Skylighting Guidelines

NORTHEAST REGION

CHAPTER FIVE

May 2001

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5. Northeast Regional Guidelines

This chapter is written as an alternative Chapter 5 to the *Skylighting Guidelines*. It addresses issues of particular concern to designers and building owners in the Northeastern United States: New York and the New England states. This chapter provides a review of the region's climate, energy code requirements for the different states, and common building practices that affect the specification of skylights for commercial buildings. Most importantly, it summarizes the findings of multiple parametric runs of *SkyCalc®* for climates in seven representative Northeast cities: New York, NY; Albany, NY; Buffalo, NY; Boston, MA; Burlington, VT; Hartford, CT; and Concord, NH.

The chapter concludes with a two page set of recommendations for skylight design in the Northeast, summarizing the lessons derived from the analysis presented here.

5.1 Northeast Climates

The relatively high northern latitudes (from 40° to 44° latitude) in the Northeast, combined with frequent cloudy days in the winter, make for days of low daylight availability. Although the climate of this region is representative of the humid continental type that prevails in the Northeastern United States, its climatic diversity is unusual for an area of comparable size. The average annual mean temperature ranges from about 40°F in the Adirondacks to near 55°F in the New York City area. The heating and cooling degree days[1] for seven representative Northeast cities are displayed in Figure 5-1.

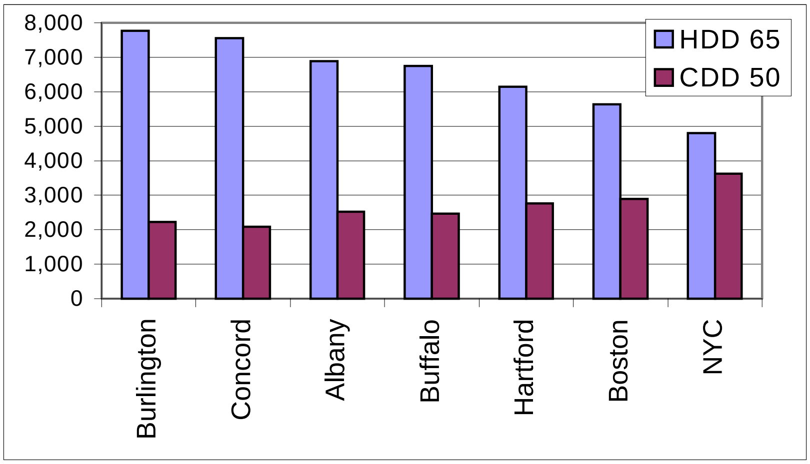

Figure 5-1: Heating and Cooling Degree Days for Seven Northeastern Cities

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[1] Base 50°F for cooling and 65°F for heating

New York State receives abundant snowfall in the winter. With the exception of the coastal region, the state receives an average seasonal rainfall of 40 inches or more. The average snowfall is greater than 70 inches over some 60% of New York's area. New York's winter can be mild to cold. The summer is pleasantly cool (70°F - 85°F) in the Adirondacks, Catskills, and higher elevations of the Southern Plateau. The New York City area and lower portions of the Hudson Valley have considerably warmer summers[2].

Massachusetts State has a milder climate than most of its northeast neighbors. The Bay State experiences winter temperatures that usually hover around freezing and sometimes lower. The western part of the state experiences colder weather than the eastern region due to the coastal effects of the Atlantic. Annual rainfall is between 40 and 48 inches. Summers vary from a comfortable 70°F to a warm 90°F.[3]

Vermont has four distinct seasons with daytime temperatures averaging in the mid-70°s F during the summer months and in the low 20°s F during winter. Annual rainfall is approximately 36 inches: of that precipitation, an average of 100 inches to more than 250 inches of snow falls during the winter, depending on elevation[4].

Despite New England's reputation for rugged climate, *Connecticut* offers relatively mild weather. In the Hartford area, on average, there are just 19 days a year when the temperature goes above 90°F, and only six when it falls to 0°F or below. However, this small state does experience some variation in climate, with temperatures in the northeastern hills occasionally as much as 10°F lower than in the Central Valley and Hartford.

New Hampshire, on the other hand, has a moderately colder climate than the rest of the states in the region. The average monthly temperature in Concord in the winter season is 20°F and it can reach up to an average of 60-70°F in the summer[5].

The following sections will analyze the weather conditions for a sample of cities representing each state in terms of visibility, cloudiness, and daylight illumination levels.

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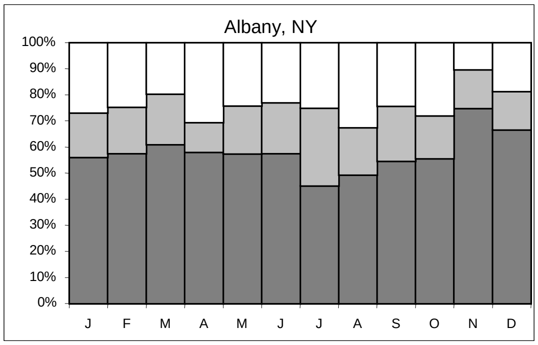
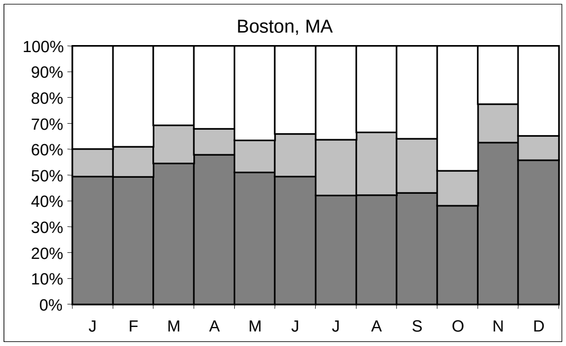
[2] Source: http://www.state.ny.us/

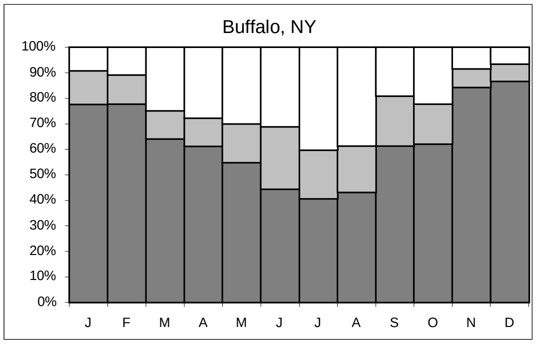
[3] Source: http://www.state.ma.us/

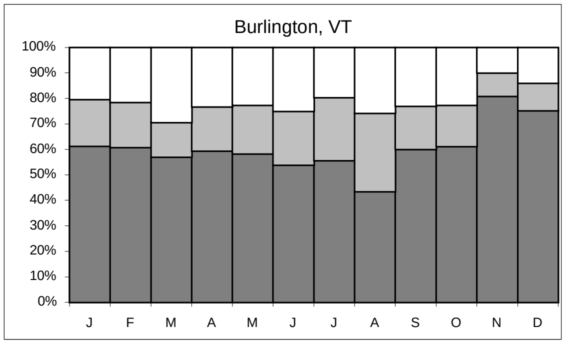
[4] Source: http://www.1-800-vermont.com/travelvt/abtvt/aboutvermont.shtml

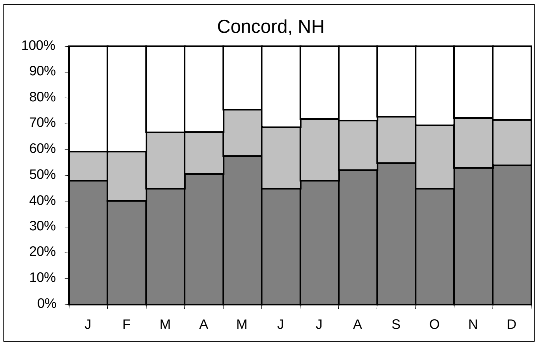
[5] Source: US Weather Bureau

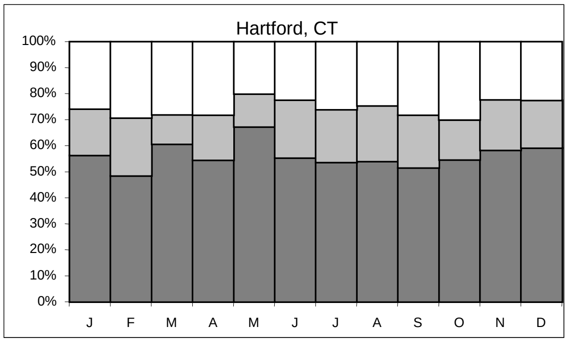


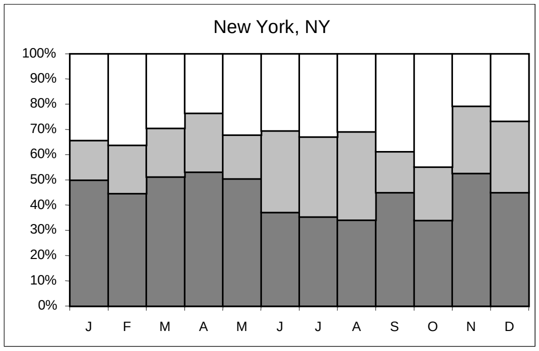












□ Clear
▨ Partly Cloudy
■ Cloudy

Cities	Cloudy	Partly Cloudy	Clear
Albany, NY	57%	19%	24%
Boston, MA	49%	16%	35%
Buffalo, NY	61%	15%	24%
Burlington, VT	59%	19%	22%
Concord, NH	50%	20%	31%
Hartford, CT	56%	18%	25%
New York, NY	44%	24%	32%

Figure 5-2: Sky Conditions in Seven Northeastern Cities

Figure 5-2 illustrates the sky conditions in seven northeastern cities, showing percentage of time for each month in full sun, partly cloudy, and completely cloudy.[6] These seven cities vary from a low of 22% clear weather in Burlington, VT to a high of 32% in Central Park, New York, NY. Buffalo, NY, furthest inland, has the cloudiest winters and the most differentiation between winter and summer cloudiness conditions. Hartford, CT, on the other hand, has remarkably uniform sky conditions year round, with only 25% clear daylit hours. For our discussion, we will focus mostly on Burlington, VT as representative of more extreme northerly conditions and Albany, NY as representative of the inland plains. In addition, these sample cities are primary weather data collection sites, which means they have the most complete weather data available.

5.1.1. Yearly Illumination Patterns

In designing for daylight, it is important to understand the great variability of daylight illumination throughout the year. The following graph helps to make this point.

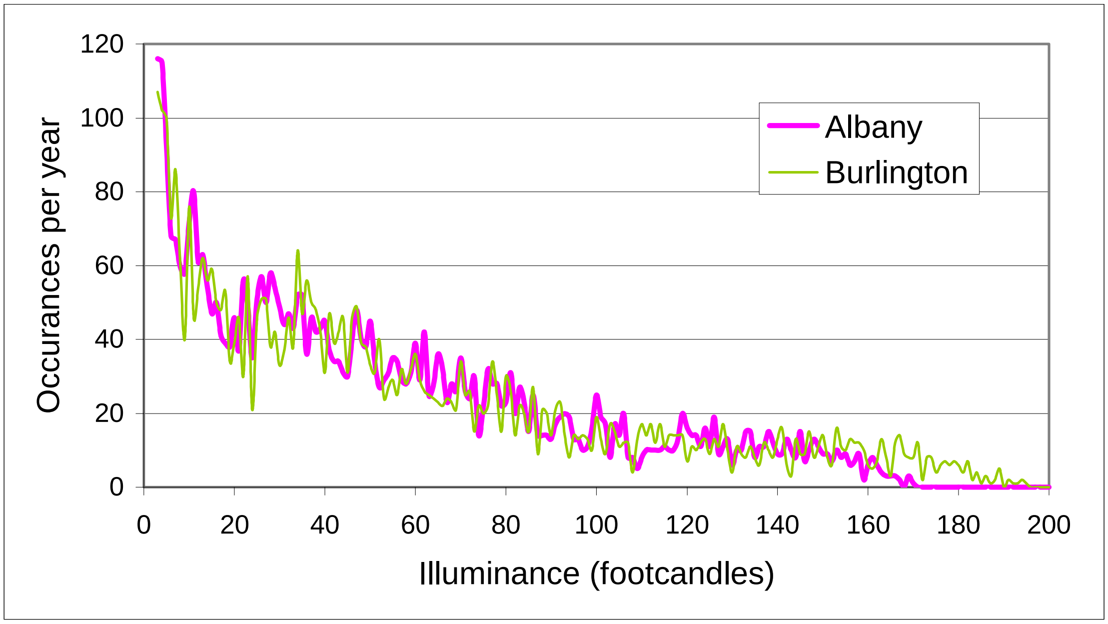


Figure 5-3: Yearly Illuminance Plots, Two Northeast Climates

Figure 5-3 plots the number of hours of interior daylight illumination levels, from 1 to 200 footcandles, for a prototypical building design in two distinctly different Northeast cities. Burlington is farther north, and has a colder climate and more cloudy days than most northeastern cities. Albany is 130 miles south of Burlington in upstate New York, and is typical of the geographical conditions of most upstate New York cities.

Despite some differences, the yearly illumination patterns in Burlington and Albany are strikingly similar. There is no clear “design condition” that occurs the majority of the time. This is also true for most of the northeastern cities; these

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[6] Derived from TMY2 (Typical Meteorological Year) data.

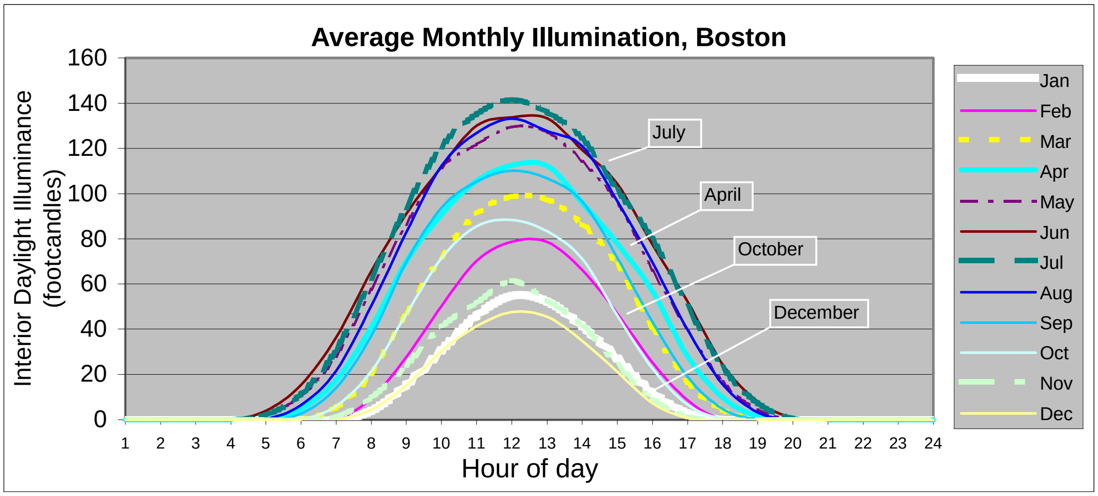
two were chosen as typical examples. In both Burlington and Albany there is a nearly equal probability that the space would experience daylight illuminances ranging from 100 to 160 footcandles. In both cities, about 50% of the hours provide interior daylight illumination below 30 footcandles in our prototype building.

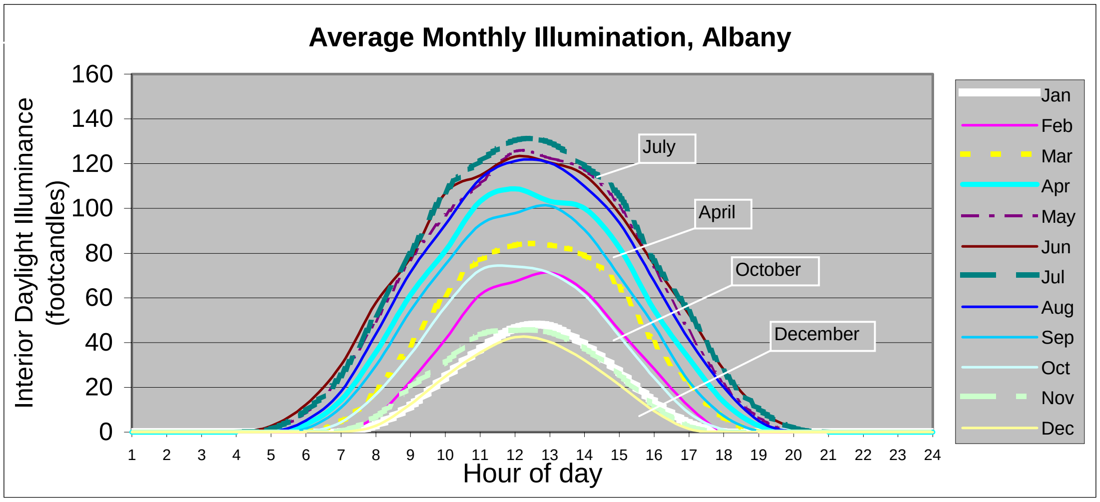
5.1.2. Monthly Illumination Patterns

The three average monthly plots shown in Figure 5-4 illustrate the variations in illumination due to time of year and climate for three cities.

Average daylight illumination in Albany is lower than Boston and Burlington at all times during the year, due to more cloudy weather conditions. The average midday illumination in December in Albany is almost 10% lower than in Boston and Burlington. Similarly, at midday in the summer, average illumination is 12% higher in Boston and 14% higher in Burlington than Albany. Thus, approximately 10-15% more skylight area might be needed to achieve the same illumination goals in Albany. Alternatively, the use of higher transmittance glazing would help increase the amount of indoor daylight illumination achieved in Albany.

The average monthly illumination, shown for these three Northeast cities in Figure 5-4, shows a fairly regular bell shaped curve, because all irregularities in the weather have been evened out through the averaging process. Actual illumination for a given day could vary substantially from these average values, as described in Figure 5-4.





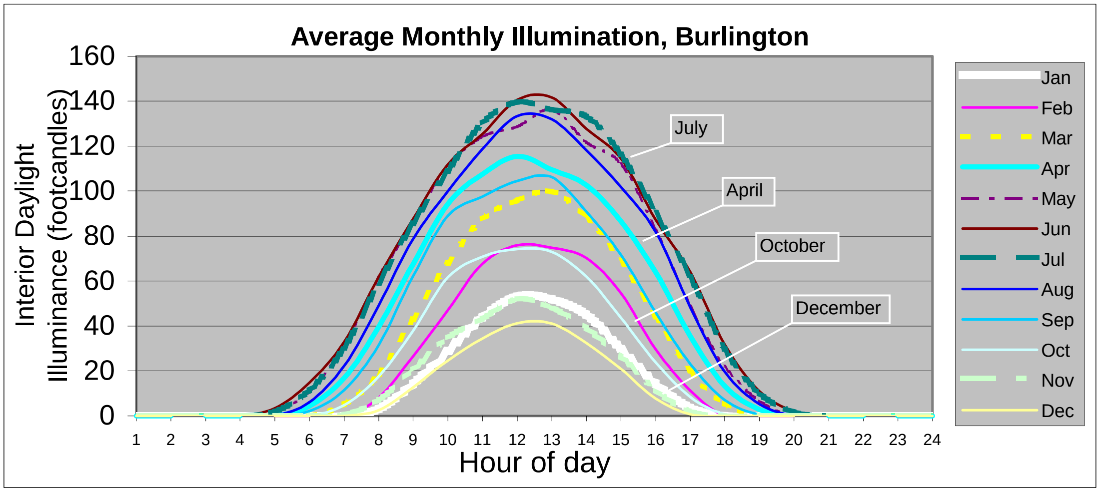


Figure 5-4: Average Monthly Illumination, Three Northeast Cities

5.1.3. Weekly Illumination Patterns

Figure 5-5 plots the interior daylight illuminance for a prototypical building with skylights in Albany during a highly variable week in July of a typical year. This graph illustrates some of the variability in illuminance levels that can be found on a day-to-day basis. The thin lines diagram the illuminance levels for each day, while the thick line represents the average for that one week. We chose this week because it shows passing cloud conditions, and illustrates the range of conditions that can occur.

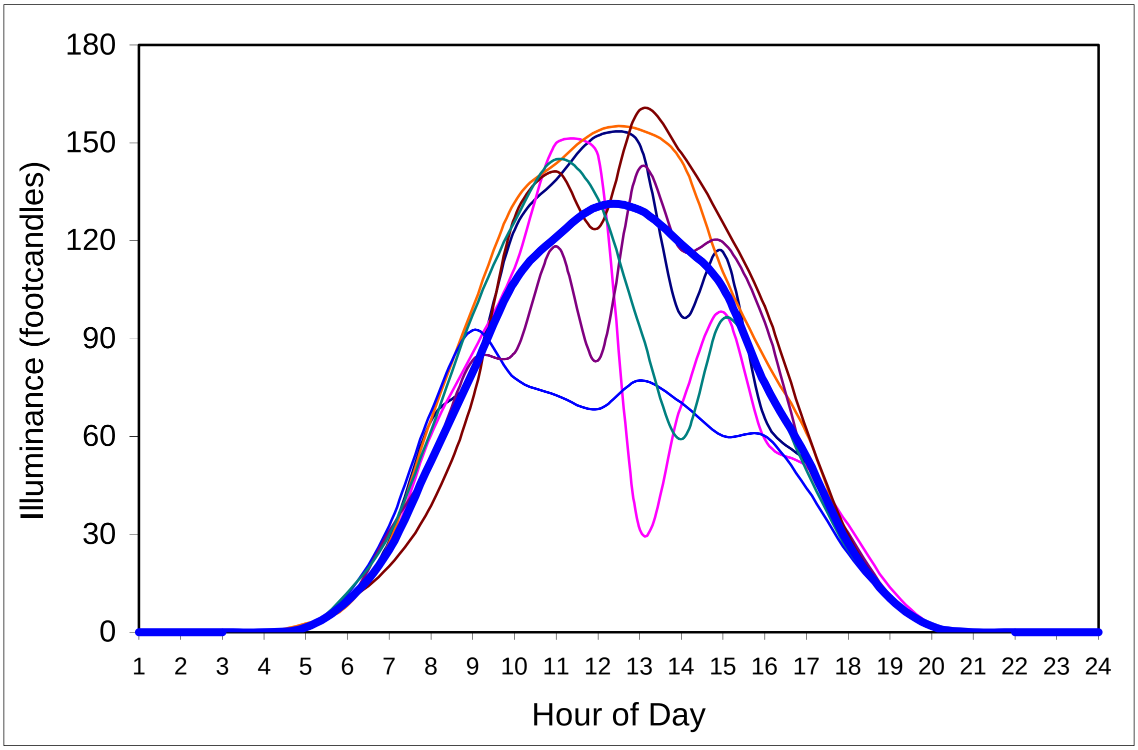


Figure 5-5: Daylight Illuminances, Albany, One Week in July

Note: Each thin line represents one day; the thick line represents the weekly average.

It is apparent from Figure 5-5 that daylight illumination levels during this particular week vary from a mid-day low of 30 footcandles to a high of 165 footcandles. The high is 5.5 times greater than the low. Within a given day, the daily high illumination could potentially occur from anytime between 10 a.m. and 3 p.m., depending on cloud patterns. The maximum values for this week are about 25% higher than the July monthly averages and the minimum values are about 50% (in this extreme case one of the minimums is 75%) lower than the monthly July average.

The point here is that monthly average illumination values will always be just a rough guide to the illumination levels that are likely to occur within a given month. It is reasonable to assume that they will vary by ±25% on any given day.

5.2. Designing for Savings

Given the natural variability in daylighting described in the previous section, the designer is faced with a wide range of potential illuminance levels from skylights. This variability is part of daylight's appeal to people in buildings, who are adapted to function in changeable conditions, but it increases the complexity of system design. The best approach is generally to design a system that will optimize daylight illuminance as a daily average, along with yearly energy use and energy costs for the whole building. The simple software tool for skylighting design, *SkyCalc,*[7] assists designers in this effort by calculating average hourly illuminance and energy performance using detailed weather data for your specific climate.

The following sections look at how a limited set of variables affect the pattern of energy and cost savings for a given skylighting design. *SkyCalc* was used to generate a series of energy and cost savings curves for each variable. These curves are not generic. They are specific to the building type, operation and location studied. They do not tell you which set of variables will perform better in all cases, or what the actual energy or cost savings are likely to be for a different building. However, they do help you to quickly see how the different sets of variables may affect relative performance, and suggest how you might proceed towards optimizing your design.

These studies all use a standard building, described as a grocery store in Albany, New York with a lighting power density of 1.39 W/sf in fluorescent lights, producing a target illumination level of 50 footcandles, and using dimming controls which reduce light output to 20%. The skylighting system used a double-glazed clear prismatic acrylic skylight with a shallow, 3 foot deep light well whose sides are splayed at a 45° angle. This skylighting system was selected because it meets current Northeast codes and presents a relatively efficient solution. All other *SkyCalc* defaults were used throughout

In each case, two curves are presented, the one on the top for yearly energy usage savings, the one on the bottom for yearly energy cost savings. In all cases the horizontal axis is skylight-to-floor ratio, SFR, also known as the gross skylight aperture. All the cost savings graphs in this chapter were calculated using 1998[8] average energy costs for each State (Figure 5-6).

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[7] SkyCalc® is a simple software tool that runs as a Microsoft Excel spread sheet macro. It calculates average daily illumination and energy savings from a uniformly designed skylighting system for all commercial building types. For more information on SkyCalc refer to: Heschong, L. et al, The Skylighting Guidelines, Los Angeles, CA 1998. http://www.energydesignresources.com.

[8] Sources: Electricity prices - "Table A15. Average Revenue per Kilowatt-hour for U.S. Electric Utilities by Sector, Census Division, and State, 1998"
http://www.eia.doe.gov/cneaf/electricity/epav1/epav1ta15.html,
Gas prices – "Natural Gas Monthly March 2000, Energy Information Administration".
http://www.eia.doe.gov/oil_gas/natural_gas/info_glance/prices.html

	Electricity $/kWh		*Natural Gas $/therm*	
State	Commercial	Industrial	Commercial	Industrial
Connecticut	$0.100	$0.076	$0.689	$0.434
Maine	$0.105	$0.064	$0.723	$0.513
Massachusetts	$0.094	$0.081	$0.732	$0.569
New Hampshire	$0.116	$0.093	$0.718	$0.466
New York	$0.117	$0.050	$0.608	$0.402
Rhode Island	$0.094	$0.078	$0.812	$0.382
Vermont	$0.101	$0.071	$0.508	$0.280

Figure 5-6: Fuel Prices for Northeast States, 1998

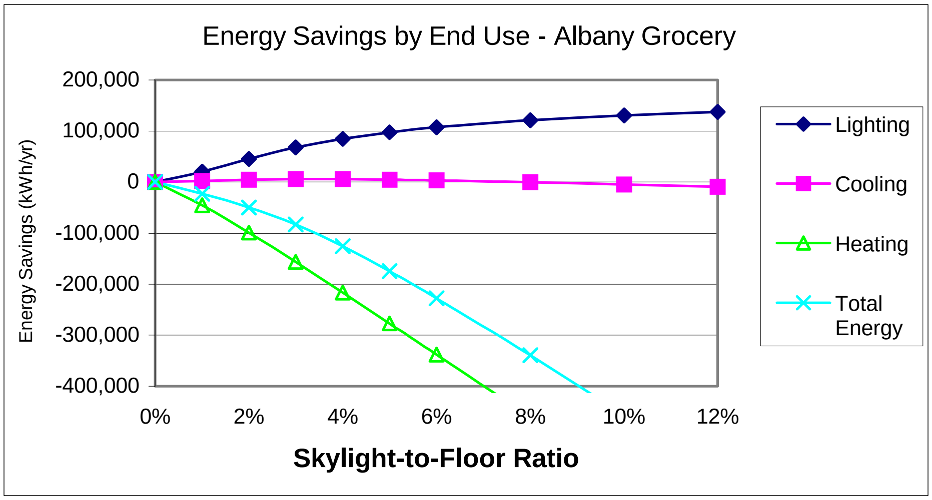
5.2.1.Heating and Cooling Effects

The three main energy uses that influence the performance of skylighting systems are lighting, cooling and heating. The combination of the three determines the whole building energy usage and cost savings that can be achieved with a skylighting design, and determines at what point the design will reach optimum savings. Figure 5-7 illustrates this relationship between the three different components of the whole building energy savings equation for our typical grocery design in Albany described above.

The relative energy impacts of these three systems—lighting, heating, and cooling—along with their relative costs determine where the optimum energy performance size for skylights will fall. The net result is that the energy curve optimizes at about 0% gross aperture in this case, while the cost curve optimizes at about 5%.

Lighting energy savings are the primary drivers, initially rising sharply and then continuing to rise, but at slower pace as the skylight aperture is increased. The cooling energy impacts are slightly positive, but not very significant for all levels of glazing. It shows negative cooling savings at SFRs greater than 8%. For this case, the most significant factor in energy losses is heating energy, which has negative savings throughout. With an efficient lighting system at 1.3W/sf, heating losses are outweighing lighting and cooling savings. As a result, the total energy savings curve of the building shows negative savings from skylights for the conventional skylighting system previously described.

However, looking at the cost savings curve in Figure 5-7, we see that the relative dollar value of gas heating is substantially less than the value of electricity used for cooling and lighting. Cooling cost savings are slightly positive for a skylight-to-floor area ratio (SFR) of up to 7% and then switch to negative cost savings for all higher SFRs. The resulting total cost savings curve is optimum at the SFR of about 5% for this design then it starts taking a downward slope for higher SFRs.



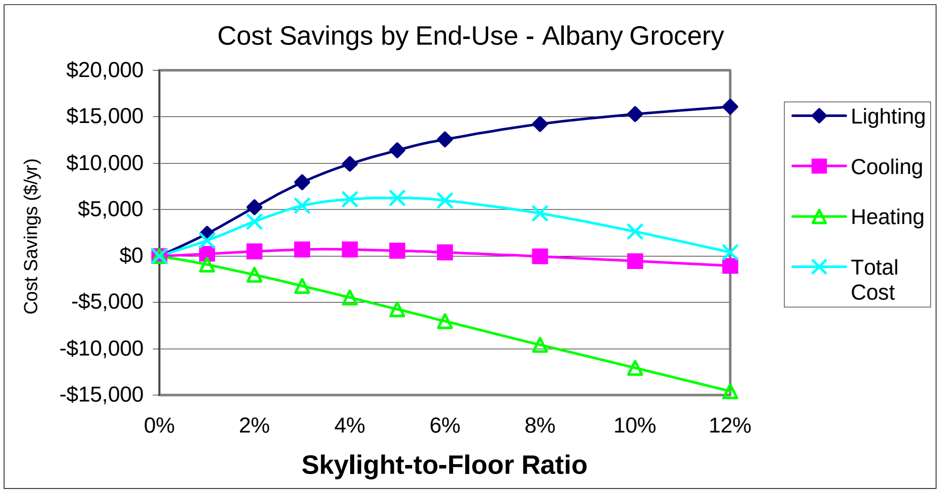
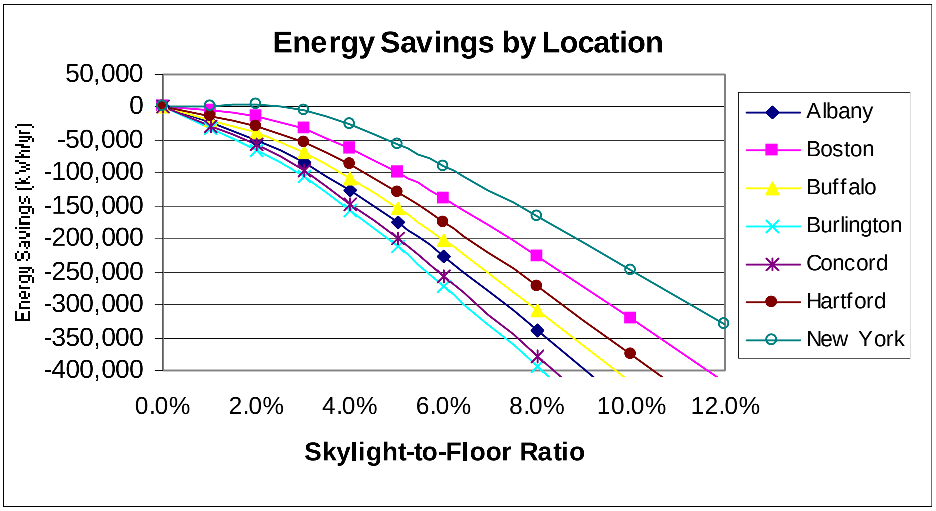


Figure 5-7: Annual Energy and Cost Savings by End Use – Albany Grocery Store

It should be noted, however, that optimizing skylights for energy performance is only one consideration. This design shows positive dollar savings anywhere from 1% to almost 12% SFR. Optimum illumination performance (see Section 5.2.6) and installation costs should also be criteria in sizing the system. In the energy analysis for this example, and many of the other cases that follow, energy savings are slightly negative at small skylight apertures and worse at larger apertures. This example was chosen because it represents a typical base case building, not the best.

5.2.2. Savings by Climate Zone

Next we look at how the same building performs in different locations. The relative influences of the heating and cooling components are evident among the seven climates. New York City, a more southern location, also affected by the tempering influence of the ocean and the "heat island" effect of the city, has the mildest climate and the sunniest days. Albany, 150 miles to the north, sits in the upper Hudson Valley with about the same heating requirements, and a bigger cooling season than Buffalo. Burlington, away from the moderating influence of either the Atlantic Ocean or the Great Lakes and at the foot of the mountains, has the most extreme heating requirements and the lowest cooling requirements. Figure 5-8 shows that, for this particular grocery store design, the magnitude of energy savings are greatest for New York City as compared to the rest of the major cities in the Northeast.



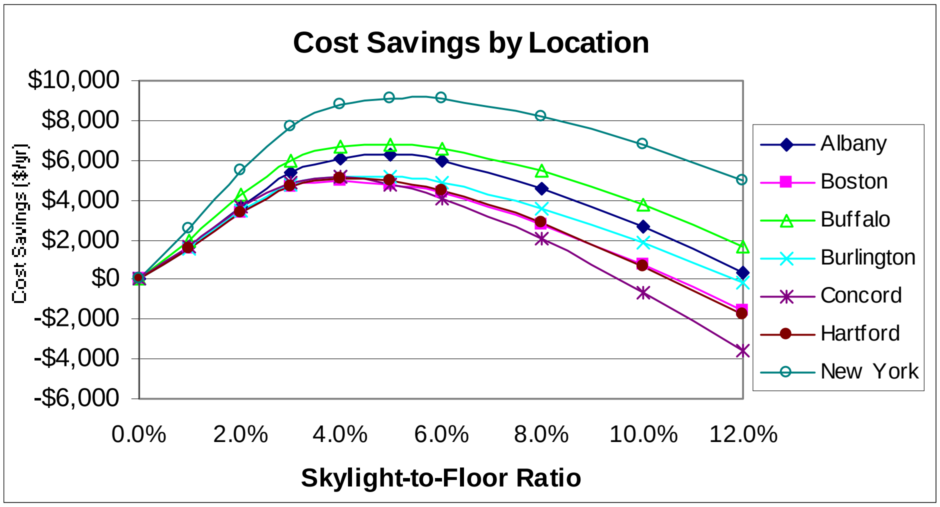
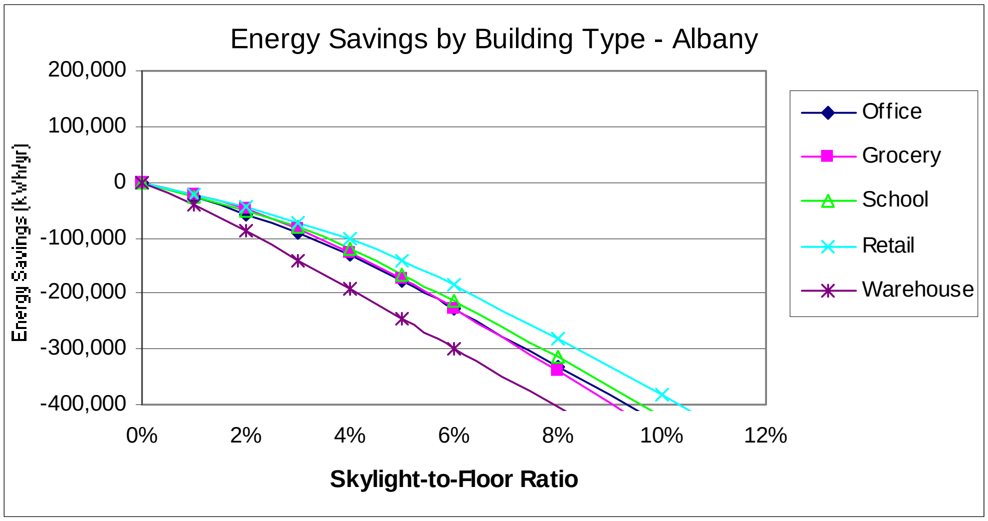


Figure 5-8: Annual Energy and Cost Savings by Climate Zone – Grocery

When we look at the dollar savings, skylights and daylighting controls save money in all climates - this because in our analysis the cost of electricity per unit of energy is much more expensive than natural gas. Also note that for the cost savings graphs, the optimum SFR shifts to the right compared to the cost savings optima. In general, larger skylight areas can provide a cost-savings optimum even when not at an energy-use optimum.

5.2.3. Savings by Building Type

Different building types also perform differently with skylighting systems. Figure 5-9 illustrates the impact of five different building types and operations on energy and cost savings. To generate these curves, we used identically sized buildings (50,000 sf), all located in Albany. Again, this is not the optimum design for any of these building types in this climate. It is used only for the sake of a consistent comparison.



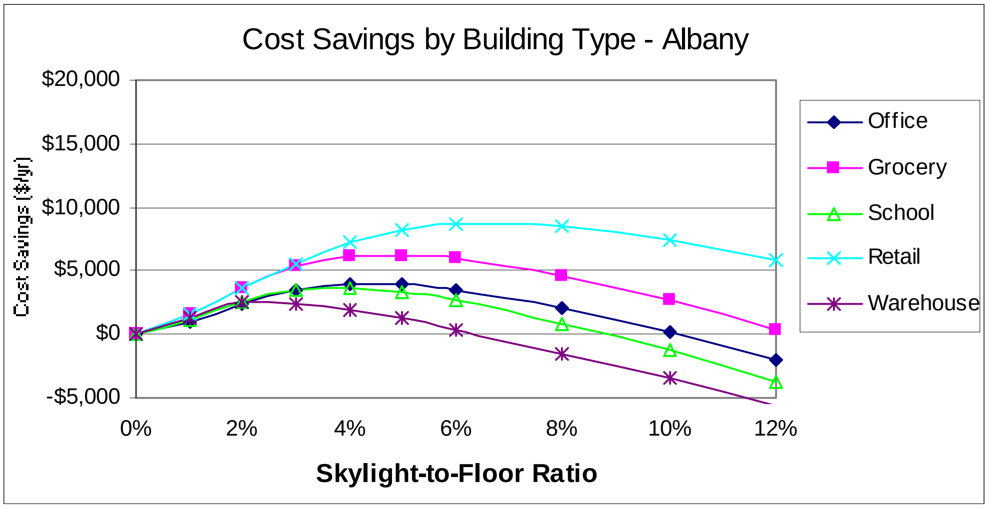


Figure 5-9: Annual Energy and Cost Savings by Building Type - Albany

A brief description of the building types:

- All examples have identical skylighting systems; clear prismatic acrylic, double-glazed skylights with 20% dimming controls.
- Office - 10' ceilings, 3' deep light well splayed 45°, 10' by 10' cubicles with 5' tall partitions, direct/indirect fluorescent light fixtures, ceiling reflectance 80%, 50 fc[9] design illuminance, LPD[10] = 1.64 W/sf.
- Grocery - 15' ceilings, 3' deep light well splayed 45°, 7' tall shelving with 10' wide aisles, open cell parabolic fluorescent light fixtures, 50 fc design illuminance, LPD = 1.39 W/sf.
- School - 900 ft^2 classrooms, 11' ceiling, 3' deep light well splayed 45°, direct/indirect fluorescent light fixtures, ceiling reflectance 80%, 50 fc design illuminance, LPD = 1.35 W/sf.
- Retail - same as grocery except 75 fc design illuminance, LPD = 2.1 W/sf.
- Warehouse - 25' ceilings, 1' vertical light well, industrial fluorescent mounted at 20', 20' tall racks with 10' wide aisles, 10 fc design illuminance, heated only, LPD = 0.5 W/sq. ft.

The buildings vary by schedule of operation, design target illumination, lighting power density, and internal loads. These were set to the building type defaults used in *SkyCalc.* All of the buildings were fully conditioned with a gas fired furnace and an electric air conditioner (with the exception of the warehouse, which was not cooled) and were only heated to 68°F during working hours with a setback to 55°F at other times.

This set of graphs clearly illustrates that the magnitude of savings is highly dependent on hours of operation and lighting power density. Retail stores and grocery stores both have 7 day a week schedules, and thus stand to save the greatest amounts of energy. Thus, in Figure 5-9 the retail stores, with the highest lighting power density, show the highest savings potential. Grocery stores, with the longest hours of operation, but lower lighting power densities, show a similar pattern, but slightly lower savings. Warehouses, with low lighting power densities, less heating and no cooling requirements, show a similar, though reduced, performance curve to retail stores. Schools and offices, both operating about five and a half days per week (but with different occupancy schedules), have similar lighting power densities and have very similar energy impacts. With essentially no cooling load (if they are not operating in the summer), and low lighting power densities, schools show no energy savings from this design, and only modest cost savings.

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[9] fc = footcandle of illuminance; the task lighting level design target.

[10] LPD = Lighting Power Density, measured as installed lighting watts per square foot

5.2.4. Savings by Glazing Type

The selection of the glazing assembly for a skylighting system can have a profound effect on its energy performance. There are three interrelated variables that need to be addressed: visible transmittance (t_{vis}), solar heat gain coefficient (SHGC), and unit U-factor (thermal transmittance).

Figure 5-10, illustrates the impact of various glazing choices by looking at the performance of six common glazing products. These are assumed to be fully diffusing, which means that they spread and distribute the light and do not provide the clear view that window glass would do. The properties of each are listed below:

Glazing Types	T_{vis}	SHGC	U-Factor
Med. Density Fiberglass Panel Crystal	0.20	0.21	0.56
Hi Density Fiberglass Panel Crystal	0.10	0.09	0.35
Acrylic Double Clear Prismatic[11]	0.74	0.67	0.97
Acrylic Double White	0.39	0.30	0.97
Acrylic Triple Clear Prismatic	0.64	0.55	0.74
Green Double Low-e Glass	0.61	0.39	0.86

Figure 5-10: Glazing Thermal Properties

In this example we are assuming that all of the glazing products are applied in the form of unit skylights with a thermally broken metal frame that is attached to the roof via a wood curb. Fiberglass panels are usually applied flush to the roof as part of a site-assembled skylight. When the panels are applied flush to the roof there is approximately 30% less heat loss than the values listed in Figure 5-10, but the visible transmittance and solar heat gain coefficients are the same. White acrylic skylights provide a low solar heat gain coefficient, but also reduce visible transmittance substantially.

For daylighting purposes it is most desirable to have a "high performance" glazing material, defined as having a significantly higher ratio of visible light transmittance than heat gain. With glass this is commonly achieved with the use of a "selective surface", or low-e coating that selectively reflects infrared heat

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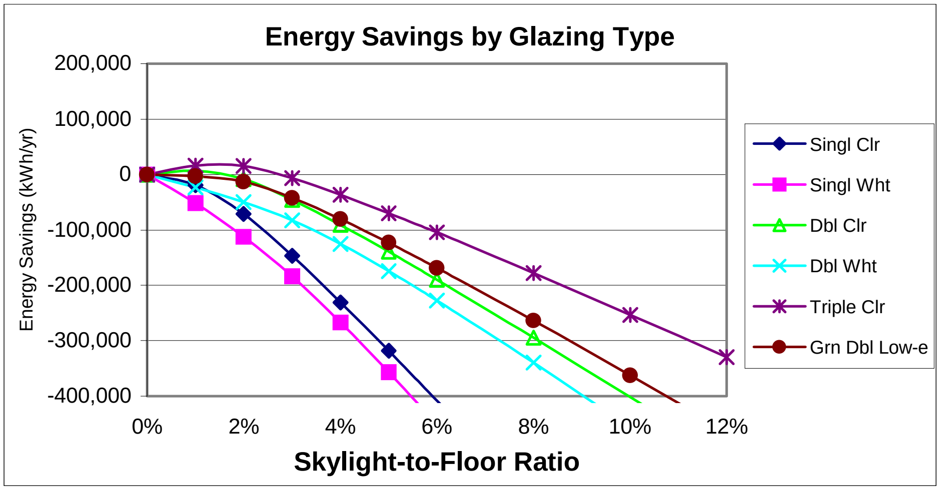
[11] Clear prismatic glazing is a highly diffusing glazing similar to prismatic lenses commonly used with fluorescent lighting. It should not be confused with clear glazing of a window. This material has high light transmittance without being transparent.

energy while allowing visible light to pass through. A high performance glass, "green double glazed low-e," with a low solar heat gain coefficient and high visible transmittance, is listed in Figure 5-10 and Figure 5-11 to represent a high performance glazing option. Plastic skylight materials are not easily coated with a selective surface and thus, currently, there are no selective surface plastic skylights commercially available.

In Figure 5-11 we see how differences in transmittance, solar heat gain coefficient, and insulation levels affect energy performance of this grocery store prototype in Albany.



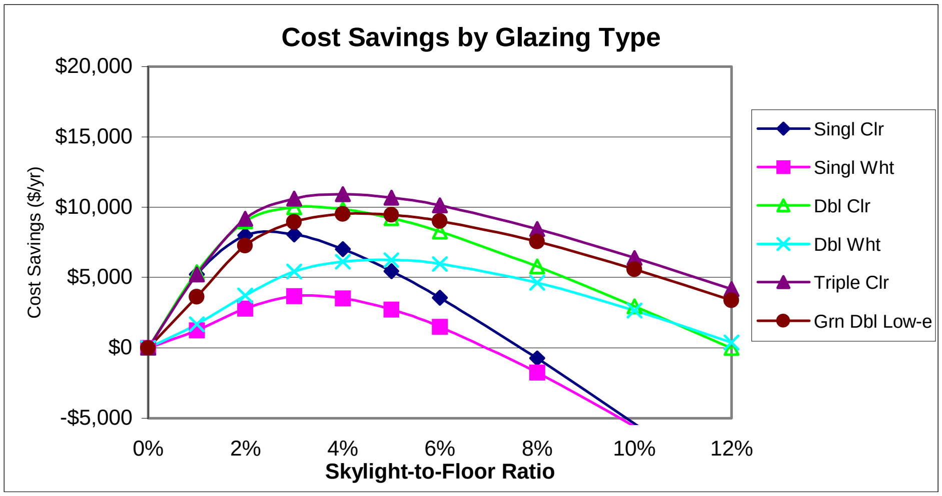


Figure 5-11: Annual Energy and Cost Savings by Glazing Type – Albany Grocery

Clear prismatic triple-glazing improves both performance and savings, but savings only increase about 7% above the double-glazed clear prismatic option. Since triple-glazing inevitably has higher initial costs than double-glazing, a cost/benefit analysis would suggest that, in this climate, double-glazing is sufficient.

It is the high transmittance, low U-factor skylights that are clearly the best performing systems in this climate.

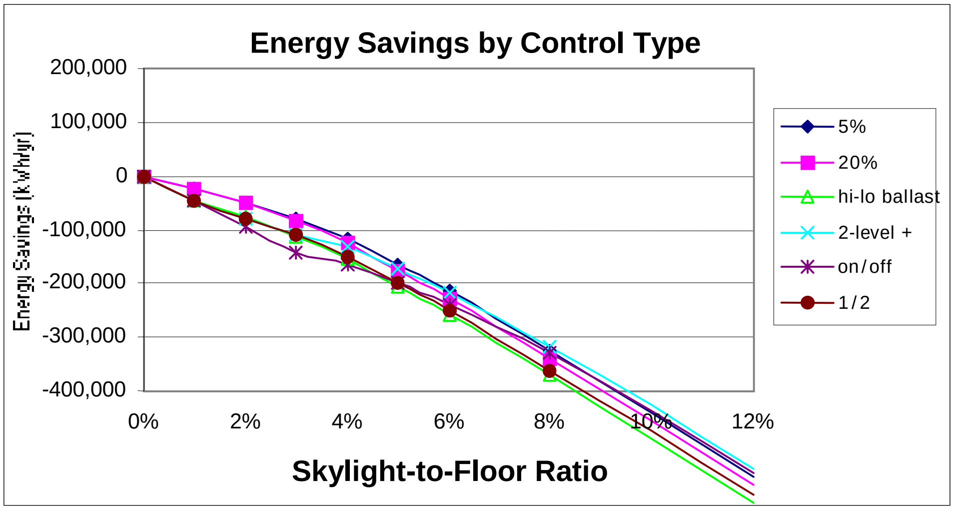
The assumption here, of course, is that all skylights are fully diffusing and can provide uniform illumination throughout the space. Simply specifying clear acrylic or glass will not achieve these goals. A carefully selected diffusion mechanism should be included in the design before a clear glazing is specified.

5.2.5.Savings by Control Type

The comparison of savings due to variation in control types is also instructive. Figure 5-12 looks at six control types:

- 5% dimming, (full lighting power down to 5% of the lighting power on)
- 20% dimming, (full lighting power down to 20% of the lighting power on)
- hi/low ballast, (full lighting power, half lighting power, and all power off)
- 2 level + off switching (full on, 1/2 on, and all lighting power off)
- On/off switching of the fixtures (full on, or all off)
- 1/2 on/off switching of the fixtures (full on, or 1/2 of fixtures off).

In general, dimming systems are preferable in this climate. The dimming systems save energy costs at even the lowest skylight-to-floor ratio. The 2 level + off controls, however, have a negative savings for lower SFRs and provide positive savings for SFRs above 2%. The same is also true for the on/off controls. However, with this control type the positive savings are realized for SFRs above 5%. The hi-lo ballast and the 1/2 on/off controls have the interesting effect of starting with a negative savings at the low skylight apertures and switching to positive savings for SFRs between 2% and 6%, then they drop to negative savings again for SFRs above 6-8. The 2 level + off control system outperforms the other systems, both in terms of energy and cost savings at SFRs above 8%. The 5% dimming controls come first in terms of performance especially with SFRs below 8%. This is because, with low transmittance glazing, a highly variable weather pattern, and low light levels in the winter, 5% dimming systems are providing more energy savings at the resulting low interior daylight illumination levels.



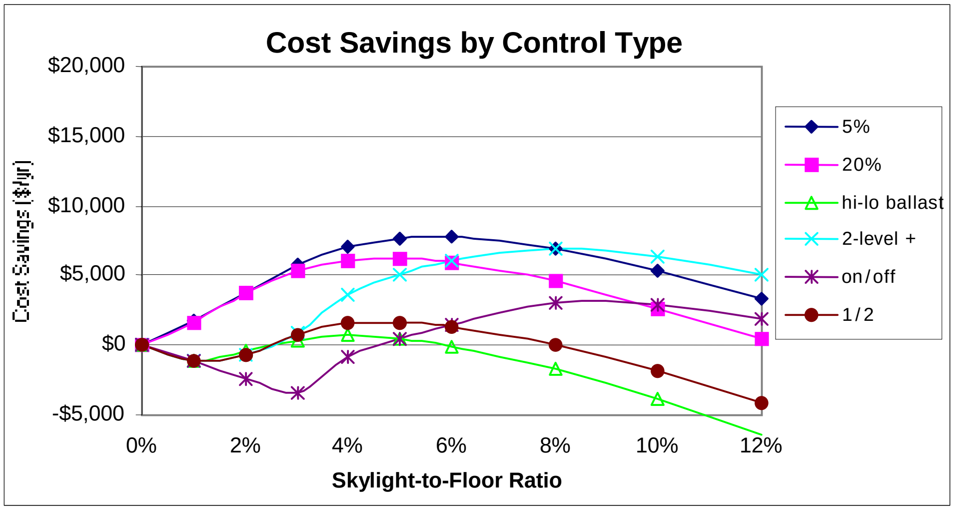


Figure 5-12: Annual Energy and Cost Savings by Control Type – Albany Grocery

Note: All systems were compared for a grocery store with a fluorescent lighting system at 50 footcandles and 1.39 W/sf.

In a sunnier climate, or with higher daylight levels from higher transmittance glazing, a switching system might start outperforming the dimming systems. On-off switching systems tend to be simpler and less expensive than dimming systems. Thus, the overall cost effectiveness of a switching system in this climate may be higher than the dimming systems, especially at larger apertures above 6% SFR.

5.2.6.Illuminance Levels

Since the primary purpose of skylights is to provide daylight, they should be designed to achieve satisfactory levels of daylight throughout the year. Merely choosing the optimum energy performance may not necessarily meet this goal. Thus, the designer should carefully look at average illumination conditions and the number of hours of daylight saturation provided throughout the year. The illumination graphs in *SkyCalc* are provided to help the designer make an informed decision about average illumination levels. Daylight saturation[12] should be a key criterion because we find that occupants are most satisfied with skylights, and are most likely to turn off electric lights, when the daylight illumination levels meet or exceed the electric illumination targets.

The graphs shown in Figure 5-13 were generated by *SkyCalc* for our typical grocery store in Albany, which set its design target illumination at 50 footcandles, and used double-glazed, white acrylic skylights. The graphs illustrate how daylight saturation changes with increasing number of skylights, resulting in a higher SFR, or gross skylight aperture.

The white areas in Figure 5-13 indicate the hours of daylight saturation on an average day in each month. The lightly shaded areas indicate the hours of the day when daylight is available (more hours in summer, less in winter) to provide 50-99% of the target illuminance in the space. The graph is designed to display the average illuminance for each hour of the day during the 12 months of a typical calendar year. For this example, the third graph indicates that the 6% SFR grocery store in Albany, NY at noon in June gets 146 fc, which is the average illumination for 12 o’clock noon of all the 31 June days of a typical year.

The graphs show how daylight saturation varies as the area of skylights increases. In the top graph, at an SFR of 2%, the average monthly conditions show that the target illumination level of 50 footcandles is rarely met. In reality, it will occur on occasional bright sunny days, but this graph simplifies the information by only presenting the average condition for each hour of the month. *SkyCalc*, in doing an hourly calculation using typical weather data, also reports in one of its summary tables, not shown here, that full daylight saturation would be achieved for 394 hours per year, resulting in 15% of total lighting energy saved from the daylighting controls.

In the middle graph, with the SFR doubled to 4%, we see that, on average, full daylight saturation is achieved for eight hours during the middle of the day, May through August. Other *SkyCalc* summary tables, not shown here, also report that for this building design in Albany, daylighting saturation would be achieved for 1520 hours per year, resulting in 21% lighting savings. Up to 90-100 footcandles can be expected at midday in midsummer, about double the target illumination at peak daylight conditions.

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[12] Daylight saturation is achieved when the skylights provide more than the specified target design illumination level (50 fc in the case of our grocery store example).

Effective Aperture = 0.89%, Skylight to Floor Ratio (SFR) = 2.05%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	1	5	10	15	19	19	16	11	5	2	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	3	9	17	25	27	29	25	18	11	5	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	2	7	16	25	31	34	34	32	26	16	8	3	0	0	0	0	0	0
Apr	0	0	0	0	0	1	6	14	25	33	42	44	42	40	33	22	13	5	1	0	0	0	0	0
May	0	0	0	0	0	4	10	20	31	39	45	51	49	47	41	30	18	9	3	0	0	0	0	0
Jun	0	0	0	0	1	5	12	23	31	43	46	50	49	46	39	30	21	11	4	1	0	0	0	0
Jul	0	0	0	0	1	4	10	21	32	43	49	53	52	48	43	31	22	11	4	1	0	0	0	0
Aug	0	0	0	0	0	2	7	18	29	37	46	49	48	44	38	27	17	8	2	0	0	0	0	0
Sep	0	0	0	0	0	1	4	12	22	30	37	39	41	36	28	19	9	3	0	0	0	0	0	0
Oct	0	0	0	0	0	0	2	7	14	23	29	30	29	25	17	10	3	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	3	8	13	18	18	18	15	10	5	1	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	1	5	10	14	17	16	13	8	4	1	0	0	0	0	0	0	0

Design Illuminance = 50 fc

< 5 fc; < 25 fc; < 50 fc; ☐ > 50 fc;

Effective Aperture = 1.76%, Skylight to Floor Ratio (SFR) = 4.03%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	2	9	19	29	37	38	31	21	11	3	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	6	18	33	49	53	57	50	36	22	9	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	4	14	31	49	61	66	66	63	51	32	17	5	0	0	0	0	0	0
Apr	0	0	0	0	0	3	11	28	49	64	82	86	82	79	65	43	26	11	2	0	0	0	0	0
May	0	0	0	0	1	7	20	39	61	77	88	99	97	93	80	58	36	17	5	0	0	0	0	0
Jun	0	0	0	0	2	10	24	46	62	85	91	98	96	91	77	59	42	22	8	2	0	0	0	0
Jul	0	0	0	0	1	8	20	42	63	85	96	104	103	94	84	61	43	22	8	1	0	0	0	0
Aug	0	0	0	0	0	4	14	35	57	74	90	96	95	87	74	53	33	16	4	0	0	0	0	0
Sep	0	0	0	0	0	1	9	24	43	59	74	78	80	72	55	38	18	6	0	0	0	0	0	0
Oct	0	0	0	0	0	0	4	13	28	44	57	59	56	49	34	19	7	1	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	5	16	25	35	36	35	30	20	9	2	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	2	10	20	28	34	32	25	17	7	1	0	0	0	0	0	0	0

Design Illuminance = 50 fc

< 5 fc; < 25 fc; < 50 fc; ☐ > 50 fc;

Effective Aperture = 2.62%, Skylight to Floor Ratio (SFR) = 6.02%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	4	14	29	44	55	56	46	32	16	5	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	8	27	49	73	79	84	75	54	33	13	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	6	21	46	73	91	99	99	93	77	47	25	8	0	0	0	0	0	0
Apr	0	0	0	0	0	4	17	42	72	96	122	129	122	118	98	64	39	16	3	0	0	0	0	0
May	0	0	0	0	1	10	29	59	91	115	132	148	145	139	120	87	54	25	8	0	0	0	0	0
Jun	0	0	0	0	3	14	35	68	92	126	136	146	143	136	116	88	62	33	12	2	0	0	0	0
Jul	0	0	0	0	2	11	30	62	94	127	143	154	153	141	125	90	64	32	12	2	0	0	0	0
Aug	0	0	0	0	0	6	21	52	85	110	134	143	142	130	111	80	49	24	6	0	0	0	0	0
Sep	0	0	0	0	0	2	13	35	64	89	110	116	120	107	83	56	27	9	1	0	0	0	0	0
Oct	0	0	0	0	0	0	5	20	41	66	86	88	84	72	51	29	10	1	0	0	0	0	0	0
Nov	0	0	0	0	0	0	1	8	24	37	52	54	53	44	30	14	3	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	3	15	29	42	50	48	38	25	11	2	0	0	0	0	0	0	0

Design Illuminance = 50 fc

< 5 fc; < 25 fc; < 50 fc; ☐ > 50 fc;

Figure 5-13: Daylight Saturation With Varying Skylight Aperture—2%, 4% and 6% SFR

In the bottom graph in Figure 5-13, with an SFR of 6%, the grocery store achieves full daylight saturation for ten hours per day May through July, nine hours in August, and eight hours in April and September. During midwinter, illumination is below the target most of the day, except at noontime. *SkyCalc* tells us that 50 footcandles or more would be available for 2230 hours per year, about half of the possible daylight hours, resulting in 24% lighting savings. Peak illumination levels rise up to 146-154 footcandles in the middle of summer, three times the target illumination level.

Figure 5-14 provides the percentage of hours with full daylighting as a function of the skylighting to floor ratio (SFR). It shows that an SFR of 6% provides the grocery store example with full daylighting for more than 50% of the possible daylighting hours during the year.

These graphs are based on a grocery store in Albany using double-glazed, white acrylic skylights. Dramatically more daylight, and daylight saturation, could be available with the use of higher transmittance skylights, such as double-glazed, clear prismatic skylights. Heat loss remains constant between the two systems, and heat gain increases, but over half of that heat gain is during spring months where the extra heat from the solar gains may be welcomed. It should be clear from the earlier analysis in Section 5.5 on Heating and Cooling Effects that the heat gains are not nearly as significant in value as the potential additional lighting savings from improved daylight saturation.

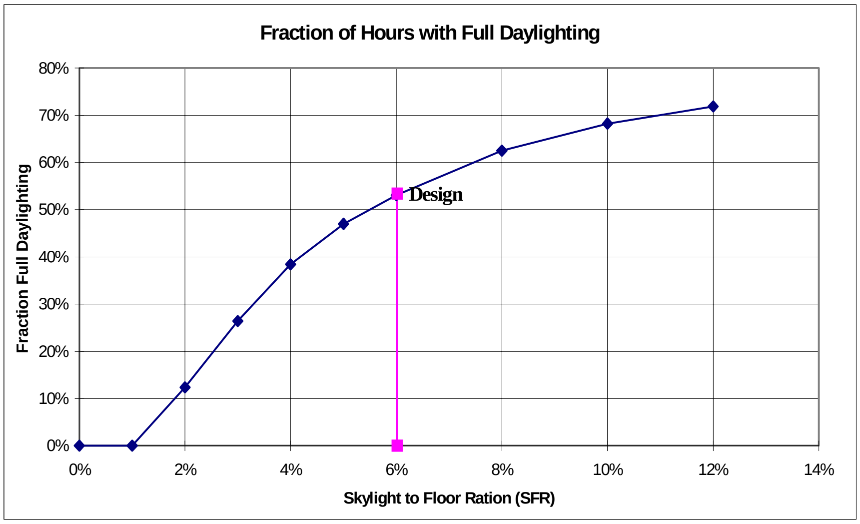

Figure 5-14: Fraction of Hours with Full Daylighting vs. SFR

5.2.7. Visible Transmittance vs. SHGC

Currently, most building codes in the Northeast require a maximum Solar Heat Gain Coefficient for skylights (See Section 5.4). The ASHRAE 90.1 code varies its requirements by the visible transmittance of glazing. Given the lack of high performance plastic glazing materials on the market, a low SHGC for a plastic skylight also mandates a low visible transmittance.

Occupant preference studies indicate that the awareness of the sun, whenever it might appear and for however short a time, is perhaps more important psychologically than shelter from the rain and cold. Hence, a “convertible” skylight, one that can allow maximum sun in when desired, and can reduce excessive daylight when it is not needed or desired, would be ideal. Such a system could involve a high tech solution such as variable glazing, or it could be as simple as adjustable louvers placed in the skylight well. Correctly oriented louvers also provide a simple way to diffuse direct sunlight so that it does not create glare problems.

In Albany, with its long periods of weak daylight, it may be most appropriate to design a skylighting system to optimize illumination rather than energy performance. Such a system would favor winter illumination over summer heat gains. Alternatively, a variable system that maximizes visible transmittance in the winter, but reduces it during the sunny days of summer and fall, may be even more attractive. It could provide both optimum illumination and better energy savings.

5.3. Northeast Building Practices

Building practices and materials vary all over the country. Some issues of particular concern to the Northeast are discussed below.

5.3.1. Water Protection

Heavy rain conditions put water leakage high on owners’ and designers’ priorities in the Northeast. Sloppy installation details have contributed to a reputation that skylights leak. People have incredibly long memories for such problems. Older skylight installations were commonly built up on site and had many glazing joints that were potential leak problems. Modern manufactured skylights have reduced leakage problems dramatically with the use of unitary plastic glazing and factory sealed joints.

Water protection must be addressed at several levels, including the skylight unit, its installation on the roof, and the roof system.

The manufacturer of the skylight is, of course, responsible for assuring that glazing seals and joints in the skylight frame are completely water tight. Wherever there are operable openings, or where there are weep holes and other openings, these must be well screened from both direct rainfall and from wind-driven water. Any such opening, which allows water to collect close by, can be susceptible to water penetration caused by wind pressure or other pressure differentials between inside and outside. Protecting against this type of leakage involves the same rain screen principles as used to make windows, doors and other building openings water tight.

Any joint in a skylight unit where water can collect, such as where the glazing material meets the framing, has the potential for wind-driven water penetration. Most good skylight designs recognize the fact that these joints will inevitably experience some leakage over time, and they provide gutters and weep holes for the water to make its way back outside. This is often the same system that deals with condensation (see below).

Since skylights are installed on roofs, the installation presents the same waterproofing problems as any other kind of roof penetration. The most reliable general solution to this problem is to use a properly flashed curb opening. The curb connection to the roof depends on the slope of the roof and the roofing material. In sloped roof conditions, with shingled roofing materials, step flashing woven into the shingles, and protected by a counter flashing at the curb, has proven to be reliable. For flat roofs, the roofing membrane should run continuously up from the roof deck, across cant strips and under the curb's counter flashing, with a minimum of joints and seams. Any roofing material joints or seams must be carefully and reliably sealed.

The connection between the skylight unit and the curb should be mechanically sound and well-protected from direct and wind-driven water penetration. Installations can be caulked or adhered with butyl tape under the flashing drip edge to address this problem. The curb must be high enough to exceed the highest water levels that could result during downpours, because of snow and slush build-up, or because of ice dams. Many owners have found greatest success with curbs that are part of the structural system of the building, rather than attached as a secondary system. Framing the curb as part of the structural system reduces the potential for movement between the skylight and the building.

The biggest vulnerability of skylights to leakage is generally the quality of workmanship around the roof penetrations. There is nothing difficult about waterproofing roof penetrations – it's done all the time – but all it takes is miss-applied flashing or a poorly sealed joint in a roof membrane to cause a leakage problem. These are usually easy to spot and to repair, unless the faults are only apparent during special conditions, such as a leak that's caused by wind-driven build-ups of water that are intermittent. The only thing different about skylights is that there are generally many of them, which simply increases the chances for a foul-up. Careful detailing and tight specifications that call for installation warrantees from contractors are the best protection against leaks. In general, it is a good idea to hold the general contractor responsible for the water tightness of the finished roof/skylight system. Some specifications detail a minimum response time to reported problems. Such a warrantee provides clear responsibility and guarantees the owner quick resolution to any problem. The resulting system should remain watertight for the life of the roof.

Rainfall on skylights is not all negative; it can also have positive effects. Frequent rain can keep skylight glazing materials cleaner and lessen the impact of dirt buildup that blocks daylight. Also, the sound of rain on the skylights can be an unexpected pleasure to the occupants of the building. It enhances the connection with the outdoors that skylights provide.

5.3.2. Condensation

Northeastern climates tend to have relatively high humidity levels in the summer. In the winter, buildings are closed and interior moisture accumulates. These conditions, combined with cold nighttime temperatures, make it likely that condensation will form on the interior surface of any skylight, even if it is double or triple-glazed. Condensation, which forms on the skylight glazing, can then drip down the side of a skylight well, causing staining, or even drip to the space below. Many cases of “leaking” skylights are actually skylights with heavy condensation that do not provide a drainage path for the condensate.

The colder, and/or the more humid, the climate, the more attention should be paid to condensation on the interior surfaces of skylights. Condensation should be physically collected and prevented from dripping. This is usually done with condensation gutters, which can be sized according to the magnitude of the problem (larger glass areas require larger gutters). An alternative is to provide weep holes from a smaller gutter to the exterior of the skylight that allow excess condensation to escape to the outside. Care should be taken that the weep holes are well screened from exterior water buildup and do not allow wind-driven rain to enter.

The American Architectural Manufacturers Association (AAMA) has developed a condensation resistance factor (CRF) to describe the resistance of a window or skylight assembly to condensation in different climates. This testing procedure is recommended when specifying large architectural skylights where the condensation on the glazing could result in a problem, especially in colder climates. The test procedures are described in Chapter 29 of the ASHRAE Handbook of Fundamentals[13].

5.3.3. Snow Loads

Snow buildup on roofs and on skylights can be heavy; these systems must be designed to withstand the load. Skylights can have an advantage over roof monitors in snow regions, in that snow tends to blow off of the horizontally mounted skylights, which are likely to be mounted a foot or more above the roof surface. Roof monitors, on the other hand, can act similar to a snow fence and disrupt the wind patterns to cause local accumulation of snow. These drifts can block a considerable amount of daylight. Heat loss through the skylight glazing and frame will tend to accelerate snow melting above and around the skylight, allowing more light in after a snow storm.

Some regions in the Northeast require up to a 200 pound per square foot live load for snow on skylights, similar to the loading on the roof in general. Check with your local code for specifics. Skylight manufacturers can report the live loads which their units are designed to carry, so it is simply a matter of specifying adequately designed products. In practice, these snow load levels rarely occur on skylights since the weight of snow will bridge across the skylight, especially as

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[13] ASHRAE Handbook of Fundamentals, 1997, pp. 29.12-29.14

any melting from below occurs. Deep accumulation of snow is likely to create pockets of little self-supporting arches over each skylight. A far greater danger is not from the weight of the snow, but from people walking around on the roof when the skylight is obscured by snow cover (see safety issues below).

5.3.4. Wind Loads

Northeast climates can tend to be windy, especially during the fall season. The northern winds and the eastern storms from the Atlantic have to be considered in designing for skylighting distribution and placements on roofs. This is especially associated with skylights on top of high-rise buildings or buildings that lie in between relatively tall buildings due to negative and positive pressure zones that can cause pressure areas on roofs and around skylights. The primary problem is not downward pressure, which will rarely exceed snow loads. The larger problem is suction or uplift pressure, which can pop poorly attached skylights out of their mounts. This is easily solved by structural attachments to hold down the units. Both building code structural requirements and manufacturers' installation recommendations provide guidance for the skylight designer.

5.3.5. Safety

Manufacturers and architects should take liability questions about falls through skylights very seriously. In New York in 1994, a school district and an architect were found jointly liable for a 30 year-old plastic skylight, which broke when a 14 year-old boy climbed onto it to reach a ball that was up on a higher level roof.

From this case it is possible that manufacturers, owners and architects may be held liable for the entire life of a skylight. Most manufacturers are not willing to guarantee the strength of their glazing materials indefinitely, regardless of maintenance and exposure to weather. Thus, it is highly recommended that some positive, physical barrier to falls be provided in or around skylights. Some state and federal codes specifically require this.

On any roof where the public may be present, now or at any time in the future, it should be assumed that a careless person might fall on a skylight, which may break. Employee injuries and death from falls through skylights seem to be even more common than with the general public. At least eight deaths were recorded in 1995 around the country from people falling through skylights. Most commonly those accidents involved authorized employees of the company who tripped or lost their balance for some reason and fell through an old skylight that could not support their weight. In some cases the skylight was unseen, obscured by debris or located behind the person who lost their balance.

Many safety standards require that such an accident will not result in more than a six-foot fall. Thus, a safety grate in the skylight well, capable of supporting a large person's full weight (typically 250 lbs. plus a 50 lb. tool belt), will often meet these requirements. A safety grate is provided by some manufacturers, or can be site-fabricated. A six-inch grid of re-bars is often used in site built systems. Raising skylight curbs to guard rail height is another simple method that can reduce injury from accidental falls. The resulting additional depth of the skylight well can also enhance light control. Other methods for protection include increasing the strength of the glazing with thicker plastics, laminated glass or wire glass; providing guard rails around the exterior of the skylight; or providing roof tie-downs for required safety ropes for anyone working on the roof. Check with local OSHA and code requirements for your area.

5.4. Northeast Energy Codes

The seven Northeast states each have slightly different requirements for skylighting in commercial buildings. Figure 5-15 below indicates the type of energy code adopted by each state. The general summaries following that figure briefs the reader on the specifics of each energy code as it applies to skylights. These summaries are based on codes and standards in force at mid-year 2000 and are provided as a convenience to the reader. Provisions and interpretations may change, so check with your local building department for current requirements.

State	Prescriptive Code	Compliance	Recent update
New York	NY Energy Code	None	IECC 2000 in 2002
Massachusetts	MA Energy Code	Com*check*-EZ™ v.2.1	August 1999
Rhode Island	ASHRAE/IESNA 90.1-1989	Com*check*-EZ™ v.2.1	April 1998
Connecticut	ASHRAE/IESNA 90.1-1989	Com*check*-EZ™ v.2.1	May 1999
Maine	ASHRAE/IESNA 90.1-1989	Com*check*-EZ™ v.2.1	January 1989
Vermont	ASHRAE/IESNA 90.1-1989 *for State-funded projects*	None	April 1994
New Hampshire	ASHRAE/IESNA 90.1-1989	Com*check*-EZ™ v.2.1	February 1999

Figure 5-15: Local Energy Codes for the Northeast States

5.4.1. New York State Energy Code

The prescriptive New York non-residential energy code, *New York Building Code Rules and Regulations (NYCRR), Title 9 Vol. B* requirements for skylights are based upon the fulfillment of two requirements; the overall thermal performance of the roof (U value), and Shading Coefficient of the glazing system. Each of these values is described below.

- The thermal performance of the roof system has a maximum $U_{av.} = 0.05$[14], and can be calculated by the following formula:

$$U_{av.} = \frac{U_R A_R + U_g A_g + U_d A_d + \ldots}{Gross\ Roof\ Area}$$

where:

$U_{av.}$ = *Average or combined thermal transmittance of the exterior roof in Btu/(hr sf °F)*
U_R = *Thermal transmittance of the opaque portion of the roof*
A_R = *Area of the opaque roof excluding skylights and other hatches or voids areas*
U_g = *Thermal transmittance of the glazing*[15]
A_g = *Area of the glazing*[16]
U_d = *Thermal transmittance of roof vents, hatches, or doors*
A_d = *Area of roof vent, hatch, or door*

- Skylights on roofs as well as east, west, and south facing walls shall have overall shading coefficients SC_o[17] not to exceed those specified in Figure 5-16. These shading coefficient values are based on the glazing-to-wall percentage of the whole building and can be calculated from the following equation:

$$\%\ Glazing = \frac{Area_{(E,W,S,windows)} + Area_{skylights}}{Total\ Area\ of\ walls}$$

Since the area of the roof is not included in the denominator, adding skylights to a building can put a designer of a building with a large roof area at a disadvantage. Basically, a designer must substitute skylight area for window area. Even so, the daylight performance of the building is likely to improve with the substitution of skylight area for window area.

% Glazing	SC_o Roof	SHGC
10-20	0.70	0.609
21-30	0.50	0.435
31-40	0.40	0.348
> 40	0.30	0.261

Figure 5-16: Overall Shading Coefficients for Buildings - New York Energy Code[18]

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[14] Article number 7813.3, NY Energy Code, Table 4-1.
[15] In the case of skylights this will be the U-value of the skylight.
[16] For skylights, this will be the area of the rough opening.
[17] Note that some skylight and glazing manufacturers provide the Solar Heat Gain Coefficient (SHGC) rather than Shading Coefficient (SC_o). For conversion: SHGC = 0.87 x SC_o.
[18] Based on table 4-2, section 7813.3, NY Energy Code

Figure 5-17 applies the formula on the previous page and illustrates how roof U-factor is required to increase in response to the addition of skylight area, as a function of the insulating value of the skylights. A quick rule of thumb is that for small SFR, skylights must be double-glazed with any frame type; for larger SFR, skylights must be double-glazed, have tinted glazing (SHGC down to 0.4) and a wood or vinyl frame. Unfortunately, there are no visible transmittance requirements for skylights.

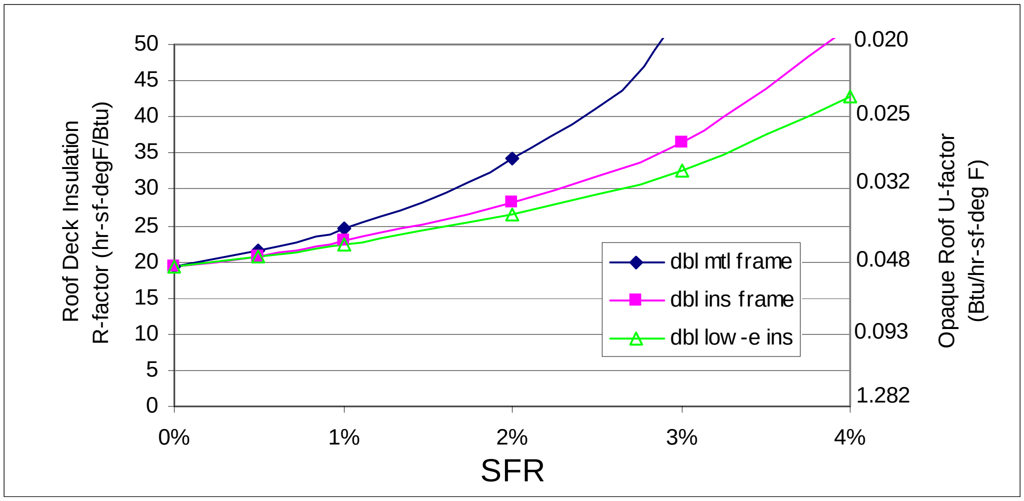

Figure 5-17: Example of New York Energy Code requirements for skylight area relative to roof insulation levels

5.4.2. Massachusetts Energy Code

On July 13, 1999 the Board of Building Regulations and Standards (BBRS) voted to adopt a complete revision to the energy conservation requirements for new commercial buildings in the Massachusetts Building Code (780 CMR, Chapter 13.) The new requirements took full effect on January 1, 2001 and are mandatory for any commercial building permit submitted after December 1999. These changes include elements from both the revised ASHRAE Standard 90.1-1999 and from the International Energy Conservation Code (IECC 2000), as well as some requirements that are unique to Massachusetts. The code defines skylight as a fenestration surface having a slope of less than 60% from the horizontal plane. Massachusetts Energy Code requirements for skylights are simple. According to article 1304. 2, Prescriptive Building Envelope Criteria: "the *skylight fenestration area* does not exceed **3%** of the *gross roof area* for each *space-conditioning category."* Skylights shall have a maximum thermal transmittance (U-factor) of the skylight assembly as specified in Tables 1304.2.1-12[19].

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[19] MA Energy code article #1304.2.5 Skylights. Copies of the Massachusetts Non-residential Energy Code can be downloaded from http://www.state.ma.us/bbrs/text.htm

Frame Material & Glazing Type of Skylights[a]	Single Glazed	Double Glazed	Double Glazed Low-e	Triple Glazed	Triple Glazed Low-e
Metal w/. out Thermal Break	1.98	1.31	1.20	1.12	1.08
Metal w/. Thermal Break	1.89	1.11	1.00	0.89	0.85
Wood/Vinyl/Fiberglass	1.47	0.84	0.74	0.64	0.59

[a] *Certain values in this table do not meet the limits of 780CMR 1304.2, Prescriptive Building Envelope Criteria, or 780 CMR 1305, Building Envelope Trade-Off Option, and may be used only when demonstrating compliance using 780CMR 1309, Building Design by Systems Analysis.*

Figure 5-18: U-factor Default Table for Skylights—Massachusetts Energy Code, Table 1301.9.3.1a

U-factor is required to be no more than 0.8 and the shading coefficient a maximum of 0.57. Figure 5-18 shows the default values for skylights. Skylights with metal frames or single glazing do not comply with the code. Note that again there are no visible transmittance requirements for skylights.

To specify more skylight area than 3% of the roof area, the Building Envelope Trade-off Option, Article 1304.5, or the Building Design by System Analysis Approach, Article 1309, can be used. The Trade-off Option allows the permit applicant to trade-off components in the building envelope as long as the overall energy consumption does not increase. The Simplified Trade-Off Approach uses a basic annual loads calculation program, Com*check*-EZ™ Version 2.1, April 2000, to make the comparison of the proposed building to an equivalent building that followed the Prescriptive Path.

The Building Design by System Analysis Approach allows the building designer to trade-off different components of the entire building that affect energy consumption. A proposed design that complies under this approach must not have a higher energy cost than a similar building design that complies with the prescriptive requirements of the code.

5.4.3. ASHRAE 90.1-1989

Some jurisdictions use the ASHRAE 90.1-1989 Energy Code for Commercial and High-Rise Residential Buildings. In some cases, there may be local amendments to this code, or the jurisdiction may be using the new ASHRAE non-residential energy code ASHRAE 90.1-1999. Check with the local building department to clarify which version of ASHRAE 90.1 is being used and if there are any local amendments.

The ASHRAE 90.1-1989 Code recognizes that skylights can save energy if there is the correct balance between solar gains, heat loss and electric lighting reductions. This code exempts a given area of skylights from the calculation of overall roof U-factor, provided the skylighting system meets the six criteria described below.

1. U-factor of the opaque section of the roof must meet the prescriptive requirements in table 402.3.1b.
2. Fraction of roof area devoted to skylights must not exceed the prescriptive maximum allowed in Table 402.3.1(b) as a function of skylight visible light transmittance, interior design illuminance level, and lighting power density. See Figure 5-19 below for exempt skylight allowances based on climatic conditions in the Northeast.
3. Automatic controls must be installed to control the lighting in the daylit zone beneath the skylights. The definition of the daylit zone is demonstrated in Figure 5-20 below.
4. The skylight U-factor is less than 0.70 Btu/h·sf·°F for most of the northeast cities that have less than or equal to 8000 HDD65 (heating degree days, base 65°F) and this U-factor is less than 0.45 for other cities that exceeds 8000 HDD65. This is based upon default tables of skylight U-factor[20,21] so that double-glazed skylights would comply if there is a ½" gap between the glazing layers.
5. The skylight curb must be insulated so that the U-factor is less than 0.21 Btu/h·ft^2·°F. Metal or wood curbs with an inch of rigid insulation will satisfy this requirement.
6. Air leakage less than 0.05 cfm/ft^2. (Note: This very low leakage rate is probably unenforceable and is possibly based on a typographical error. The current version of the ASHRAE Handbook[22] states that the maximum infiltration value for manufactured fenestration products is 0.5 cfm/ft^2.)

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[20] 1985 ASHRAE Fundamentals Handbook, Atlanta.

[21] *Table 402H Fenestration U-factors*, p 402-72, 90.1 Code Compliance Manual, USDOE Office of Codes and Standards, Feb. 1995

[22] P. 29-12 1997 ASHRAE Fundamentals Handbook,

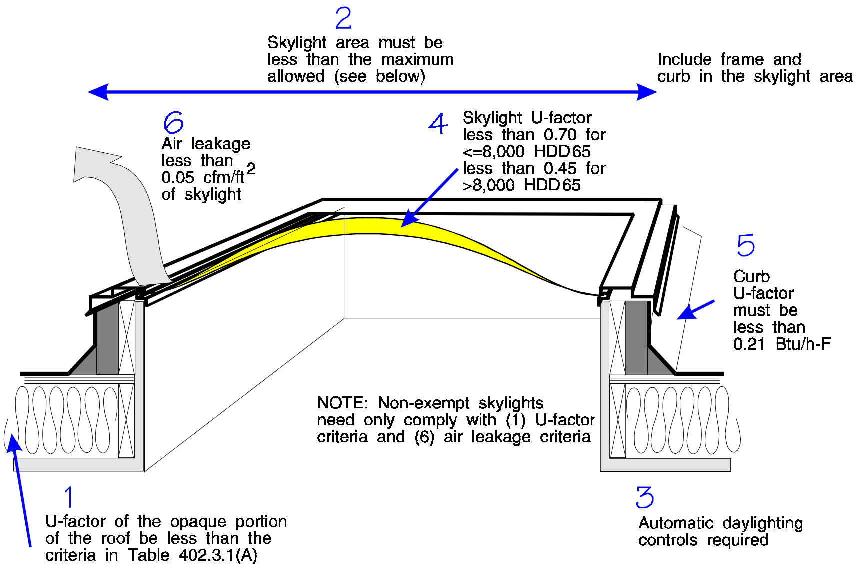

Figure 5-19: Six Requirements of Exempt Skylights

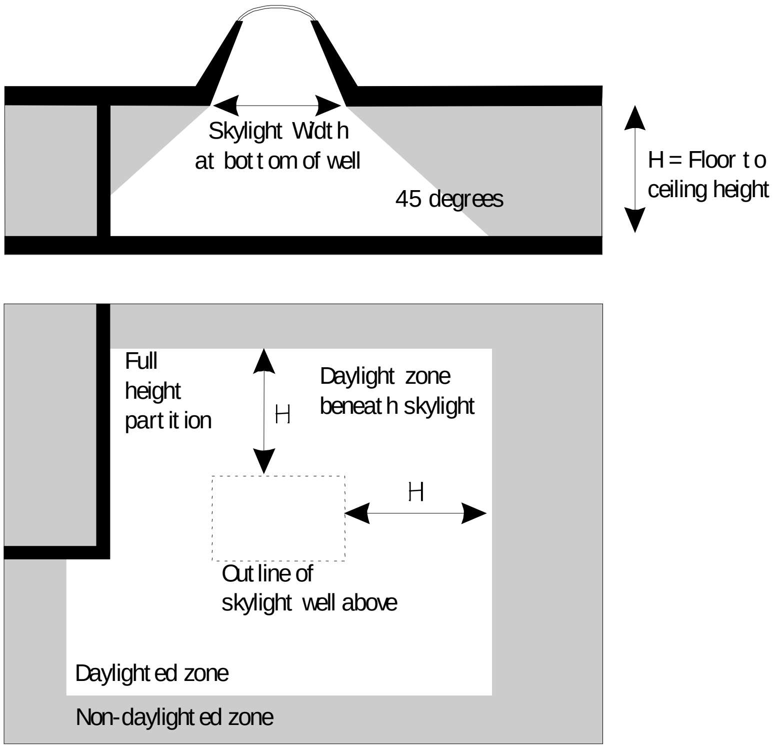

Figure 5-20: Daylit zone under skylights

Additional skylight area can be added above the exempt skylight allowance, but the additional area must be considered in the calculation of overall roof U-factor. Thus, roof insulation has to be increased if more than the exempt area of skylights is specified. Note that there are no requirements concerning the solar heat gain coefficient or shading coefficient of skylights.

For the northeast region of the United States, the exempt skylight area allowed in ASHRAE 90.1-1989 is shown in Figure 5-21 below. For skylights with a visible transmittance between 75% and 50%, one may interpolate between values. No other form of interpolation or extrapolation is allowed. If a skylight has a visible light transmittance (VLT) greater than 75%, use the exempt skylight area for a VLT of 75% and if the skylight has lower transmittance than 50% use the exempt area corresponding to skylights with a VLT of 50%.

Table 402.3.1(B) MAX. EXEMPT SKYLIGHT AREA AS % OF ROOF AREA

Visible Light Trans. VLT	Light Level (fc)	Range of Lighting Power Densities (W/sf)			
		<1.00	1.00 - 1.50	1.51 - 2.00	>2.00
75%	30	2.3	3.4	4.5	5.6
	50	2.5	4.0	5.5	7.0
	70	2.8	4.6	6.4	8.2
50%	30	3.6	5.1	6.6	8.1
	50	3.9	6.0	8.1	10.2
	70	4.2	6.9	9.6	12.3

Figure 5-21: Exempt Skylight Area in ASHRAE 90.1-1989

Photocontrols are required to control the electric lights in the daylit zone beneath the skylights to qualify for the skylight exemption. In addition, the connected lighting power value may be reduced to reflect the reduced energy consumption of lights on automatic controls. Lighting Power Adjustment Factors (PAF) discount the installed lighting equipment by 10% (for on/off switching) or up to 30% (for continuous dimming). Additional credit is given if other lighting control strategies (such as occupancy sensors) are combined with daylight controls. To qualify for the daylight sensing power adjustment factors, at least 50% of the light fixtures must be in the daylit zone and the control must be able to reduce the power draw of the fixtures by 50% or more. The lighting power adjustment factors give the designer the flexibility to install more lighting equipment.

The Energy Cost Budget (ECB) method is also available for compliance. This is similar to the Systems Analysis Approach discussed previously. The use of a simulation program offers the opportunity to account for all of the effects of skylights and photocontrols in relationship to the operation of the building.

The Energy Cost Budget method allows trade-offs between all energy using systems of the building (HVAC, lighting, and envelope measures) relative to a base case that complies with the simpler prescriptive approach.

5.4.4. ASHRAE 90.1-1989

The new *ASHRAE 90.1-1999 Standard for Buildings except Low-Rise Residential Buildings* has made a number of revisions to the older ASHRAE 90.1 1989 that is currently in use around the country. This new standard will be increasingly influential in the future as it is adopted by reference in other building codes.

Limitations on skylight area have been simplified to a 5% limit of gross roof area. U-factor requirements for skylights are now a function of climate zone, skylight type (glass vs. plastic, curb vs. no curb) and conditioned vs. semi-heated space. The definition of the skylight U-factor has also changed. Because of such changes in definitions, it is not possible to directly compare the requirements of the two codes.

Solar heat gain coefficient (SHGC) has been added as a criterion for skylights, and is a function of climate, skylight-to-roof area ratio, skylight type and space type.

The ASHRAE 90.1-1999 Code under its prescriptive path has no requirements for daylighting controls, nor does it provide lighting power adjustment credits. An alternative to the prescriptive approach is the Energy Cost Budget method. This method uses a building energy simulation program such as DOE-2 to model the interaction of lighting, envelope, mechanical and controls components. Under Energy Cost Budget method, trade-offs can be made between all building components as long as the overall annual energy costs of the proposed design are less than a similar building that complied with all the prescriptive requirements of the Code. Since energy savings from photocontrols could be documented under this approach, use of these controls could be used to offset more attractive. It could provide both optimum illumination and better energy savings.

5.5. Skylighting Recommendations for the Northeast

We recommend the use of *SkyCalc* for the design of skylighting systems. It has many advantages in allowing designers to quickly see the potential energy and lighting impacts of different specification choices. The parametric runs discussed above provide some guidance, but using *SkyCalc* to study individual situations will provide more accurate answers.

Despite its usefulness, there are a number of design and operational options that *SkyCalc* cannot model which merit some consideration by the designer. A future version of *SkyCalc* may incorporate more of these capabilities, such as the use of movable insulation, or the use of adjustable louvers that can act to moderate solar gains and illumination levels as appropriate.

Many people wonder at the cost effectiveness of skylights versus vertical glazing on the roof, such as monitors. We cannot answer that question with this tool. There are advantages and disadvantages to both daylighting techniques. We consider skylighting only one option in the design palette of a good designer. Below are a few of the advantages of skylights in the Northeast::

- Overcast skies result in the brightest area of the sky at its zenith. Thus, skylights are likely to bring in more light on an overcast northeastern day than will vertical glazing. Skylights, however, are exposed to more direct sunlight than vertical glazing.
- Dense foliage patterns from the surrounding landscape as well as other surrounding buildings may reduce daylight for vertical glazing by blocking a view of sky. Skylights, on the other hand, can see a fairly unobstructed view of the overhead sky at almost any urban or rural site.
- Skylights can be effectively mounted on both flat and sloped roofs, providing top lighting without major structural changes to most roof designs.
- Skylights can often collect more daylight per square foot of glazing than vertically mounted glass, regardless of orientation. Thus, the size of the daylight aperture can be reduced, and heat loss correspondingly minimized. Glazing costs can also be substantially reduced.

An ideal skylighting system in the Northeast would maximize collection of daylight in the morning and evening hours, and during overcast winter days. It would also prevent over-heating from too much sun during the late summer and early autumn days. It would minimize heat loss while maximizing visible transmittance. Thus, the system might include the following attributes:

- Have an optimum SFR and skylight unit size that can provide adequate and uniform illumination and provide maximum overall energy saving to the building. SkyCalc is a tool that can help to find this optimum design.
- Use dimming photocontrols to save maximum lighting energy.

  - If using switching controls, provide at least three steps in illumination levels.
- Orient the long dimension of a bubble or pyramid skylight north-south. This provides greater transmittance of low angle sunlight in the morning and evening.
  - Provide a skylight well deep enough to intercept the low angle sun so that it reflects off of the well before entering the space below.
- Maximize daylight transmission and minimize heat loss by using smaller apertures with the highest transmission glazing available.
  - Consider the use of adjustable louvers or movable insulation to vary the heat loss and heat gain properties of the skylight by season, and/or time of day.
  - Align any louvers or diffusing elements in the well along the east-west axis of the skylight well, thus the louvers would be tilting north-south and intercepting high solar angles in the summer and fall mid-day.
  - Make sure that all light transmitted through the skylight can be uniformly diffused throughout the space.
  - For glass skylights, consider the use of high performance glazing that maximizes transmittance and minimizes solar heat gain.
- Use double-glazed skylights with an insulated skylight well and curb, to reduce heat loss and condensation build-up.
  - Specify a condensation gutter capable of collecting and eliminating the volume of condensation generated by a worst case condition.
- Carefully consider requirements for weather protection, snow and ice conditions, maintenance and safety.
  - Raise skylight curb a minimum of 12” above expected ponding levels of a flat roof.
  - Consider the use of skylight shapes that will best shed snow and encourage early melting.
  - Provide positive falling protection, even if skylight is obscured under snow cover.
- Check with local codes on structural, fire safety and energy requirements for skylight performance requirements.