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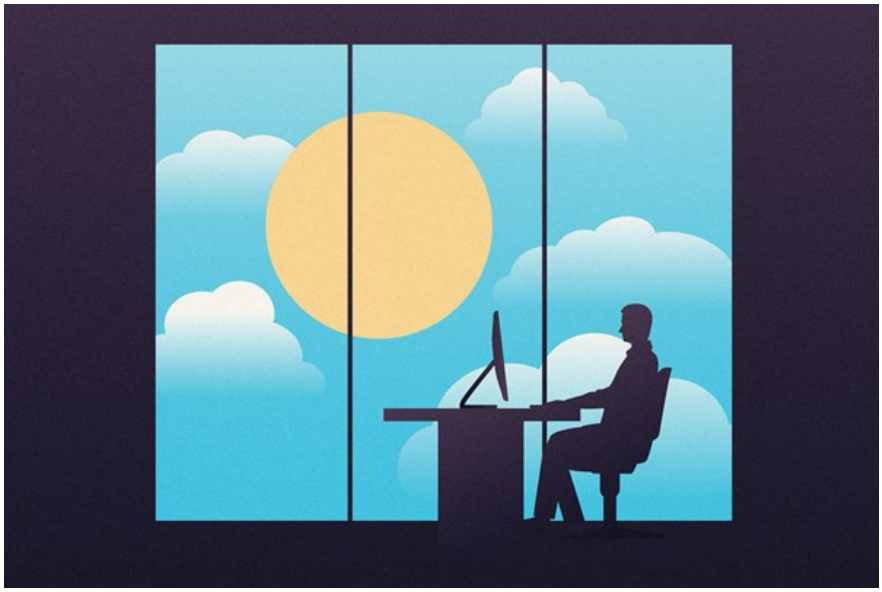
Technology

The Benefits of Natural Light

Research supports daylighting's positive effect on building performance and human health.

By Kevin Van Den Wymelenberg



Credit: Tang Yau Hoong

In 1862, Henry David Thoreau wrote, "In Wildness is the preservation of the world." If he were to see our modern cities, our buildings, and what remains of the wild, perhaps his reaction would be similar to what David Orr, the Paul Sears distinguished professor of environmental studies and politics at Oberlin College, noted in his book *Design on the Edge: The Making of a High-Performance Building* (The MIT Press, 2006): "Modern designers filled the world with buildings and developments divorced from their context, existing as if in some alien realm disconnected from ecology?…?and place." In cities today, daylight might be the last trace of Thoreau's idea—and might be, in fact, the preservation of wildness.

In the practice of architecture, daylighting refers to the use of natural light, be it brilliant sunlight or muted overcast light, to support the visual demands of building occupants. In "Daylight Dialect," which I wrote for Architectural Lighting in March 2008, I noted that daylighting purists argue that for a space to be considered daylit, it must use natural light as the primary source of daytime illumination, create a visually and thermally comfortable place connected to outdoor phenomena, and persistently maximize electric lighting energy savings while minimizing peak energy demand. The rest of us, however, might consider a space daylit if it simply has a window with a view.

Daylighting, Efficiency, and Productivity

Daylighting has been touted for its many aesthetic and health benefits by designers and researchers alike. Scientists at the Lighting Research Center (LRC), in Troy, N.Y., for example, have reported that daylit environments increase occupant productivity and comfort, and provide the mental and visual stimulation necessary to regulate human circadian rhythms.

Utilizing natural light can lead to substantial energy savings. Electric lighting in buildings consumes more than 15 percent of all electricity generated in the United States, according to the U.S. Department of Energy and the U.S. Energy Information Administration. Spaces outfitted with daylight-sensing controls can reduce the energy used for electric lighting by 20 percent to 60 percent, according to the studies "Photoelectric Control: The Effectiveness of Techniques to Reduce Switching Frequency" (2001) and "Summertime Performance of an Automated Lighting and Blinds Control System" (2002), both of which are published in the journal *Lighting Research & Technology*; and "The New York Times Headquarters Daylighting Mockup: Monitored Performance of the Daylighting Control System" (2006), which was published in the journal *Energy and Buildings*.

Independent field studies published in the past two decades have also shown a range of results, from outperforming predicted savings by 56 percent to experiencing an uptick in energy usage due to increased voltage of some dimming ballasts or lights left powered on after hours even though they were daylight controlled to an off setting. Given these findings, as well as the known thermal interdependencies associated with daylight glazing, a strategy to integrate daylight into a building can reduce or increase its total energy consumption.

"Daylight can also be too much of a good thing," says Joseph Park, national sales manager for the commercial window treatments division at Lutron Electronics, headquartered in Coopersburg, Pa. A building that has aggressive daylighting goals but is poorly operated will likely use more energy and might subject its occupants to excessive glare and thermal stress. On the other hand, Lisa Heschong, managing principal at TRC Companies—which acquired Heschong's namesake California-based consulting firm, Heschong Mahone Group (HMG), in January 2013—says that when she interviews workers in daylit retail, commercial, and education spaces, "they consistently report how they love working there, and hope they never have to transfer elsewhere."

Along with happier workers, substantial financial and human-performance benefits have been associated with increased daylight. In 2003's "The Benefits of Daylight Through Windows," LRC researchers discussed anecdotal evidence that commercial real estate with no windows leases for about 20 percent less—or $2 to $4 per square foot less—than spaces with windows.

The 1999 study "Skylighting and Retail Sales: An Investigation Into the Relationship Between Daylighting and Human Performance" and the 2002 study "Daylighting Impacts on Retail Sales Performance," both by HMG, are arguably two of the most robust investigations into daylight and its effects on retail sales to date. The studies concluded that the presence of skylights was the third-most-important criteria of five observed and statistically significant factors in increasing sales volume; the first and second were hours of operation per week and years since the last retrofit, respectively.

In the 1984 *Science* article "View through a Window may Influence Recovery from Surgery," Roger Ulrich, now a professor of architecture as well as a co-founding director of the Center for Health Systems and Design at Texas A&M University, reported that surgery patients in rooms that had windows facing trees recovered 8.5 percent faster and took fewer analgesics than did those patients whose view was a brick wall. Subsequent research by others has substantiated the results for patients who stayed in general hospital rooms.

In a 1999 study "Daylighting in Schools: An Investigation into the Relationship between Daylighting and Human Performance," commissioned by the Pacific Gas and Electric Company, HMG found a high correlation between schools that reported improvements in student test scores—upwards of 10 percent—and those that reported increased daylight in the classroom. The findings sparked discussion on the influence attributable to daylighting, or the daylighting effect size. HMG attempted to pinpoint the relationship in a look-back paper "Daylighting Impacts on Human Performance in School," published in *Leukos, the Journal of the Illuminating Engineering Society* in 2002. Though HMG and research collaborator RLW Analytics found a statistically significant relationship between lighting conditions and student test scores, they could not definitively explain the effect. Peter Boyce, LRC's head of the human factors program, likewise cautioned against prematurely drawing scientific relationships in his 2005 *Leukos* article, "Reflections on Relationships in Behavioral Lighting Research."

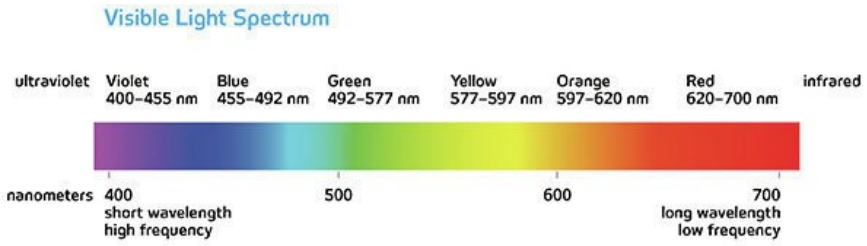
For its part, HMG could not replicate exactly the results of its 1999 study in a 2003 follow-up, but they still found evidence that an "ample and pleasant view out of a window, that includes vegetation or human activity and objects in the far distance, support better outcomes of student learning."

As Lutron's Park notes, poorly daylit and glaring spaces can have detrimental effects. While these decreases in performance have yet to be quantified, I have found in the course of my doctoral research that occupants in environments they describe as having "just uncomfortable" glare rather than the "most preferred" conditions did report a 10 percent decrease in their own perceived productivity.

Despite all the research mentioned, a quantitative relationship between daylighting and human health and productivity remains elusive. "Productivity is incredibly difficult to quantify in terms of time and money," Park says. Yet, it is the factor that decision-makers most often value when choosing whether to include daylight and advanced controls for lighting and blinds. A belief that daylighting is beneficial does exist, but hard evidence is still scarce. This is due, in large part, to the difficulty in conducting research tied to the dynamic nature of daylight, along with the myriad other variables that are difficult to control in the field. Is it the amount of light that matters, or is it the variability, the view, or the connection to nature?

Overall, the available research suggests that a successful daylighting design—one that factors in taming glare and solar heat gain—is likely to improve worker satisfaction, mood, and productivity. "The right balance can be achieved through the use of active daylighting control strategies, [such as] automated shades, as well as passive strategies, [such as] light shelves or louvers," Park says. "The markets for automated shades, light shelves, and dynamic glazing are increasing rapidly within the industry." These technologies mitigate the dynamic movement of direct sunlight while admitting diffuse daylight inside the space.

Recent research has underscored the effect of daylight on human health and biological functions. According to the U.S. Environmental Protection Agency, humans in modern cities spend upwards of 90 percent of their lives indoors. If they are occupying statically, perhaps stagnantly, lit environments, they can become disassociated with the natural outdoor cycles and variation of illuminance levels.



Daylight and the Circadian Cycle

The biological processes that regulate our sleep–wake cycle make up our circadian system. Primarily through the use of the neurohormone melatonin, our circadian system regulates our patterns of alertness and sleepiness. Without exposure to normal 24-hour light–dark cycles, a person's sleep–wake cycle can stray by as much as two hours per day.

The cumulative effect of this can be significant. An imbalanced sleep–wake cycle may produce advanced or delayed sleep-phase disorders and lead to chronic sleep debt. In "The Benefits of Daylight Through Windows" (2003), LRC investigators also noted that "[p]eople with chronic sleep debt feel permanently tired and are unlikely to work effectively." Furthermore, in the 2006 longitudinal study "Light at Night—Cancer Risks of Shift Work," researchers from Thomas Jefferson University (TJU), in Philadelphia, and the Mary Imogene Bassett Hospital, in Cooperstown, N.Y., found an increased rate of breast cancer in night-shift workers that resulted from the suppression of the pineal gland's production of melatonin.

A lack of daylight inside a building doesn't necessarily spell doom for its occupants. Exposure to bright light at the appropriate time of day and for the appropriate duration can alleviate these disorders. Daylight just happens to be one resource that can provide this exposure with the timing and duration that is most beneficial for humans. Darkness at night, not just brightness during the day, is also critical to a healthy sleep–wake cycle.

In order to minimize melatonin suppression, "one should keep exposure to light at night as short as possible, as dim as possible, and as warm or red as possible," says Steven Lockley, an associate professor of medicine in the division of sleep medicine at Harvard Medical School and at Brigham and Women's Hospital in Boston. With this in mind, daylighting design in spaces with sleeping quarters should also consider accommodating nighttime darkness.

The discovery of both a novel retinal photoreceptor in the human eye and the photopigment melanopsin has renewed the attention paid to circadian research and has drawn substantial interest from the lighting community. In the 2001 paper "Action Spectrum for Melatonin Regulation in Humans: Evidence for a Novel Circadian Photoreceptor," TJU researchers found that the circadian system is most sensitive to short-wavelength (bluer) light, ranging from 446 to 477 nanometers (see "Visible Light Spectrum" above). They also found evidence supporting the existence of a photopigment that mediates circadian photoreception, now coined as cirtopic vision. Cirtopic vision complements scotopic vision (which is rod-dominated, dim-light vision, with a peak of 507 nanometers) and photopic vision (which is cone-dominated, bright-light vision, with a peak of 555 nanometers).

Since photopic vision is critical to visual tasks, most electric light sources are designed to support it. However, short-wavelength light of 460 nanometers has been found to increase alertness as compared to longer-wavelength light of 555 nanometers. Furthermore, multiple studies have shown that students who did not receive short-wavelength visible light in the morning had delayed melatonin production and sleep onset in the evening by about 30 minutes.

Integrating Daylight with Design

While daylight is a variable, often unpredictable, light source with a spectrum that depends on solar position and sky conditions, it is also rich in the short-wavelength portion of the visible spectrum found to support both alertness and circadian sleep–wake entrainment. As a result, daylight in buildings may support human health and well-being, particularly for people in northern latitudes who occupy areas near a window or other daylight sources. But regardless of latitude or exposure duration, daylight may support human alertness and productivity. At the same time, it is important to remember that it is the daily—and possibly the seasonal—variation associated with the day–night light and dark cycles that supports human health. Lighting manufacturers, for one, have jumped on the bandwagon and attempted to mimic these cycles through electric light sources and lighting systems.

Designers can glean two points from this trove of research. First, daylit spaces hold the potential to yield substantial benefits, including increased energy savings, increased revenue in retail applications, and improvements to human health and productivity. Second, several important factors ranging from design to installation and operation must be carefully addressed in order to realize these benefits.

Many resources are available to guide decision-making in daylighting design (for a starter list, see "Resources" below), but three tasks that are critical to a successful daylighting installation are: the control of direct sunlight at visual task areas during all occupied hours; the provision of balanced luminance on interior surfaces, particularly between perimeter windows and key vertical surfaces within the interior volume; and the provision of sufficient ambient daylight illumination for visual tasks. Modeling and testing design decisions with the increasing selection of daylighting software tools are also important. Once a design is executed, ensure operational success by educating building occupants and operators on the intent of the daylighting design, how to use lighting controls, and how to access and use shading controls.

It is the "seasonal variability of interior daylight illumination," Heschong says, "along with views to the outdoors that provides important stimulus to the circadian system, [and] along with making any space more pleasurable and interesting for its occupants."

If Thoreau's belief about "Wildness" is true, then we should take the opportunity to introduce the wildness of daylight into our structures. It can be difficult to tame, but its presence in our buildings is important for the preservation of the rhythms of human life, connecting people more closely to place, and revealing local ecology in our built environment.

Resources

Quantifying the effects of daylight is a nascent topic of study but research on daylight and design in general has been growing for decades. Below is an introductory list of educational resources and articles.
(Note: For articles published by government agencies referenced throughout this article, it is best to use Firefox as your web browser to link to the documents.)

Online

Daylighting Pattern Guide, by New Buildings Institute with the University of Idaho and the University of Washington.
Available at *patternguide.advancedbuildings.net*
This free resource features design strategies for common building types.

Daylighting, by the Illuminating Engineering Society, uploaded February 2012.
Available at *youtube.com/user/IES1906*
Five narrated presentations, subtitled Podcast 01 to Podcast 05, cover basic daylighting concepts and design strategies.

eLAD Body of Knowledge, by the U.S. Department of Energy, last modified Aug. 5, 2012.
elad.su-per-b.org
This free resource is intended for users of all experience levels interested in daylighting design.

In Print

Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) , by the Illuminating Engineering Society (IES), 2013.
This document defines recommended daylighting metrics and the associated simulation protocols, and provides design criteria recommendations.

Daylighting Design in the Pacific Northwest , by Christopher Meek and Kevin Van Den Wymelenberg, University of Washington Press, 2012.
This architectural monograph reviews the daylighting consulting work of the Pacific Northwest Daylighting Labs at the University of Idaho and the University of Washington.

"The Benefits of Daylight Through Windows," by Peter Boyce, Claudia Hunter, and Owen Howlett, Lighting Research Center, 2003.
This literature review examines the effects of daylight on human health and worker performance.

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