Daylighting Every Building

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By: Steven E. Ternoey, AIA, IES
Principal, LightForms LLC, Santa Barbara, CA and Technical Director of the Daylighting Collaborative

Harmony Library, Ft. Collins Colorado
The Davis Partnership Architects
Lightforms : Daylighting, Lighting & Energy Consultants

Cool Daylighting ™ The Cornerstone Strategy to Green Buildings

Twenty-five years ago, we called it energy responsiveness. Next, we called it environmental protectionism, followed by environmentally sustainable design, and now, green buildings. The names and solutions have evolved as we better defined our environmental imperative and possible answers to it. The good news is we have concluded our experimentation into many possible solutions and now tend to know which are most appropriate for specific design challenges. The bad news is an environmentally sustainable future for all requires about an 80% reduction in primary energy use and fossil fuel air emissions within the next 40 to 60 years in developed nations. Well, there's just no way to avoid it any longer. Let's roll up our sleeves and get to work!

As individuals, we can make a difference in a hundred different ways. In fact, that has become part of the problem!

Many well-meaning organizations have bombarded us with grand, unprioritized laundry lists of a hundred ways for us to participate in our collective environmental challenge. After all, with a little thought, nearly everything we do can be improved upon. The result: most people are confused. What are the **cornerstone strategies** that produce huge benefits for modest actions? In short, how do we prioritize the laundry list and know where to begin?

The answer to that question will vary for each energy use sector, such as home, work/school/business, transportation, and industrialized processes. There are cornerstone alternative solutions to each of these. Here, we'll focus on typical non-residential buildings that have windows and air-conditioning systems, such as offices, schools, libraries, shops, airports, etc. Specifically, we'll look at the insitu environmental issues of such buildings, leaving for a later discussion the equally important discussion of where these buildings should be placed to lower transportation energy use. These buildings use about 46.5% of all electricity generated, which represents an enormous investment in money and environmental resources. There is a lone cornerstone strategy that can eliminate one-third to two-thirds of the total lifetime primary energy use and air emissions in new buildings of this type. That same cornerstone strategy can also eliminate one-quarter to half of primary energy use and air emissions in existing buildings when retrofitted properly. Moreover, these savings can be obtained with no to minimal first cost increases compared to standard new and renovation construction practices, while increasing building user satisfaction.

The name of that strategy is **cool daylighting ™**; a cornerstone strategy the Daylighting Collaborative proposes be used on every windowed building with air-conditioning that is occupied during daytime hours.

Cool daylighting is a relatively new concept, so we'll use much of this article to define it and demonstrate the benefits it provides. First, we'll start with some basic definitions, followed by examples of how cool daylighting influences environmental, social and economic performance in the built environment. Then, we'll list the cool daylighting goals that we propose be used for **all** windowed commercial buildings with air-conditioning. Finally, we'll overview the many ways the Daylighting Collaborative can assist you to use cool daylighting on every building.

Common Terms and Definitions:

As a noun, **Daylight,** or **Natural Light**, describes all direct, diffuse and reflected light from the sun in the daytime. As a verb, **Daylight** or **Daylighting** is the choice, act, art, science or practice of using daylight as the primary daytime illuminant in a room or building. From the environmental perspective, the definition of daylighting also includes the inherent ability to turnoff electric lighting when not needed in the daytime. Except for the last 50 years, the art and practice of daylighting was common to building design throughout recorded history. In the 1950's, the confluence of reliable fluorescent lighting, air-conditioning and inexpensive electricity combined to make a new commercial building paradigm. Today, the sealed air-conditioned box with electric lights is the norm, while daylighting practices have become faded memories. However, daylighting is experiencing a renaissance since aspects of this approach have been shown to significantly increase human, environmental and economic performance compared to standard construction with electric lighting.

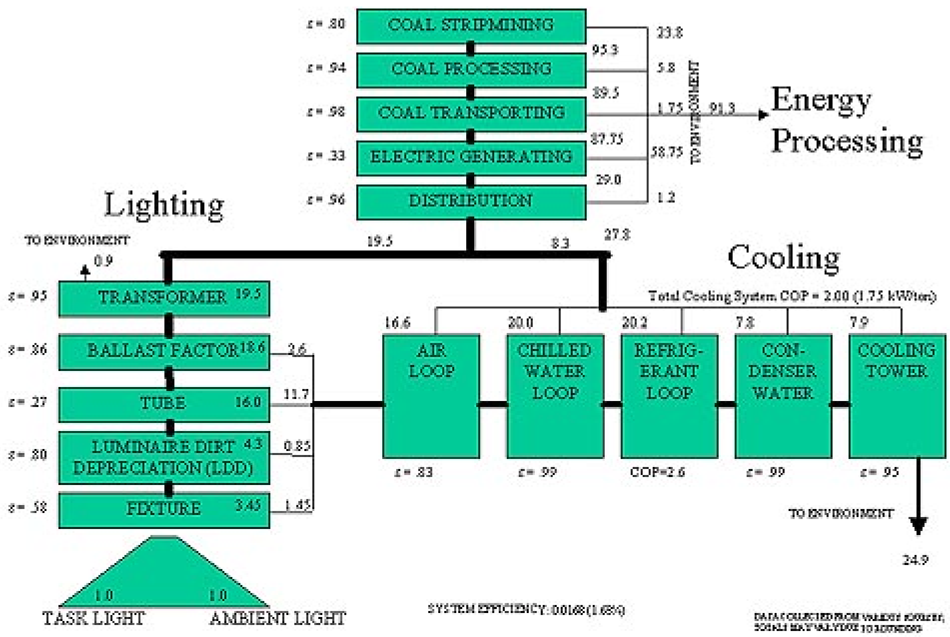
Buildings are generally classified into two different categories according to how they use energy. **Envelope (Externally) Load Dominated Buildings**, like your house, use the majority of their utility bill to stay comfortable. Over a year's time, the largest use of energy is for climate related loads exchanged through the building envelope, with the energy needs for all other uses, such as lights, appliances, hot water, etc., being less. Location does alter energy use patterns in such buildings, with Houston homes using more energy for summertime space cooling, and Green Bay homes using the most for winter heating. Yet, both homes can be called Envelope Load Dominated Buildings, since their energy use patterns tend to mirror climatic imposed loads. To significantly lower energy use in these types of buildings, one typically improves the building envelope by adding insulation, or weather-strip windows, etc.

The second building energy use category is **Internally Load Dominated Buildings**. These buildings, which are offices, schools, libraries, airports, stores, etc., use the majority of energy for internal needs such as lights, computers, photocopy machines, ventilation air, etc. Building envelope loads have much less to do with the energy use in such buildings, and a library in Houston can have very similar energy use patterns to one in Green Bay. Why? Sealed commercial buildings trap the heat of lights, equipment and people inside requiring the use of space cooling most of the year. These internal loads act like small furnaces scattered about the building, and are on during all occupied hours, summer and winter. The result is a very large energy need for lights, equipment and the cooling/fan systems that extract the internally released heat. Typically, it must be freezing or below outside before an Internally Load Dominated Building requires heating in perimeter zones. Additionally, interior or core zones, which are usually 40 to 60% of the area of such buildings, very seldom, if ever, require heating. Energy-related solutions for internally load dominated buildings are very different than for envelope load dominated buildings. For instance, more insulation on a internally load dominated building might actually increase energy use since the internal heat gains are further trap inside, requiring extra energy for fans and cooling to remove it. The lone envelope related energy strategy that can make a difference is the shading of unwanted solar heat gains in the summer.

Cool Daylighting, a term coined by the author in 1995, is the successful application of daylighting to the contemporary challenge of internally load dominated buildings. The goal is to use daylighting to reduce the need for electric lighting while simultaneously reducing the need for space cooling. The term was devised to help identify and prevent common mistakes made by people new to daylighting, and to frame and define successful contemporary daylighting solutions. For example, many first-time daylighters, in their over-exuberance, tend to dump so many footcandles into a room that glare renders the space less useful to people while excess solar heat gains (which are space cooling loads) negate all electric lighting energy savings. Cool Daylighting techniques and strategies carefully bridge the simultaneous need for natural light without the admittance of unnecessary solar heat gains and glare in contemporary buildings.

Figure 1: Energy Flow Diagram: Electric Lighting in an Air-conditioned Office Building

Source: Per John Helverson 1978, with updated transfer coefficients by Jason Bittner, Energy Center Wisconsin 1999



In the next section, the human, environmental and economic advantages of cool daylighting will be overviewed. But first, let's use Figure 1 as a summary. While Figure 1 depicts an office building, the numbers are almost identical for any windowed non-residential building with air-conditioning. To get two units of light energy (1 for task lights, and 1 for ambient light) in an internally load dominated office building requires about 119 units of primary energy from the ground; a process less than 2% efficient. This fact brings up two points for discussion. First, daylighting is so enormously beneficial because electric lighting is so inherently inefficient. Even if new lamps, ballasts, fixtures and lighting controls are invented that achieve a 100% increase in current lighting system efficiency, the overall process would still be only 3.3% efficient! For a daytime use facility, no lighting system will ever be more efficient than a well designed daylighting system. However, and point two, it must always be remembered that any source of light in the building, natural or electrical, causes the use of energy for space cooling in an internally load dominated building. For a daylighting system to be truly environmentally beneficial and user friendly, great care must be exercised to eliminate all unnecessary solar heat gains and glare. **Cool daylighting** is the use of daylight in a way that simultaneously lowers peak and annual cooling loads and eliminates glare.

Cool Daylighting & Human Health and Performance:

Early contemporary efforts in daylighting design focused on the environmental benefits of reducing the use of electric lighting. Almost as a side issue, human health and performance advantages of contemporary daylit buildings began to surface in the late '70s and early '80s. There were noticeably less disciplinary problems and absenteeism in daylit classrooms. Retail sales increases of 8 to 12% were recorded in daylit areas. Office worker productivity and absenteeism could be measurably impacted for the better. Since the cost of people in buildings is often 75 to 100 times greater than the cost of utility bills (see Figure 2), these health and performance benefits became the major thrust of 1990's daylighting research and experimentation.

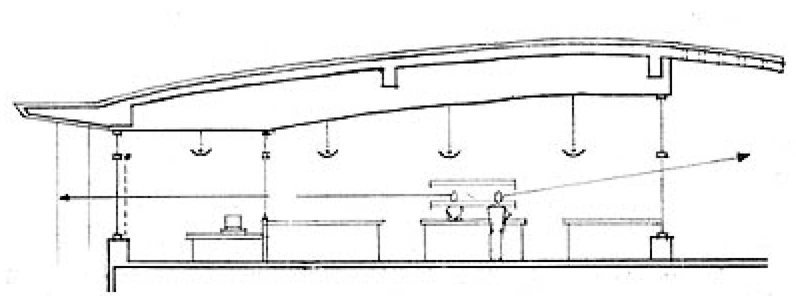
Figure 2: 20-year Cost of Owning and Operating an Office Building
Source : Temoey, S.E. et al, The Design of Energy Responsive Commercial Buildings,John Wiley & sons, 1985

The impact of daylight on people is still an evolving topic. However, **human health** appears to be measurably benefited by relatively small indoor doses of diffuse daylight. The health benefits of natural light/windows in hospital patient recovery rooms have been a given fact for half a century. This research is now expanding into the benefits of daylight in other building types. For instance, existing research indicates people have fewer cavities in Southern states than in Northern states. In all states, higher rates of tooth decay are reported in the winter than in the summer. Recently, this same correlation of daylight to tooth decay was found comparing typical schools to daylit schools in the same locale. Students in the daylit schools had measurably fewer cavities compared to students occupying traditional schools with electric lighting. Further, elementary school children grew on average 2 cm per year taller in the daylit schools. We have not evolved to become indoor animals. As societal patterns increasingly move us indoors during daytime hours, new ways to provide healthy built environments must be found. Contemporary daylighting appears to be a fundamental element in this transition.

Human performance also can be influenced by daylighting strategies. Recently, higher standard test scores have been documented in daylit schools. The book collections in daylit libraries are used up to 50% more than in traditional library designs. A growing number of references suggest a strong correlation between daylighting, increased office productivity, and reduced absenteeism. Consistently, a view out is of the highest ranking in building user satisfaction surveys. Nearly everyone prefers a windowed office or classroom to a windowless room. These intuitive desires have been often denied in the era of sealed-box architecture for "economic, energetic or human performance reasons." Ironically, environmental, economic and human performance reasons are finally now re-justifying these very same amenities.

Figure 3: Combing High Transparency and Solar Shading

Source : Electronics and Telecommunications Research institute of Korea



Daylit buildings can increase human performance because people enjoy such spaces and will stay a little longer and/or return more frequently to work, study, or shop. Daylight itself does not increase human performance per se. Rather, it is the sense of **transparency** to the outdoors that people enjoy (See Figure 3 for an example). Physically and psychologically, people desire to be connected to the rhythms and changes of the outdoor world, within the limits of visual and thermal comfort, and not to the point of distraction. Cool daylighting practices must be used to insure glare control and the highest possible lighting quality. In such buildings, people can have a relationship to the sun, the sky, changing weather patterns and seasonal conditions while still fulfilling their indoor responsibilities. A sense of time is imparted since morning, noon, afternoon and evening become different and unique experiences. Building transparency allows people to be inside while still feeling connected to their environment. After 50 years of the sealed architectural box, people find transparent buildings very beautiful and enjoyable. Transparency gives them one less reason to want to leave.

Lastly, human issues are critical to successful daylighting design because, done improperly, daylighting can go the other way and significantly reduce human comfort, health and performance. The enormous environmental and economic cost of labor, plus the increasing dominance of computers in offices, schools, libraries, etc., demands precision and control of daylight to provide the highest quality, glare-free luminous environments. The perceived interior brightness of exterior light sources, such as the sun, sky, clouds, etc. must be carefully controlled within prescribed limits. Shading, glass, window treatments, and all resulting surface brightness must be designed together for maximum lighting quality. No potential environmental benefit of daylighting would ever negate the need for the highest quality, user friendly lighting solutions. Regretfully, not all daylighting examples have followed these simple cool daylighting fundamentals.

Cool Daylighting & Environmental Performance: A Simple Example

Professionally designed non-residential buildings last about 75 years in the United States. How much environmental resources do we invest in a building over this period? In addition, how are these resource used, and what percent of that need can be eliminated by cool daylighting strategies? While the answers to these questions will change somewhat by building type, location, internal loads, construction budgets, etc., one very representational 60,000 ft^2 office building example is summarized in Figure 4. If one tracks lifetime primary energy use for building construction & finance, maintenance & repair, and gas & electric utilities, 1,095,698,000,000 BTUs are required to subsidize the 75-year existence of the facility (the equivalent of about 132 gallons/S.F. of imported crude oil). A full 70% of this need is the direct and indirect use of primary energy to provide electricity to the building. Also, since the source of air emissions generally follows the combustion of fossil fuels, electrical energy is responsible for the large majority of air emissions associated with this facilitiy onsite needs. Certainly, if a substantial reduction in energy use and air emissions is expected for the project, major electrical energy reductions must be found.

What is the electrical energy used for in the building? As demonstrated in Figure 5, lights, cooling and fans (81% of total gas & electricity use; 86% of total electrical use) dominate the annual energy cost of an office building. The far right bar graph is an energy simulation for the same building, except electric lights (0 w/S.F.) and solar heat gains through glass (0 glass shading coefficient) are eliminated. Note that annual energy cost decline by about 69%. Also note that key building peak capacities, such as building peak kW, fan CFM & horsepower, and air-conditioning chiller tonnage, fall by about 75% when electric lights and solar heat gains through glass are eliminated. In short, over two-thirds of the annual energy bill and about three-quarters of key peak building systems capacities are caused by the use of electric lights and the admittance of unwanted solar heat gains.

Quite simply, daylighting and eliminating unwanted solar heat gains through glass will substantially reduce the environmental impacts of typical air-conditioned buildings with windows. Since the careful control of daylight source brightness through windows was already identified as a daylighting necessity for human performance reasons, these two design responses actually work very well together. Again, we call the result **cool daylighting**. Cool daylighting can readily reduce lifetime utility cost and peak building capacities by 50% or more in new buildings. Reallocating construction funds from downsized electrical and HVAC components often pay for most, if not all, of the cool daylighting strategies. Since cool daylighting offers huge energy reductions without significantly increasing the overall first cost of new construction, it is often called the cornerstone to sustainable/green building design.

Figure 4 : Total Lifetime (75-year) Primary Energy Use of a 60,000 sq. ft. Office building.

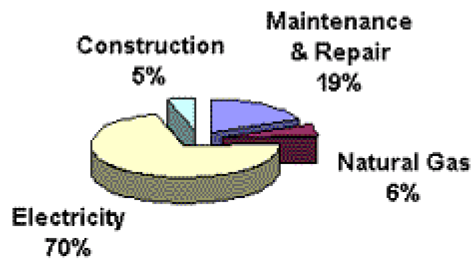
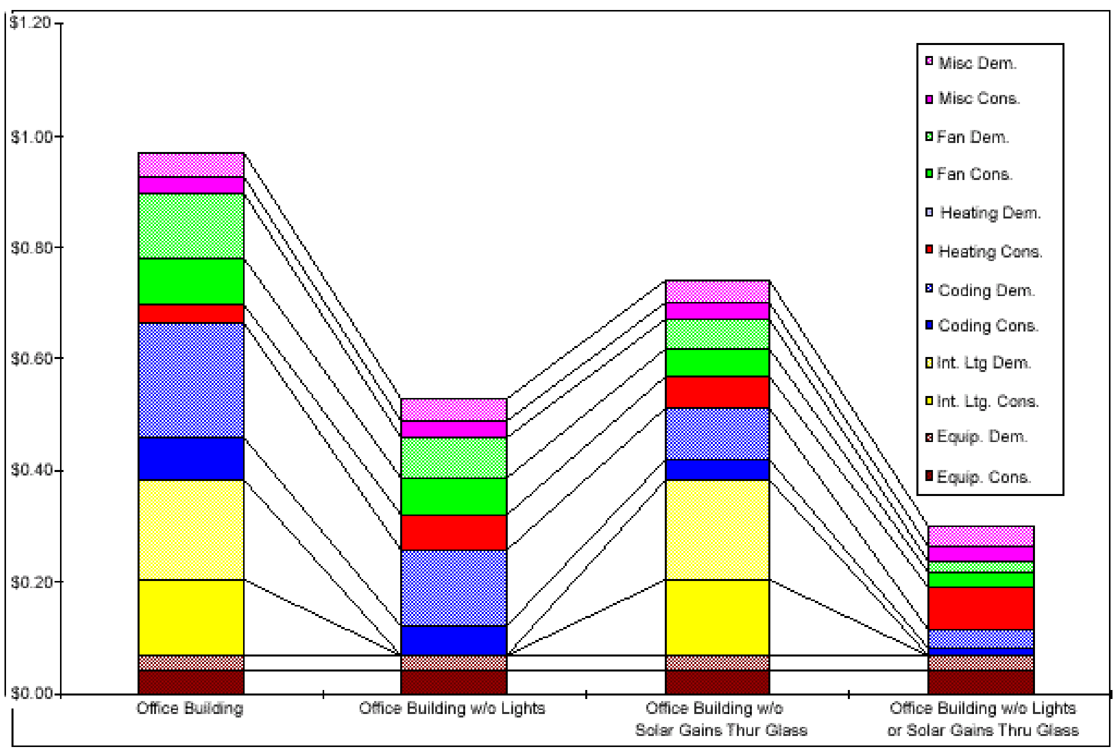


Figure 5: OFFICE BUILDING ANNUAL ENERGY USE
and
SELECT ELIMINATION PARAMENTRICS

Source: LightFormsExhibit, Copyright 1995 LightForms LLC, Boulder, CO, All Rights Reserved



Building kW	364.5		204.2		256.5		95.7
Mo/Day/Time	SEP/6/17		SEP/6/17		JUL/26/18		SEP/6/17
Supply Fan CFM	60,117		47,261		29,731		16,311
Supply Fan HP	91.4		71.9		45.2		24.2
Pump HP	4.8		4.3		4.2		3

Cool Daylighting & Economic Performance: A Simple Example Continued

Over the life of a professionally designed non-residential building, how much money is spent, for what, and how much of that total can be saved with cool daylighting techniques? Again, the answers to these questions will vary somewhat by building type, location, budget, etc. Figure 6 represents typical answers for the same building used in the above example.

As shown on the left side of Figure 3, a standard 60,000 ft^2 office building could cost about $4.7 million ($78.84/ ft2) to design and construct (all $ values in this example are constant 1995 dollars). Over the expected life of the building, another $19,118,300 will be spent to maintain, repair and provide preventative maintenance for the building, and about $4,365,000 will be invested in gas and electric bills (The design is ASHRAE 90.1 energy code compliant). In total, $28,214,000 ($470/ ft^2) will be paid to design, build, maintain and power/heat/cool a "standard" office building.

The information on the right side of Figure 6 summarizes the same economic factors for a cool daylighting solution. An elongated architectural form allows access to light and views for all occupants (factors that can increase user satisfaction, performance, and energy efficiency). Cool daylighting strategies and components, such as fixed exterior shading devices, high performance glazing, the elongated architectural form, and improved window treatments, add about 10% to the cost of the building. However, the design lowers air-conditioning tonnage by 61%, installed fan horsepower by 56% and the initial mechanical budget by 52% compared to the Standard Building. These cost savings approximately equal the added architectural expenses, resulting in no net change to the overall construction budget. The HVAC downsizing also reduces duct sizes significantly, allowing a floor-to-ceiling increase of 1’-0", while raising the floor-to-floor distance by only 6" (higher ceilings allow a deeper penetration of high quality daylight).

First cost is about the same for the two possible solutions. However, by reducing the need for daytime electric lighting, and by lowering peak and annual solar cooling loads, the Daylit Building reduces lifetime utility cost by $2,475,000 (57%) compared to the Standard Building. Lifetime maintenance cost drop significantly, the net result of increased cost items (such as increased glass cleaning and breakage) and a variety of lowered cost items (downsized HVAC replacement in year 25, etc.). In total, the Daylit Building reduces lifetime cost to $22,615,000 ($376.92/ft2). Compared to the Standard Building, total 75 year cost are reduced by $5,599,000 ($93.31/ft2), a value greater than the original construction cost for the building.

Commercial construction in the US is first cost dominated. Construction innovations that improve the final product without increasing cost tend to be absorbed readily into standard construction practices. Cool daylighting techniques can achieve this level of performance and industry absorption if done properly. Literally, unnecessary waste inherent in current design practice is typically sufficient, if corrected, to make cool daylighting a no- to low-cost change in most windowed commercial buildings with air-conditioning.

In conclusion, cool daylighting can be a superior investment for building owners. Lowering maintenance and operating expenses without significantly increasing first cost increases the value of the project, improves the owner's monthly cash flow, and can reduce the owner's equity participation required for financing. At this point, there are no significant economic barriers to the utilization of cool daylighting techniques in contemporary windowed commercial buildings. This fact applies to all building owner types: developers, owner occupied, institutions, etc. Great economic rewards await all that seek a gentler way to live upon the earth.

Daylight Every Building: Cool Daylighting Project Goals

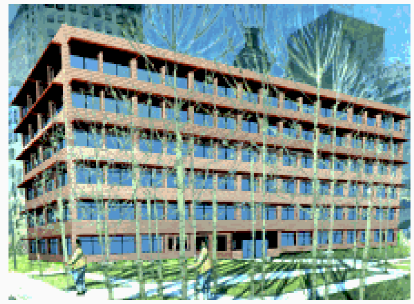
Cool Daylighting, the simple use of daylight while providing superior cooling load and glare avoidance, is the cornerstone strategy for Green Commercial Buildings. Typically, buildings which utilize cool daylighting strategies seek to achieve the following four goals compared to standard construction: 1) Increase human health, satisfaction and performance, 2) Significantly reduce non-renewable energy use and environmental pollution, 3) Substantially decrease lifetime building operating and maintenance costs, and 4) Cost no more to construct. In short, cool daylighting is a socially and environmentally responsible approach to construction that offers superior economic benefits to the building owner. These goals are achievable and recommended for all windowed buildings (offices, schools, libraries, factories, airports, stores, etc.) with air-conditioning. Additional cool daylighting goals and design criteria for specific building types can be found in the training and web site materials dedicated to those topics.

Fig. 6: A Simple Comparative Example

Source: LightForms Exhibit, Copyright © 1995 LightForms LLC

Capacities

Standard		Daylit
365	Peak kW	153
115	AC Tons	45
91	Fan H.P.	40
	Lights W/sf	
1.50	day	0.41
1.50	night	0.67



Standard Building

ASHRAE 90.1 Energy Code Compliant

- 100'x100' footprint
- 12.5' floor to floor ht.
- 50% access to views
- 6 stories

Daylit Building

Exceeds ASHRAE 90.1 Energy Code

- 50'x200' footprint
- 13' floor to floor ht.
- 100% access to views
- 6 stories

Construction Costs

Standard Building		Daylit Building
$86,036	Foundations	$94,947
$28,078	Substructure	$28,078
$779,386	Superstructure	$795,382
$422,251	Exterior Closure	$904,232
$32,318	Roofing	$34,033
$748,986	Interior Construction	$556,875
$190,818	Conveying	$190,818
$850,111	Mechanical	$410,673
$332,281	Electrical	$313,666
$86,529	Site Work	$86,529
$284,543	Design Fees	$314,543
$355,679	Contractor Markup	$341,523
$533,519	Contingencies	$512,285
$0	Utility Rebates	$0
$4,730,535	**TOTAL**	**$4,583,582**

Lifetime Maintenance Costs (75 Years)

Standard Building		Daylit Building
$2,784,959	Exterior Closure	$4,164,604
$357,359	Roofing	$357,359
$9,917,471	Interior Construction	$7,351,420
$582,000	Conveying	$582,000
$4,055,634	Mechanical	$2,683,472
$1,339,122	Electrical	$879,935
$81,760	Site Work	$81,760
$19,118,305	**TOTAL**	**$16,100,549**

Lifetime Utility Costs (75 Years)

Standard Building		Daylit Building
$4,365,000	Electricity and Gas	**$1,890,000**
$28,213,840	**75 YEAR TOTAL (in 1995 dollars)**	**$22,615,166**

The Daylighting Collaborative: Your Cool Daylighting How-To Resource

Now that we have identified the key cornerstone environmental strategy for non-residential buildings, how do you apply it to real buildings? The **Daylighting Collaborative** intends to be your Cool Daylighting How-to Guide and Resource Center.

The mission of the Daylighting Collaborative is to accelerate the acceptance and inclusion of cool daylighting strategies into all new and retrofit construction projects with significant daytime lighting loads. Formed through the request of the Wisconsin Public Service Commission and initially funded by Wisconsin Utilities, the program is administered through the Energy Center of Wisconsin. The program is a true collaborative effort that solicits and invites the participation of many additional partners such as foundations, environmental non-profits, governmental agencies, manufacturers and numerous professional societies. Simple "repeatable models of success" will be offered to building owners, users and designers for inclusion/adaptation into their mainstream building projects. Through education, training, demonstrations, market research and some limited design assistance, the program will promote no- to low-cost cool daylighting technologies that increase human, environmental and economic performance in buildings.

Frequently Asked Questions about Cool Daylighting

Q. **How can daylight be admitted to a building while solar heat gains are not?**

A. As Dr. Donald Aitken often states, "Only 1 or 2 percent of exterior daylight is required to light a building." Particularly on the bright, clear sky, hot summer afternoons when building peak kW and AC tons capacities are set, only a tiny fraction of outdoor light is required indoors. In fact, on the very day we would like daylighting to work the best is the same day daylight is most readily available! Most windowed buildings let in far more light from the outside than required with little concern for light quality or cooling load avoidance. All that is required is to thoughtfully use daylight while avoiding excess heat gains during the hotter months of the year. For instance, sunlight is typically avoided, while soft diffuse skylight and ground reflected light is welcomed. Vertical glass/clerestories tends to work better than horizontal glass (skylights), since they admit indirect daylight while avoiding direct sunlight from the high summer sun. Vertical glass also tends to admit more light in the winter, when it is physiologically and psychologically desired (SAD) and the heat easily removed by introducing cool outside air. Western exposures/glass should be avoided, or carefully shaded from the hot late afternoon sun in the summertime. While cool daylighting strategies apply to air-conditioned buildings, these are the same common sense shading and glare control actions one would take to stay comfortable in non-air-conditioned buildings.

Q. **Why is HVAC downsizing emphasized while equipment efficiency is made a**

secondary concern?

A. Eliminating the unnecessary is far superior to improving its efficiency, and therefore, should be the first concern. For instance, high performance glazing will generally reduce the required size of the HVAC system, lower peak electrical demand, lifetime energy use and maintenance costs for a facility and, through first cost reallocation, be less expensive than that portion of the HVAC system it replaces. Alternately, for example, one could construct an ice storage system to lower peak electrical demand. Not only does the ice system increase first cost, but it will increase lifetime maintenance as well. Also, it will need to be bought two or three more times and replaced since the system's useful life is less than the useful life of the building. Whether it is dimming ballasts, complicated control systems, or movable louver shading systems, beware of any component that increases net first cost without lasting the life of the building. For any component that does not last the life of the building, the first priority is to downsize, eliminate or simplify it. Smaller equipment cost less initially, cost less each time it is replaced, and invariably uses less resources and energy to operate and maintain. Then, and only then, might systems and components that increase cost and complexity, in the name of energy efficiency, be useful.

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DAYLIGHTING collaborative
Daylighting Collaborative
Energy Center of Wisconsin
595 Science Drive
Madison, WI 53711
Phone: (608) 238-4601
Fax: (608) 238-8733
Email: daylighting@ecw.org
Abby Vogen, Program Director