Introduction 1.

The use of skylights has grown in recent years, both because they enliven building interiors and because they can save energy dollars through daylighting. Skylighting can be a solid asset for buildings, and satisfying for building designers, occupants, and owners. Skylights can make a number of major contributions to the built environment since they:

- Provide excellent lighting conditions to the interior of buildings
- Reduce the use of electric lighting, to save energy and reduce peak electric loads when combined with photocontrols
- Satisfy human needs for contact with the outdoors
- Increase safety and security with highly reliable daytime lighting
- Provide emergency smoke vents

We have prepared these *Guidelines* to help you use skylights to maximum advantage in commercial and industrial buildings. They describe opportunities for energy savings and good lighting design offered by skylights. They explain how to integrate skylights with the other building elements. They show how to estimate the possible energy and dollar savings. Finally, they help you avoid mistakes that could reduce the value of your skylight design.

These *Guidelines* apply primarily to skylight applications designed to provide uniform lighting for commercial or industrial buildings. They refer to manufactured, off-the-shelf skylight components used in commercial applications, commonly referred to as "unit skylights." These are typically simple, rectangular, or linear skylights, although with creativity they can be applied to nearly any design situation. Many of the lighting principles covered here are also applicable to residential buildings, although the energy impacts are entirely different in homes and should not be extrapolated from the information in this handbook. Similarly, atrium skylights and other large, custom-designed skylights involve many other issues that are not addressed in this publication. The reader is referred to more specialized texts and tools for the analysis of custom applications.

1.1. How Skylights Improve Buildings

Skylights use the most ancient and universal light sources, the sun and the sky, to bring natural light into buildings. This daylight can do many useful things for the building and its occupants.

At the most basic level, daylight can illuminate the people and activities that occupy the building. Depending on the design of the skylight system, the daylight can be uniformly spread over a wide area, or it can be localized for particular tasks. For many types of buildings, skylighting is a very practical complement to electric lighting.

Beyond basic illumination, however, daylight helps buildings to be more attractive for human occupation. It brings some of the lively qualities of the outdoor environment indoors. The movement of sun and clouds across the sky produces a more interesting environment than does constant interior lighting. The differences in brightness and changes in lighting color evoke a pleasant response in people. Skylights also can improve the appearance of architectural spaces and detailing. A dramatic, ever-changing light source models form and helps people to perceive and enjoy shape, color, and texture. Daylight also helps plants to grow, which further enlivens the interior of a building.

Figure 1-1: Skylights Improve Buildings

For these reasons and more, skylights are a desirable amenity that makes people feel good about their environment and improves morale. As an additional benefit, the amenities of skylights can raise the value of real estate through higher rents and resale prices.

When asked what the greatest advantages of skylights were, a random survey of building professionals overwhelming responded "natural light" as the most important quality. This was augmented by those who believed that skylights provided "better light," "better working conditions," "better color," or "better aesthetics." Altogether, the people who named improvements to the lighting quality of the building as the most important characteristic of skylights represented 82 percent of the sample[1].

All of these advantages and benefits of skylights have their exceptions, of course, but with good design you can avoid problems. Considerations for the designer to take into account when designing skylight systems for daylighting include:

- Visual and thermal comfort
- Seasonal and daily shifts in daylight availability
- Heat loss and heat gain
- Integration with the electric lighting system
- Choice of daylighting control strategy
- Integration with the roofing system
- Integration with the HVAC design
- Utility costs and peak electric demand
- Structural and safety concerns

The following chapters will give you the information and tools you need to design good and valuable skylighting systems, and will help you avoid problems. With effective design, everybody will be a winner: your building, its occupants, and you too.

Clearly the primary role of skylights is to provide the best possible lighting conditions in the buildings they serve, and to enhance the visual environment so that the occupants of the building can be as productive and comfortable as possible. It is in this spirit that this *Skylighting Guidelines* book is written, to help the designer and building owner understand how to apply skylights to their buildings for maximum effect.

How Skylights Save Energy 1.2.

Skylights save energy by providing adequate daylight illumination in buildings so that electric lights can be turned off when they are not needed. Daylight costs nothing, and adds considerably less heat to a space than the equivalent amount of illumination from electric lights. By reducing the amount of heat contributed to a building by electric lighting, skylights can also significantly reduce the need for cooling.

Skylights can potentially also increase heating loads by allowing more heat to escape through the roof and increase cooling loads by letting more of the sun's heat enter a building. The optimum balance of lighting and cooling savings versus increased needs for heating or cooling is a function of the building design, the building operation, and the local climatic conditions.

However, the potential energy savings are substantial. To give you a quick sense of the magnitude of these savings, we calculated the potential savings for a few typical buildings in the Los Angeles area, using 1998 energy costs[2], weather conditions from the San Bernardino Valley, and many default assumptions. An average grocery store might save about $16,000 per year in operating costs, or $.32/sf with the use of an appropriately sized skylighting system. A typical elementary school might save about $7,500 per year in operating costs, or $.23/sf. An industrial processing and distribution center might save about $.12/sf. These numbers vary considerably, based on building design, operation, climate location, and energy costs. Given these variables, the value of savings from skylighting might reasonably be expected to vary between a high of about $.75/sf for air-conditioned buildings with intensive lighting use, and a low of $.05/sf for unconditioned buildings with low lighting requirements (for 1998 energy prices).

Skylighting as a lighting strategy is most obviously applicable to single-story buildings which have large open areas. These generally include retail stores and shopping malls, grocery stores, schools, single-story office buildings, manufacturing and agricultural buildings, and warehouses and distribution centers.

The vast majority of commercial and industrial buildings in California are indeed single-story buildings, and most of them are appropriate for skylighting applications. More and more, our new buildings are large single-story buildings with mostly flat roofs. They are often far too wide for windows to contribute much of a daylighting effect. Look out of an airplane sometime, and notice how many large, flat roofs you see as you fly over any part of the state. However, only a small percentage of these buildings have skylights, and an even smaller percentage of those use daylighting controls to save energy from the skylights.

The Commercial Building Energy Consumption Survey (CBECS) for 1993, prepared by the U.S. Energy Information Agency, revealed that about one percent of all commercial building square footage in the United States had any skylights. That number increased to about two percent in the southwestern states, primarily because of more common use of skylights in southern California and Arizona.

A recent analysis of lighting energy use in California showed that the building types mentioned above use a majority of the indoor lighting energy in commercial buildings.[3] The percentage of commercial building lighting energy use in California for these building types is:

Retail Buildings	18.0%
Grocery Stores	8.5%
Schools	8.5%
Small Offices	5.0%
Warehouses	12.0%
Total	52.0%

There are significant statewide energy savings to be achieved by implementing skylighting (skylights plus daylighting controls) in these building types.

1.3. How To Use These *Guidelines*

These *Skylighting Guidelines* focus on the use of skylights to provide uniform illumination in simple commercial and industrial buildings. They do not address residential buildings, or special, custom-designed architectural spaces such as shopping mall arcades or grand hotel lobbies.

We use the term "skylighting" throughout this text to refer to an illumination system that includes skylights, electric lighting controls, and a building designed to optimize the distribution of daylight.

The *Guidelines* start with the basics of skylighting, and become progressively more detailed. We begin with a look at the qualities of daylighting from skylights, and the ways that they

are used in buildings. Next, we discuss a number of important concepts that will allow you to better understand how skylighting works and how to optimize its benefits. These benefits include energy savings by using daylighting controls to reduce electric lighting. The choice of the lighting control system has as much impact on energy savings as the choice of the skylights themselves.

This picture of energy savings is then expanded to include the effects of skylighting on heating and cooling loads in buildings, on peak electric demand, and on other factors affecting skylight economics. A simplified analysis method called *SkyCalc* will help you to quantify savings and other skylighting parameters. All of this will get you on the right track when designing with skylights.

If you are new to skylight design, plan to spend enough time to cover the basics before you use the more advanced material. If you already know about skylight design, skim the earlier sections and concepts, and proceed to the technical materials and the *SkyCalc* User's Guide (Chapter 6). If you want specific answers on a particular topic, refer to the Table of Contents to find the appropriate section.

The *SkyCalc* Spreadsheet Tool 1.4.

Correctly sized and with appropriate lighting controls, skylights can be a tremendous energy saver. An undersized skylighting system does not justify the cost of the electric lighting controls and never attains the pleasing effect of a well daylit space. An oversized skylighting system will over-light the space, admitting too much solar heat during the day and losing too much heat on cold winter nights.

SkyCalc, included on the CD-ROM in this package, is a simple computer tool designed to help the building designer quickly determine the skylight strategy which will optimize lighting and HVAC energy savings. It is a spreadsheet application for Microsoft Excel®, and can be run by anyone with Excel installed on their computer. The spreadsheet uses simple inputs to describe the building and the skylighting strategy to calculate the lighting and energy impacts of the design. It produces informative graphs and charts which describe the yearly energy use patterns.

The program can be run at three levels of detail. The first level requires little information from the user and uses extensive defaults based on the initial selections to describe the skylighting system and the building operation. A second level allows the user to selectively change these defaults to more precisely describe their building. The third level of analysis allows the advanced user to create custom-defined products, building types, and schedules. At this level, you can enter performance data from specific products or detailed information about the actual operation of your building.

The program allows you to run this analysis for a variety of typical climate conditions in California. Based on the climate zone selected, *SkyCalc* calculates the level of illumination obtained from the skylights on an hourly basis throughout the year. The chart in Figure 1-2: *SkyCalc* Daylight Illumination Chart illustrates the average hourly daylight illumination which would result from a given skylighting design for a particular climate. It is shaded to show which hours fall below the target setpoint of 50 footcandles.

Figure 1-2: *SkyCalc* Daylight Illumination Chart

Effective Aperture = 2.50%, Skylight to Floor Ratio (SFR) = 5.00%

Average daylight foot-candles

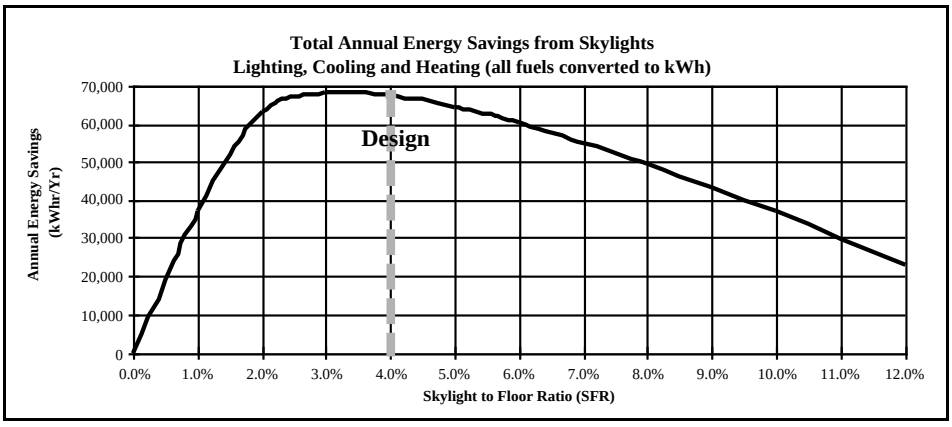
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	2	8	19	32	42	45	39	27	14	5	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	3	14	29	47	55	57	55	45	27	11	3	0	0	0	0	0	0
Mar	0	0	0	0	0	0	2	9	25	42	57	66	70	67	59	41	20	6	0	0	0	0	0	0
Apr	0	0	0	0	0	1	6	20	45	65	79	88	90	84	70	55	29	11	3	0	0	0	0	0
May	0	0	0	0	0	3	12	33	56	75	89	98	99	93	85	63	39	17	5	0	0	0	0	0
Jun	0	0	0	0	0	4	14	32	55	75	93	103	107	102	89	71	46	22	8	0	0	0	0	0
Jul	0	0	0	0	0	3	11	31	57	81	98	110	113	108	95	75	50	23	9	1	0	0	0	0
Aug	0	0	0	0	0	1	8	22	46	68	90	101	105	101	85	64	39	16	5	0	0	0	0	0
Sep	0	0	0	0	0	0	4	17	41	64	84	93	96	88	72	50	23	8	1	0	0	0	0	0
Oct	0	0	0	0	0	0	2	10	29	46	64	69	71	63	47	26	10	2	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	5	15	29	42	48	48	42	26	12	4	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	2	8	18	29	40	39	33	22	11	3	0	0	0	0	0	0	0

Design Illuminance = 50 fc

< 5 fc; < 25 fc; < 50 fc; > 50 fc;

An optimization feature helps the designer to assess the energy performance of the skylights and lighting controls over a wide range of potential skylight areas and to identify where the current design lies. The graph below shows an optimization curve for a grocery store in Bakersfield with single-glazed, white acrylic skylights and dimming controls. The designer has selected skylights with an area equal to four percent of the gross roof area of the building. It is apparent from this graph that this design will save a significant amount of energy, and that it is close to the optimum area for skylights in terms of overall building energy use. A similar graph also calculates energy savings in terms of dollars saved.

Figure 1-3: *SkyCalc* Optimization Graph



Reports in *SkyCalc* are easily printed, just as from any other Excel file, and adjustments can be made to the basic spreadsheet by anyone familiar with the program. *SkyCalc* is installed as an Excel template, so that a new copy of the basic file can be saved for different

building projects and/or climate zones. *SkyCalc* can be used in conjunction with these *Guidelines* to make it easier for the designer to select the best skylighting system for a given building.

Footnotes, Chapter 1

[1] Heschong Mahone Group, "Skylighting Baseline Study" for PG&E, October 1998.

[2] Assumed a yearly average of $.09/kWh for electric lights and cooling, and $.45/therm for gas heating.

[3] Heschong Mahone Group, *The Lighting Technology Report, Vol 1, California Baseline,* May 1997. The California Energy Commission, contract 400-95-012.