2.84
"	45	"	50.6	94.2	73.4	82.5	2.89	3.92	2.63	2.59
Window	*90*	*Heating*	*-35.1*	*-72.7*	*-53.9*	*-51.3*				
Skylight	0	Heating	-119.5	-119.5	-119.5	-119.5	3.41	1.64	2.22	2.33
"	18	"	-98.1	-135.7	-118.8	-116.9	2.80	1.87	2.20	2.28
"	30	"	-85.1	-140.9	-115.6	-113.0	2.43	1.94	2.14	2.20
"	45	"	-71.4	-142.9	-109.7	-105.8	2.04	1.96	2.04	2.06

Appendix A.3. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Burlington VT										
Window	*90*	*Cooling*	*13.6*	*19.5*	23.4	*29.2*				
Skylight	0	Cooling	93.5	93.5	93.5	93.5	6.86	4.80	4.00	3.20
"	18	"	79.9	103.2	89.0	95.5	5.86	5.30	3.81	3.27
"	30	"	66.2	101.9	79.2	90.3	4.86	5.23	3.39	3.09
"	45	"	45.5	93.5	70.1	81.8	3.33	4.80	3.00	2.80
Window	*90*	*Heating*	*-37.7*	*-103.2*	*-65.6*	*-62.3*				
Skylight	0	Heating	-140.3	-140.3	-140.3	-140.3	3.72	1.36	2.14	2.25
"	18	"	-105.2	-168.8	-139.6	-137.7	2.79	1.64	2.13	2.21
"	30	"	-87.0	-179.9	-137.0	-133.1	2.31	1.74	2.09	2.14
"	45	"	-72.1	-185.7	-130.5	-126.6	1.91	1.80	1.99	2.03
Charleston SC										
Window	*90*	*Cooling*	*51.9*	*71.4*	*82.5*	*76.6*				
Skylight	0	Cooling	277.9	278.6	277.9	277.9	5.35	3.90	3.37	3.63
"	18	"	246.1	291.6	272.7	266.2	4.74	4.08	3.31	3.47
"	30	"	215.6	287.0	260.4	249.4	4.15	4.02	3.16	3.25
"	45	"	174.0	267.5	237.7	224.0	3.35	3.75	2.88	2.92
Window	*90*	*Heating*	*-13.0*	*-37.0*	*-22.1*	*-20.1*				
Skylight	0	Heating	-48.1	-48.1	-48.1	-48.1	3.70	1.30	2.18	2.39
"	18	"	-34.4	-58.4	-48.7	-46.8	2.65	1.58	2.21	2.32
"	30	"	-27.3	-63.0	-48.1	-44.8	2.10	1.70	2.18	2.23
"	45	"	-23.4	-68.2	-46.8	-43.5	1.80	1.84	2.12	2.16
Cheyenne WY										
Window	*90*	*Cooling*	*13.6*	*22.7*	*27.3*	*35.1*				
Skylight	0	Cooling	115.6	115.6	115.6	115.6	8.48	5.09	4.24	3.30
"	18	"	96.1	125.3	109.1	114.3	7.05	5.51	4.00	3.26
"	30	"	77.3	123.4	100.0	108.4	5.67	5.43	3.67	3.09
"	45	"	51.9	114.3	88.3	96.8	3.81	5.03	3.24	2.76
Window	*90*	*Heating*	*-42.2*	*-153.9*	*-94.2*	*-88.3*				
Skylight	0	Heating	-188.3	-188.3	-188.3	-188.3	4.46	1.22	2.00	2.13
"	18	"	-131.2	-238.3	-191.6	-186.4	3.11	1.55	2.03	2.11
"	30	"	-102.6	-259.1	-190.9	-183.8	2.43	1.68	2.03	2.08
"	45	"	-80.5	-273.4	-187.7	-178.6	1.91	1.78	1.99	2.02
Chicago IL										
Window	*90*	*Cooling*	*27.9*	*40.3*	*48.1*	53.2				
Skylight	0	Cooling	174.0	174.0	174.0	174.0	6.23	4.32	3.62	3.27
"	18	"	148.7	187.0	169.5	170.1	5.33	4.65	3.53	3.20
"	30	"	127.9	188.3	161.0	162.3	4.58	4.68	3.35	3.05
"	45	"	94.8	176.0	146.1	148.7	3.40	4.37	3.04	2.79
Window	*90*	*Heating*	*-29.2*	*-108.4*	*-59.7*	*-56.5*				
Skylight	0	Heating	-125.3	-126.0	-126.0	-125.3	4.29	1.16	2.11	2.22
"	18	"	-85.7	-161.0	-127.3	-122.7	2.93	1.49	2.13	2.17
"	30	"	-66.9	-175.3	-126.0	-119.5	2.29	1.62	2.11	2.11
"	45	"	-53.2	-185.7	-122.1	-114.3	1.82	1.71	2.04	2.02

Appendix A.4. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft^2) North	South	East	West	Solar Load Ratio North	South	East	West
Cincinnati OH										
Window	*90*	*Cooling*	*27.9*	*39.6*	*46.1*	*48.7*				
Skylight	0	Cooling	172.1	172.1	172.1	172.1	6.16	4.34	3.73	3.53
"	18	"	150.0	181.8	165.6	166.2	5.37	4.59	3.59	3.41
"	30	"	126.6	179.9	155.8	157.1	4.53	4.54	3.38	3.23
"	45	"	94.8	164.9	137.0	139.6	3.40	4.16	2.97	2.87
Window	*90*	*Heating*	*-27.9*	*-73.4*	*-44.2*	*-41.6*				
Skylight	0	Heating	-98.7	-98.7	-98.7	-99.4	3.53	1.35	2.24	2.39
"	18	"	-74.0	-118.2	-98.1	-96.1	2.65	1.61	2.22	2.31
"	30	"	-61.7	-125.3	-95.5	-92.2	2.21	1.71	2.16	2.22
"	45	"	-51.9	-129.9	-90.9	-86.4	1.86	1.77	2.06	2.08
Denver CO										
Window	*90*	*Cooling*	*24.0*	*36.4*	*45.5*	*52.6*				
Skylight	0	Cooling	179.2	179.2	179.2	179.2	7.46	4.93	3.94	3.41
"	18	"	148.7	193.5	168.2	175.3	6.19	5.32	3.70	3.33
"	30	"	123.4	191.6	156.5	166.9	5.14	5.27	3.44	3.17
"	45	"	83.1	175.3	137.7	149.4	3.46	4.82	3.03	2.84
Window	*90*	*Heating*	*-31.8*	*-128.6*	*-75.3*	*-68.2*				
Skylight	0	Heating	-140.9	-140.9	-140.9	-141.6	4.43	1.10	1.87	2.08
"	18	"	-94.2	-183.1	-146.1	-139.0	2.96	1.42	1.94	2.04
"	30	"	-72.7	-202.6	-148.7	-137.7	2.29	1.58	1.97	2.02
"	45	"	-59.1	-217.5	-148.1	-134.4	1.86	1.69	1.97	1.97
El Paso TX										
Window	*90*	*Cooling*	*38.3*	*54.5*	*78.6*	*81.2*				
Skylight	0	Cooling	306.5	306.5	306.5	306.5	8.00	5.62	3.90	3.78
"	18	"	264.9	318.2	293.5	297.4	6.92	5.83	3.74	3.66
"	30	"	227.9	311.0	277.3	282.5	5.95	5.70	3.53	3.48
"	45	"	172.7	285.7	252.6	257.8	4.51	5.24	3.21	3.18
Window	*90*	*Heating*	*-12.3*	*-48.1*	*-28.6*	*-23.4*				
Skylight	0	Heating	-55.2	-55.8	-55.8	-55.2	4.47	1.16	1.95	2.36
"	18	"	-36.4	-70.8	-57.8	-53.9	2.95	1.47	2.02	2.31
"	30	"	-26.0	-79.2	-58.4	-52.6	2.11	1.65	2.05	2.25
"	45	"	-20.8	-88.3	-60.4	-52.6	1.68	1.84	2.11	2.25
Fort Worth TX										
Window	*90*	*Cooling*	*41.6*	*56.5*	*68.8*	*76.6*				
Skylight	0	Cooling	257.8	257.8	257.8	257.8	6.20	4.56	3.75	3.36
"	18	"	227.9	270.8	245.5	255.8	5.48	4.79	3.57	3.34
"	30	"	198.7	263.0	228.6	243.5	4.78	4.66	3.32	3.18
"	45	"	152.6	242.2	205.2	220.8	3.67	4.29	2.98	2.88
Window	*90*	*Heating*	*-14.9*	*-42.9*	*-25.3*	*-24.0*				
Skylight	0	Heating	-56.5	-56.5	-56.5	-56.5	3.78	1.32	2.23	2.35
"	18	"	-41.6	-68.2	-57.1	-55.2	2.78	1.59	2.26	2.30
"	30	"	-32.5	-74.0	-55.8	-54.5	2.17	1.73	2.21	2.27
"	45	"	-26.6	-79.2	-54.5	-51.9	1.78	1.85	2.15	2.16

Appendix A.5. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Fresno CA										
Window	*90*	*Cooling*	*34.4*	*55.8*	*67.5*	*79.9*				
Skylight	0	Cooling	268.8	268.8	268.8	268.8	7.81	4.81	3.98	3.37
"	18	"	226.0	287.7	253.2	266.9	6.57	5.15	3.75	3.34
"	30	"	187.7	287.7	237.0	257.8	5.45	5.15	3.51	3.23
"	45	"	135.7	271.4	211.7	240.3	3.94	4.86	3.13	3.01
Window	*90*	*Heating*	*-14.9*	*-47.4*	*-27.9*	*-26.6*				
Skylight	0	Heating	-59.7	-59.7	-59.7	-59.7	4.00	1.26	2.14	2.24
"	18	"	-42.9	-73.4	-60.4	-59.1	2.87	1.55	2.16	2.22
"	30	"	-34.4	-79.2	-59.7	-57.8	2.30	1.67	2.14	2.17
"	45	"	-29.2	-85.7	-59.7	-57.1	1.96	1.81	2.14	2.15
Great Falls MT										
Window	*90*	*Cooling*	*13.0*	*27.9*	*26.6*	*33.8*				
Skylight	0	Cooling	102.6	102.6	102.6	102.6	7.90	3.67	3.85	3.04
"	18	"	79.2	116.2	94.8	105.2	6.10	4.16	3.56	3.12
"	30	"	61.0	117.5	87.0	100.0	4.70	4.21	3.27	2.96
"	45	"	38.3	112.3	76.6	90.9	2.95	4.02	2.88	2.69
Window	*90*	*Heating*	*-38.3*	*-116.9*	*-76.0*	*-67.5*				
Skylight	0	Heating	-145.5	-146.1	-146.1	-146.8	3.80	1.25	1.92	2.17
"	18	"	-107.1	-180.5	-149.4	-142.2	2.80	1.54	1.97	2.11
"	30	"	-88.3	-194.2	-149.4	-139.0	2.31	1.66	1.97	2.06
"	45	"	-72.1	-204.5	-147.4	-133.8	1.88	1.75	1.94	1.98
Honolulu HI										
Window	*90*	*Cooling*	*75.3*	*114.9*	*144.2*	*100.6*				
Skylight	0	Cooling	452.6	452.6	452.6	451.9	6.01	3.94	3.14	4.49
"	18	"	396.8	474.7	463.0	416.9	5.27	4.13	3.21	4.14
"	30	"	338.3	467.5	447.4	381.8	4.49	4.07	3.10	3.79
"	45	"	263.0	426.0	407.8	327.9	3.49	3.71	2.83	3.26
Window	*90*	*Heating*	*0.0*	*0.0*	*0.0*	*0.0*				
Skylight	0	Heating	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
"	18	"	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
"	30	"	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
"	45	"	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Jacksonville FL										
Window	*90*	*Cooling*	*51.3*	*74.7*	*91.6*	*73.4*				
Skylight	0	Cooling	286.4	286.4	286.4	285.7	5.58	3.83	3.13	3.89
"	18	"	250.6	301.9	286.4	269.5	4.89	4.04	3.13	3.67
"	30	"	216.9	298.1	276.6	248.1	4.23	3.99	3.02	3.38
"	45	"	171.4	277.9	257.1	218.8	3.34	3.72	2.81	2.98
Window	*90*	*Heating*	*-9.1*	*-29.2*	*-16.9*	*-14.3*				
Skylight	0	Heating	-36.4	-36.4	-36.4	-35.7	4.00	1.24	2.15	2.50
"	18	"	-25.3	-44.2	-36.4	-34.4	2.79	1.51	2.15	2.41
"	30	"	-19.5	-48.7	-36.4	-33.8	2.14	1.67	2.15	2.36
"	45	"	-16.2	-51.9	-36.4	-31.8	1.79	1.78	2.15	2.23

Appendix A.6. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Juneau AK										
Window	*90*	*Cooling*	*0.0*	*0.0*	*0.0*	*0.0*				
Skylight	0	Cooling	1.3	1.3	1.3	1.3	0.00	0.00	0.00	0.00
"	18	"	0.6	1.3	0.6	1.3	0.00	0.00	0.00	0.00
"	30	"	0.0	1.3	0.6	1.3	0.00	0.00	0.00	0.00
"	45	"	0.0	1.3	0.0	1.3	0.00	0.00	0.00	0.00
Window	*90*	*Heating*	*-39.6*	*-78.6*	*-57.1*	*-54.5*				
Skylight	0	Heating	-116.9	-117.5	-117.5	-116.9	2.95	1.50	2.06	2.14
"	18	"	-98.1	-133.8	-116.9	-113.6	2.48	1.70	2.05	2.08
"	30	"	-86.4	-139.6	-114.3	-110.4	2.18	1.78	2.00	2.02
"	45	"	-75.3	-142.2	-109.7	-105.2	1.90	1.81	1.92	1.93
Kansas City MO										
Window	*90*	*Cooling*	*36.4*	*48.7*	*80.5*	*51.3*				
Skylight	0	Cooling	218.8	218.8	218.8	218.8	6.02	4.49	2.72	4.27
"	18	"	190.3	231.8	226.6	200.0	5.23	4.76	2.81	3.90
"	30	"	163.0	229.2	222.7	183.8	4.48	4.71	2.77	3.58
"	45	"	123.4	214.3	207.8	162.3	3.39	4.40	2.58	3.16
Window	*90*	*Heating*	*-28.6*	*-87.0*	*-61.0*	*-38.3*				
Skylight	0	Heating	-102.6	-102.6	-102.6	-102.6	3.59	1.18	1.68	2.68
"	18	"	-73.4	-127.9	-111.0	-94.2	2.57	1.47	1.82	2.46
"	30	"	-59.7	-139.0	-113.0	-89.0	2.09	1.60	1.85	2.32
"	45	"	-50.0	-146.1	-113.6	-82.5	1.75	1.68	1.86	2.15
Lake Charles LA										
Window	*90*	*Cooling*	*48.7*	*67.5*	*79.9*	*75.3*				
Skylight	0	Cooling	265.6	265.6	265.6	265.6	5.45	3.93	3.33	3.53
"	18	"	236.4	274.0	258.4	253.9	4.85	4.06	3.24	3.37
"	30	"	208.4	268.2	246.1	239.6	4.28	3.97	3.08	3.18
"	45	"	166.2	248.1	224.7	214.9	3.41	3.67	2.81	2.85
Window	*90*	*Heating*	*-10.4*	*-26.0*	*-17.5*	*-16.2*				
Skylight	0	Heating	-37.7	-37.7	-37.7	-37.7	3.62	1.45	2.15	2.32
"	18	"	-29.2	-44.8	-37.7	-37.0	2.81	1.72	2.15	2.28
"	30	"	-24.0	-48.1	-37.7	-36.4	2.31	1.85	2.15	2.24
"	45	"	-20.1	-50.6	-37.0	-35.7	1.94	1.95	2.11	2.20
Las Vegas NV										
Window	*90*	*Cooling*	*37.0*	*64.3*	*81.8*	*90.3*				
Skylight	0	Cooling	313.0	313.0	313.0	313.0	8.46	4.87	3.83	3.47
"	18	"	260.4	334.4	298.1	305.2	7.04	5.20	3.64	3.38
"	30	"	216.9	333.8	281.8	292.9	5.86	5.19	3.44	3.24
"	45	"	155.8	312.3	255.2	267.5	4.21	4.86	3.12	2.96
Window	*90*	*Heating*	*-11.7*	*-51.9*	*-27.9*	*-24.0*				
Skylight	0	Heating	-53.2	-53.2	-53.2	-53.2	4.56	1.02	1.91	2.22
"	18	"	-33.8	-70.1	-55.2	-52.6	2.89	1.35	1.98	2.19
"	30	"	-24.0	-78.6	-55.8	-51.3	2.06	1.51	2.00	2.14
"	45	"	-19.5	-87.0	-56.5	-50.0	1.67	1.67	2.02	2.08

Appendix A.7. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Los Angeles CA										
Window	*90*	*Cooling*	*14.3*	*26.0*	*24.0*	*28.6*				
Skylight	0	Cooling	111.7	111.7	111.7	111.7	7.82	4.30	4.65	3.91
"	18	"	91.6	116.9	100.0	108.4	6.41	4.50	4.16	3.80
"	30	"	70.8	119.5	87.0	104.5	4.95	4.60	3.62	3.66
"	45	"	44.2	101.3	76.0	94.8	3.09	3.90	3.16	3.32
Window	*90*	*Heating*	*-17.5*	*-41.6*	*-28.6*	*-33.1*				
Skylight	0	Heating	-68.2	-68.2	-67.5	-68.2	3.89	1.64	2.36	2.06
"	18	"	-54.5	-77.9	-65.6	-69.5	3.11	1.88	2.30	2.10
"	30	"	-46.1	-83.1	-63.6	-70.8	2.63	2.00	2.23	2.14
"	45	"	-39.0	-88.3	-63.6	-72.1	2.22	2.13	2.23	2.18
Medford OR										
Window	*90*	*Cooling*	*26.0*	*42.9*	*44.2*	*59.7*				
Skylight	0	Cooling	185.7	185.7	185.7	185.7	7.15	4.33	4.21	3.11
"	18	"	151.3	203.2	168.2	188.3	5.82	4.74	3.81	3.15
"	30	"	124.0	205.8	154.5	183.1	4.77	4.80	3.50	3.07
"	45	"	81.8	194.8	134.4	170.1	3.15	4.55	3.04	2.85
Window	*90*	*Heating*	*-24.0*	*-57.1*	*-35.7*	*-37.0*				
Skylight	0	Heating	-78.6	-78.6	-78.6	-78.6	3.27	1.37	2.20	2.12
"	18	"	-62.3	-92.2	-77.3	-79.2	2.59	1.61	2.16	2.14
"	30	"	-53.9	-97.4	-76.0	-77.9	2.24	1.70	2.13	2.11
"	45	"	-47.4	-101.3	-73.4	-76.0	1.97	1.77	2.05	2.05
Memphis TN										
Window	*90*	*Cooling*	*42.2*	*58.4*	*71.4*	*77.3*				
Skylight	0	Cooling	256.5	256.5	256.5	256.5	6.08	4.39	3.59	3.32
"	18	"	226.6	268.8	245.5	252.6	5.37	4.60	3.44	3.27
"	30	"	200.0	266.9	234.4	243.5	4.74	4.57	3.28	3.15
"	45	"	153.9	244.2	209.1	218.8	3.65	4.18	2.93	2.83
Window	*90*	*Heating*	*-17.5*	*-59.1*	*-32.5*	*-29.9*				
Skylight	0	Heating	-70.1	-70.1	-70.1	-70.1	4.00	1.19	2.16	2.35
"	18	"	-48.1	-87.7	-70.1	-68.2	2.74	1.48	2.16	2.28
"	30	"	-36.4	-95.5	-70.1	-66.2	2.07	1.62	2.16	2.22
"	45	"	-29.2	-102.6	-67.5	-63.6	1.67	1.74	2.08	2.13
Miami FL										
Window	*90*	*Cooling*	*70.8*	*109.1*	*111.0*	*102.6*				
Skylight	0	Cooling	367.5	367.5	367.5	367.5	5.19	3.37	3.31	3.58
"	18	"	324.7	388.3	365.6	352.6	4.59	3.56	3.29	3.44
"	30	"	281.8	385.7	351.9	332.5	3.98	3.54	3.17	3.24
"	45	"	226.6	361.0	321.4	295.5	3.20	3.31	2.89	2.88
Window	*90*	*Heating*	*-0.6*	*-1.9*	*-1.3*	*-1.3*				
Skylight	0	Heating	-3.2	-3.2	-3.2	-3.2	5.00	1.67	2.50	2.50
"	18	"	-1.9	-3.9	-3.2	-3.2	3.00	2.00	2.50	2.50
"	30	"	-1.9	-5.2	-3.9	-3.2	3.00	2.67	3.00	2.50
"	45	"	-1.3	-5.8	-3.9	-3.9	2.00	3.00	3.00	3.00

Appendix A.8. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Minneapolis MN										
Window	*90*	*Cooling*	*22.1*	*33.8*	*37.7*	*44.8*				
Skylight	0	Cooling	136.4	136.4	136.4	136.4	6.18	4.04	3.62	3.04
"	18	"	115.6	147.4	129.2	133.8	5.24	4.37	3.43	2.99
"	30	"	95.5	147.4	121.4	127.9	4.32	4.37	3.22	2.86
"	45	"	68.8	140.3	106.5	119.5	3.12	4.15	2.83	2.67
Window	*90*	*Heating*	*-35.1*	*-107.1*	*-64.3*	*-62.3*				
Skylight	0	Heating	-133.8	-133.8	-133.8	-133.8	3.81	1.25	2.08	2.15
"	18	"	-97.4	-164.9	-133.8	-131.8	2.78	1.54	2.08	2.11
"	30	"	-78.6	-177.3	-131.8	-128.6	2.24	1.65	2.05	2.06
"	45	"	-64.3	-185.7	-126.6	-122.7	1.83	1.73	1.97	1.97
Nashville TN										
Window	*90*	*Cooling*	*33.1*	*44.8*	*54.5*	*54.5*				
Skylight	0	Cooling	196.1	196.8	196.1	196.1	5.92	4.39	3.60	3.60
"	18	"	174.0	205.2	192.2	189.6	5.25	4.58	3.52	3.48
"	30	"	153.9	203.2	183.1	179.2	4.65	4.54	3.36	3.29
"	45	"	119.5	190.9	168.8	163.6	3.61	4.26	3.10	3.00
Window	*90*	*Heating*	*-19.5*	*-53.9*	*-32.5*	*-31.8*				
Skylight	0	Heating	-74.0	-74.0	-74.0	-74.7	3.80	1.37	2.28	2.35
"	18	"	-55.8	-88.3	-74.0	-72.7	2.87	1.64	2.28	2.29
"	30	"	-44.8	-94.2	-72.1	-70.1	2.30	1.75	2.22	2.20
"	45	"	-36.4	-98.1	-67.5	-66.2	1.87	1.82	2.08	2.08
New York NY										
Window	*90*	*Cooling*	*26.0*	*38.3*	*40.9*	*40.9*				
Skylight	0	Cooling	140.9	140.9	140.9	140.9	5.42	3.68	3.44	3.44
"	18	"	122.1	150.0	136.4	135.1	4.70	3.92	3.33	3.30
"	30	"	103.9	149.4	128.6	127.3	4.00	3.90	3.14	3.11
"	45	"	77.9	140.9	114.9	113.6	3.00	3.68	2.81	2.78
Window	*90*	*Heating*	*-30.5*	*-74.7*	*-48.1*	*-46.8*				
Skylight	0	Heating	-103.9	-103.9	-103.9	-103.9	3.40	1.39	2.16	2.22
"	18	"	-81.2	-122.1	-103.2	-101.9	2.66	1.63	2.15	2.18
"	30	"	-68.8	-129.2	-100.6	-98.7	2.26	1.73	2.09	2.11
"	45	"	-58.4	-133.1	-96.1	-94.2	1.91	1.78	2.00	2.01
Oklahoma City OK										
Window	*90*	*Cooling*	*35.7*	*49.4*	*61.7*	*68.2*				
Skylight	0	Cooling	226.0	226.0	226.0	226.0	6.33	4.58	3.66	3.31
"	18	"	200.0	239.6	216.2	224.0	5.60	4.86	3.51	3.29
"	30	"	172.7	234.4	203.2	213.0	4.84	4.75	3.29	3.12
"	45	"	132.5	214.3	183.1	194.8	3.71	4.34	2.97	2.86
Window	*90*	*Heating*	*-22.1*	*-68.8*	*-41.6*	*-39.0*				
Skylight	0	Heating	-87.0	-87.0	-87.0	-87.0	3.94	1.26	2.09	2.23
"	18	"	-63.0	-107.1	-87.7	-85.7	2.85	1.56	2.11	2.20
"	30	"	-49.4	-115.6	-87.0	-83.8	2.24	1.68	2.09	2.15
"	45	"	-40.3	-122.1	-85.1	-80.5	1.82	1.77	2.05	2.07

Appendix A.9. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Omaha NB										
Window	*90*	*Cooling*	*29.9*	*43.5*	*54.5*	*61.0*				
Skylight	0	Cooling	192.9	193.5	192.9	192.9	6.46	4.45	3.54	3.16
"	18	"	164.9	206.5	183.1	190.3	5.52	4.75	3.36	3.12
"	30	"	139.6	204.5	170.8	183.8	4.67	4.70	3.13	3.01
"	45	"	100.6	189.0	153.9	168.2	3.37	4.34	2.82	2.76
Window	*90*	*Heating*	*-30.5*	*-101.9*	*-58.4*	*-53.9*				
Skylight	0	Heating	-118.8	-118.8	-118.8	-118.8	3.89	1.17	2.03	2.20
"	18	"	-83.8	-150.0	-120.1	-116.2	2.74	1.47	2.06	2.16
"	30	"	-66.9	-163.0	-119.5	-113.6	2.19	1.60	2.04	2.11
"	45	"	-53.9	-172.1	-115.6	-108.4	1.77	1.69	1.98	2.01
Philadelphia PA										
Window	*90*	*Cooling*	*25.3*	*36.4*	*40.3*	*46.8*				
Skylight	0	Cooling	155.2	155.2	155.2	154.5	6.13	4.27	3.85	3.31
"	18	"	133.8	165.6	145.5	152.6	5.28	4.55	3.61	3.26
"	30	"	112.3	163.6	137.0	144.8	4.44	4.50	3.40	3.10
"	45	"	81.2	152.6	121.4	131.2	3.21	4.20	3.02	2.81
Window	*90*	*Heating*	*-27.9*	*-86.4*	*-49.4*	*-46.1*				
Skylight	0	Heating	-107.1	-107.8	-107.8	-107.1	3.84	1.25	2.18	2.32
"	18	"	-77.9	-132.5	-107.8	-104.5	2.79	1.53	2.18	2.27
"	30	"	-63.0	-142.9	-105.8	-101.9	2.26	1.65	2.14	2.21
"	45	"	-51.9	-149.4	-100.6	-95.5	1.86	1.73	2.04	2.07
Phoenix AZ										
Window	*90*	*Cooling*	*44.2*	*83.8*	*93.5*	*102.6*				
Skylight	0	Cooling	357.8	357.8	357.1	357.8	8.10	4.27	3.82	3.49
"	18	"	300.0	388.3	341.6	352.6	6.79	4.64	3.65	3.44
"	30	"	250.6	387.0	324.0	335.7	5.68	4.62	3.47	3.27
"	45	"	184.4	367.5	293.5	307.8	4.18	4.39	3.14	3.00
Window	*90*	*Heating*	*-5.2*	*-19.5*	*-11.7*	*-9.1*				
Skylight	0	Heating	-22.7	-22.7	-22.7	-22.7	4.37	1.17	1.94	2.50
"	18	"	-15.6	-28.6	-24.0	-21.4	3.00	1.47	2.06	2.36
"	30	"	-11.7	-31.8	-24.0	-22.1	2.25	1.63	2.06	2.43
"	45	"	-10.4	-35.1	-25.3	-21.4	2.00	1.80	2.17	2.36
Pittsburgh PA										
Window	*90*	*Cooling*	*26.0*	*33.8*	*27.9*	*54.5*				
Skylight	0	Cooling	124.0	124.0	124.0	124.0	4.78	3.67	4.44	2.27
"	18	"	110.4	131.2	107.8	135.1	4.25	3.88	3.86	2.48
"	30	"	96.1	129.9	97.4	135.1	3.70	3.85	3.49	2.48
"	45	"	74.0	122.1	82.5	128.6	2.85	3.62	2.95	2.36
Window	*90*	*Heating*	*-34.4*	*-70.8*	*-44.8*	*-55.8*				
Skylight	0	Heating	-107.1	-107.1	-107.1	-107.1	3.11	1.51	2.39	1.92
"	18	"	-89.0	-122.7	-103.9	-109.7	2.58	1.73	2.32	1.97
"	30	"	-77.3	-128.6	-99.4	-109.1	2.25	1.82	2.22	1.95
"	45	"	-66.2	-130.5	-93.5	-105.8	1.92	1.84	2.09	1.90

Appendix A.10. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
Portland ME										
Window	*90*	*Cooling*	*14.9*	*20.8*	*22.1*	*24.7*				
Skylight	0	Cooling	74.7	74.7	74.7	74.7	5.00	3.59	3.38	3.03
"	18	"	63.0	81.8	71.4	74.0	4.22	3.94	3.24	3.00
"	30	"	52.6	79.9	66.2	70.1	3.52	3.84	3.00	2.84
"	45	"	38.3	73.4	57.1	61.0	2.57	3.53	2.59	2.47
Window	*90*	*Heating*	*-39.6*	*-100.6*	*-65.6*	*-64.9*				
Skylight	0	Heating	-139.6	-140.3	-139.6	-139.6	3.52	1.39	2.13	2.15
"	18	"	-108.4	-166.2	-139.0	-138.3	2.74	1.65	2.12	2.13
"	30	"	-91.6	-175.3	-135.7	-135.1	2.31	1.74	2.07	2.08
"	45	"	-74.7	-180.5	-129.2	-127.9	1.89	1.79	1.97	1.97
Portland OR										
Window	*90*	*Cooling*	*31.2*	*40.9*	*87.7*	*24.7*				
Skylight	0	Cooling	129.9	130.5	129.9	129.2	4.17	3.19	1.48	5.24
"	18	"	110.4	139.6	160.4	98.1	3.54	3.41	1.83	3.97
"	30	"	92.2	140.3	168.8	81.2	2.96	3.43	1.93	3.29
"	45	"	68.8	130.5	168.8	63.6	2.21	3.19	1.93	2.58
Window	*90*	*Heating*	*-24.0*	*-44.8*	*-45.5*	*-23.4*				
Skylight	0	Heating	-62.3	-62.3	-62.3	-62.3	2.59	1.39	1.37	2.67
"	18	"	-53.2	-71.4	-71.4	-55.2	2.22	1.59	1.57	2.36
"	30	"	-49.4	-75.3	-74.7	-51.9	2.05	1.68	1.64	2.22
"	45	"	-44.2	-77.9	-77.9	-47.4	1.84	1.74	1.71	2.03
Reno NV										
Window	*90*	*Cooling*	*20.1*	*28.6*	*39.0*	*51.3*				
Skylight	0	Cooling	174.0	174.0	174.0	174.0	8.65	6.09	4.47	3.39
"	18	"	145.5	187.0	161.0	176.0	7.23	6.55	4.13	3.43
"	30	"	120.8	184.4	148.1	169.5	6.00	6.45	3.80	3.30
"	45	"	81.8	172.1	129.2	155.8	4.06	6.02	3.32	3.04
Window	*90*	*Heating*	*-26.0*	*-107.1*	*-64.3*	*-55.2*				
Skylight	0	Heating	-124.0	-124.0	-123.4	-124.0	4.78	1.16	1.92	2.25
"	18	"	-81.2	-160.4	-128.6	-119.5	3.13	1.50	2.00	2.16
"	30	"	-61.7	-176.0	-129.9	-116.9	2.38	1.64	2.02	2.12
"	45	"	-48.7	-189.6	-129.9	-114.3	1.88	1.77	2.02	2.07
Salt Lake City UT										
Window	*90*	*Cooling*	*31.2*	*48.1*	*64.3*	*72.1*				
Skylight	0	Cooling	227.3	227.3	227.3	227.3	7.29	4.73	3.54	3.15
"	18	"	191.6	245.5	217.5	225.3	6.15	5.11	3.38	3.13
"	30	"	158.4	246.1	204.5	216.2	5.08	5.12	3.18	3.00
"	45	"	111.0	231.2	187.7	200.0	3.56	4.81	2.92	2.77
Window	*90*	*Heating*	*-26.6*	*-94.8*	*-54.5*	*-51.9*				
Skylight	0	Heating	-106.5	-106.5	-105.8	-106.5	4.00	1.12	1.94	2.05
"	18	"	-72.7	-135.1	-108.4	-105.2	2.73	1.42	1.99	2.03
"	30	"	-57.8	-148.1	-107.8	-103.9	2.17	1.56	1.98	2.00
"	45	"	-49.4	-159.7	-107.1	-103.2	1.85	1.68	1.96	1.99

Appendix A.11. Skylight Solar Loads and Load Ratios (continued)

	Tilt	Load	Solar Load (kBtu/ft²) North	South	East	West	Solar Load Ratio North	South	East	West
San Antonio TX										
Window	*90*	*Cooling*	*50.0*	*72.1*	*77.9*	*90.3*				
Skylight	0	Cooling	297.4	297.4	297.4	297.4	5.95	4.13	3.82	3.29
"	18	"	265.6	310.4	281.8	296.1	5.31	4.31	3.62	3.28
"	30	"	229.2	305.2	262.3	283.8	4.58	4.23	3.37	3.14
"	45	"	181.8	282.5	233.8	260.4	3.64	3.92	3.00	2.88
Window	*90*	*Heating*	*-9.1*	*-22.1*	*-15.6*	*-14.3*				
Skylight	0	Heating	-31.8	-31.8	-31.8	-31.8	3.50	1.44	2.04	2.23
"	18	"	-25.3	-37.0	-32.5	-31.2	2.79	1.68	2.08	2.18
"	30	"	-20.8	-39.0	-32.5	-31.2	2.29	1.76	2.08	2.18
"	45	"	-16.9	-42.2	-32.5	-30.5	1.86	1.91	2.08	2.14
San Diego CA										
Window	*90*	*Cooling*	*24.7*	*35.7*	*30.5*	*44.8*				
Skylight	0	Cooling	137.7	137.7	137.7	137.7	5.58	3.85	4.51	3.07
"	18	"	113.0	147.4	122.7	145.5	4.58	4.13	4.02	3.25
"	30	"	93.5	146.8	114.3	141.6	3.79	4.11	3.74	3.16
"	45	"	72.7	137.7	92.2	129.9	2.95	3.85	3.02	2.90
Window	*90*	*Heating*	*-11.0*	*-29.9*	*-18.2*	*-20.8*				
Skylight	0	Heating	-43.5	-43.5	-43.5	-43.5	3.94	1.46	2.39	2.09
"	18	"	-33.8	-51.3	-42.2	-44.2	3.06	1.72	2.32	2.12
"	30	"	-27.9	-55.8	-41.6	-45.5	2.53	1.87	2.29	2.19
"	45	"	-24.0	-60.4	-41.6	-46.1	2.18	2.02	2.29	2.22
San Francisco CA										
Window	*90*	*Cooling*	*4.5*	*9.7*	*9.1*	*10.4*				
Skylight	0	Cooling	29.2	29.2	29.2	29.2	6.43	3.00	3.21	2.81
"	18	"	23.4	33.8	27.9	27.9	5.14	3.47	3.07	2.69
"	30	"	17.5	34.4	26.0	26.6	3.86	3.53	2.86	2.56
"	45	"	13.0	33.8	23.4	24.7	2.86	3.47	2.57	2.37
Window	*90*	*Heating*	*-29.9*	*-82.5*	*-53.2*	*-61.7*				
Skylight	0	Heating	-131.2	-131.2	-131.2	-131.2	4.39	1.59	2.46	2.13
"	18	"	-100.6	-154.5	-125.3	-132.5	3.37	1.87	2.35	2.15
"	30	"	-81.8	-164.3	-120.8	-132.5	2.74	1.99	2.27	2.15
"	45	"	-65.6	-170.8	-114.9	-129.2	2.20	2.07	2.16	2.09
Seattle WA										
Window	*90*	*Cooling*	*7.8*	*14.3*	*13.0*	*22.1*				
Skylight	0	Cooling	53.2	53.2	53.2	53.2	6.83	3.73	4.10	2.41
"	18	"	42.2	59.1	45.5	55.8	5.42	4.14	3.50	2.53
"	30	"	33.1	60.4	40.3	56.5	4.25	4.23	3.10	2.56
"	45	"	19.5	55.8	33.8	50.6	2.50	3.91	2.60	2.29
Window	*90*	*Heating*	*-37.0*	*-76.0*	*-53.9*	*-55.8*				
Skylight	0	Heating	-117.5	-117.5	-117.5	-117.5	3.18	1.55	2.18	2.10
"	18	"	-97.4	-133.1	-116.2	-117.5	2.63	1.75	2.16	2.10
"	30	"	-84.4	-138.3	-113.0	-114.9	2.28	1.82	2.10	2.06
"	45	"	-72.1	-142.2	-107.8	-110.4	1.95	1.87	2.00	1.98

Appendix A.12. Skylight Solar Loads and Load Ratios (continued)

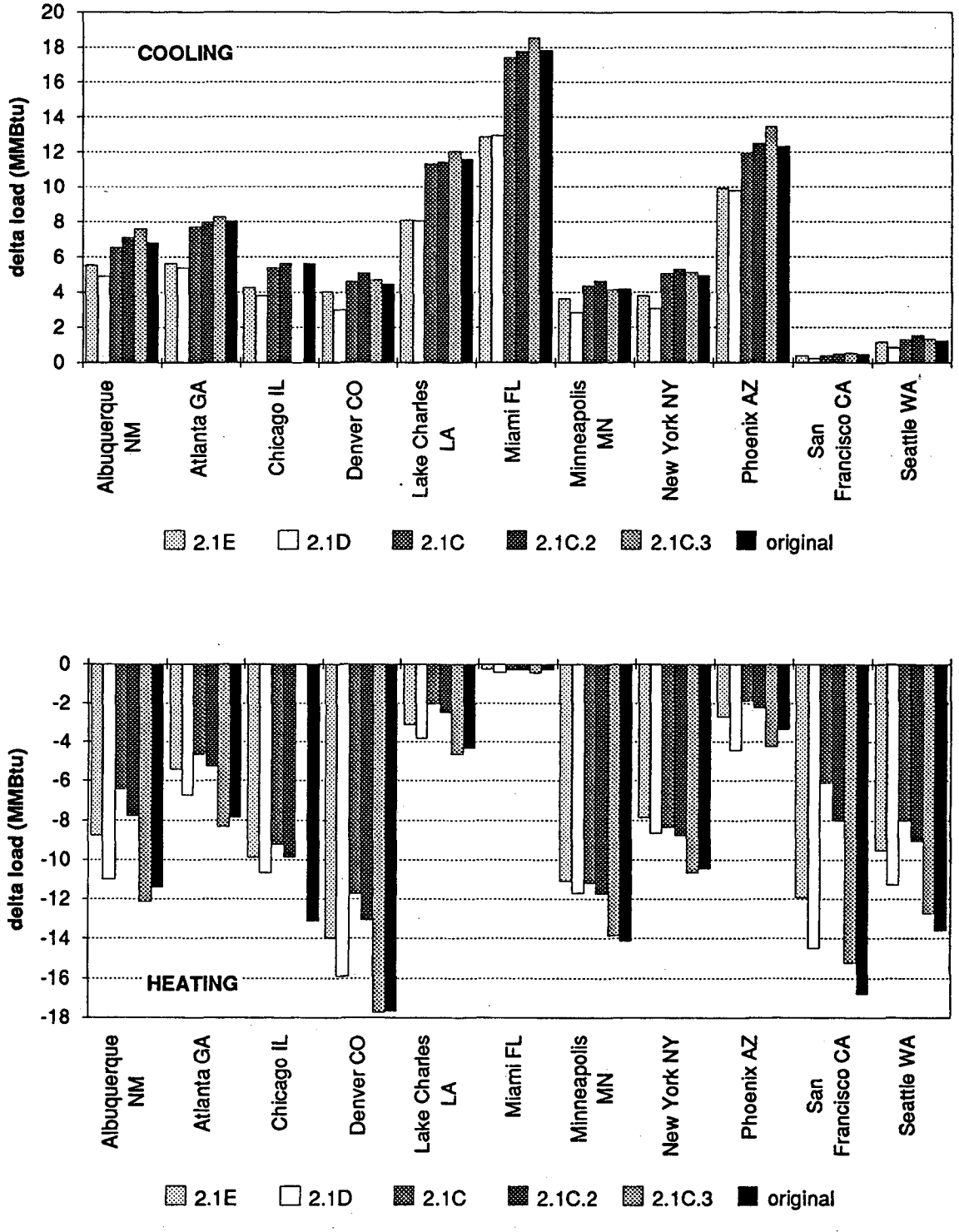
	Tilt	Load	Solar Load (kBtu/ft^2) North	South	East	West	Solar Load Ratio North	South	East	West
Washington DC										
Window	*90*	*Cooling*	*36.4*	*51.3*	*55.8*	*63.6*				
Skylight	0	Cooling	200.0	200.6	200.0	200.0	5.50	3.91	3.58	3.14
"	18	"	174.0	212.3	189.6	198.1	4.79	4.14	3.40	3.11
"	30	"	150.6	209.7	176.0	189.6	4.14	4.09	3.15	2.98
"	45	"	117.5	196.8	157.1	173.4	3.23	3.84	2.81	2.72
Window	*90*	*Heating*	*-26.0*	*-75.3*	*-43.5*	*-42.2*				
Skylight	0	Heating	-96.1	-96.1	-96.1	-96.1	3.70	1.28	2.21	2.28
"	18	"	-70.8	-115.6	-94.8	-94.2	2.73	1.53	2.18	2.23
"	30	"	-57.1	-123.4	-92.9	-90.9	2.20	1.64	2.13	2.15
"	45	"	-47.4	-128.6	-87.7	-85.7	1.82	1.71	2.01	2.03

APPENDIX B - DOE-2 MODEL CALIBRATION

A major concern was the use of a simulation model that wold provide similar results to the earlier work. In particular, we wanted to ensure that calculated solar gains were of similar magnitudes as those in the original SP53 data base. Thus, we attempted to either locate or recreate the exact DOE-2 input files and executable code used six years ago. The original SP53 analysis was done with a developmental version of DOE-2.1C. We were not able to locate or recreate a working version of this code. Initial simulations using the original input files with DOE-2.1D for the base case house with 12% window area were significantly different from the results in the earlier work (the solar load was calculated as the difference between the heating or cooling load with the window shading coefficients equal to 1 and 0). We tried an even more recent version of DOE-2.1E, but these results were also unacceptable. Finally, we used DOE-2.1C, which required some re-working of the input files since 2.1C does not allow some input commands that were available in the developmental version (primarily concerning the natural ventilation algorithm). We ultimately used this version with the slightly modified input file in the analysis. A comparison of the results from these different models in 11 different climates is given in Figure B1. While the final model gives slightly higher window solar loads for cooling as compared to the original model, the results for heating are much closer to the original than those of the other models tested.

Figure B.1 Incremental Loads between Full Window Solar and No Solar Cases

Window area = 12% of floor area, equally distributed among the four cardinal orientations.



Notes: 2.1C model has WS-HEIGHT=50, NATURAL-VENT-AC=10 and other natural venting code removed.
2.1C.2 model has NATURAL-VENT-AC=5.
2.1C.3 model has old foundation fluxes, avg winter WS-HEIGHT, VENTTEMPSET seasons by location.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720