THE IMPACT OF LIGHTING AND VIEWS ON THE WORKPLACE OF THE FUTURE

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EXECUTIVE SUMMARY

Controllable daylight and electric light, along with the provision of views, can positively influence various psychological and physiological processes to improve occupant well-being, workplace productivity, and job satisfaction. The visual environment often influences the first impression of a space or company and has the potential to aid recruitment and increase property value; both experimental studies and large-scale surveys show that daylight and views are desired by occupants and contribute to employee retention. Furthermore, there can be significant energy benefits associated with daylighting and personal lighting control.

Impacting nearly every facet of our lives, the visual environment directly influences our mood, alertness, and cognitive performance during the day and the quality of our sleep at night. Light regulates the human circadian system which, in turn, governs many aspects of health and physiological activity. Increased exposure to bright light during the day is beneficial, but more research must be done to quantify the impacts of intensity, wavelength and timing. Additionally, while increased daylight exposure can yield significant positive effects, care must be taken to mitigate the potential for glare. Further research is needed to define how specific characteristics of light and views affect human behavior and health, but there is consensus that increased access to light, particularly bright daylight, and views during the day can improve productivity and well-being.

Occupant interactions with light and views significantly influence the experience of the built environment and impact interrelated physiological and psychological responses. Facilitating occupant control of the visual environment and increasing access to daylight and views improves satisfaction, supports social interaction, and has the potential to improve creative problem solving. However, successful lighting implementation is critical and must carefully balance occupant desires for personal control with intelligently designed automatic operation. We must also note that attempts to improve visual comfort could have a negative overall effect if they adversely impact thermal and acoustic comfort.

Personal controls can be considered an integral part of a comprehensive daylighting scheme that also considers building form, aperture size and orientation, interior space layouts, furniture designs, daylight and solar controls, and integrated lighting controls. We recommend a complementary approach, based on such a scheme, using a combination of automated solar and electric lighting control systems along with personal controls with automated system overrides. This approach will help modulate illumination, glare, solar gain, access to view, and circadian stimulus to produce individualized, comfortable, and healthy visual environments. Advances in dynamic facades and shading systems, such as automated and light redirecting blinds, automated shades, electrochromics, thermochromics, and spectrally selective dynamic filters can facilitate this process. Personal workstation-based shading systems also hold promise. These new tools facilitate a layered approach to the provision of daylight and views and will increasingly enable designers aiming to deliver optimal indoor environments.

INTRODUCTION

The provision of controllable daylight and views can provide significant benefits to both employers and employees. Daylit spaces, appropriately designed and controlled, can meet the occupants' visual and thermal needs and reduce energy consumption. Furthermore, daylit spaces have been shown to influence several mechanisms that impact human health and improve overall environmental quality, positively impacting job satisfaction, productivity, employee retention, and recruitment. Office work has largely transitioned from paper tasks on a horizontal work plane to a combination of horizontal and vertical tasks dominated by mobile, self-illuminated screens, requiring increased flexibility and adaptability of the visual environment. Occupants value controllable daylight and views and prioritize them over other amenities. If current trends hold, the demand for daylight, views, and personal controls will only increase, and design solutions that integrate natural elements with intuitive control and automation technology will be highly favored.

This paper reviews the published literature that supports these assertions, including peer-reviewed journal articles, public and industry funded research, and large surveys of employees. Recent findings regarding the influence of daylight and views on health, well-being, and cognitive performance are discussed along with the associated organizational impacts. A companion paper, *Lighting in the Circadian Age* (citation forthcoming), provides a more thorough discussion of the physiological responses to lighting stimulus.

THE IMPACT OF CONTROLLABLE LIGHTING AND VIEWS

Controlled lighting and views can improve occupant well-being, workplace productivity, and satisfaction by positively influencing various physiological and psychological processes. Lighting and views also impact property value and employee recruitment and retention.

Well-being

Increased access to daylight and views facilitates healing, but no direct link to reduced absenteeism has been demonstrated.

Both field and laboratory studies have demonstrated that increased access to windows, daylight, and views of nature facilitates healing in healthcare settings. Ulrich (1984) famously demonstrated that patients with views of a vegetated scene recovered more quickly from surgery than those with views of a brick wall. Walch et al. (2005) correlated increased access to sunlight with decreased use of pain medication while Joarder et al. (2013) went so far as to partially quantify the relationship between sunlight intensity, in lux, and patient recovery time. Beauchemin and Hays (1996) found that patients in 'sunny' rooms recovered more quickly from depression. Researchers have wondered if related effects on productivity might be found in other settings, but while a study by Miller et al. (2009) found that occupants of "green" buildings have been shown to take less sick leave, attempts by the Heschong Mahone Group (HMG) (2001) and Issa et al. (2011) to directly link daylight and views to decreased absenteeism in schools found no significant relationship.

Productivity

Field studies demonstrate that increased access to daylight and views is correlated with improved productivity

Avery (2001) found that exposure to bright light (2500 lux for 2 hours) at work improved subjective ratings of mood, alertness, and productivity. Zadeh et al. (2014) studied how increased access to windows and views affected nurses at work. Despite both groups experiencing similar average illuminances throughout the day (765 lux for the 'windowless' vs 627 lux for the 'windowed'), the 'windowed' group displayed improved behavioral indicators of mood and subjective alertness. Whether this improvement in subjective alertness corresponded to an objectively measured increase in productivity was not confirmed. However, studies by HMG (2003) found that employees with better (larger, more vegetated) views displayed better scores on multiple cognitive tests and completed work-related tasks more efficiently. Another series of studies by HMG (1999; 2001; 2003) also found that students with greater access to views and daylight displayed improved learning progression, but that improper thermal, acoustic, and glare control could result in overall negative impacts on academic performance (2003).

Property Value

Views, especially of vegetation and water, increase property value.

More evidence for the value of windows and views can be inferred from the many studies which demonstrate how they are positively correlated with property value. Bourassa et al. (2004) found that wide views of water add, on average, 59% to the value of a property. Views of green spaces were correlated with increased property values by Jim and Chen (2006) while Sander and Polasky (2009) correlated increasing view area, especially of vegetation or water, with increased home prices. Hui et al. (2014) share similar results but describe how the impact of view content decreases with increasing story level. This relationship is complex, but the general trend holds: willingness to pay increases with increased access to windows and their associated views

Recruitment and Retention

Daylight and views are desired by occupants and contribute to employee retention. The visual environment often forms the first impression of a space or company and has the potential to aid recruitment.

There is little peer-reviewed scientific data regarding the specific value of daylight and views in employee recruitment. Two recent surveys of office workers can provide some insight into this relationship. An international survey of 7600 employees by Browning and Cooper (2015) found that natural light was the most desired workplace element and that 33% of the participants stated that workplace design would affect their decision to work at a company. A similar survey of 1,614 office workers in North America reported that 78% of respondents claim that access to natural light and views improves their overall happiness and well-being, 73% said it improves their work satisfaction, 70% reported it improves work performance, and 54% said it increases their organizational commitment. Overall, North-American respondents rated access to natural light and views of the outdoors as their most-valued office perks, outranking onsite cafeterias and fitness centers (Future Workplace, 2018).

An indirect link between access to daylight and views and employee retention can be established via job satisfaction. Hellman (1997) correlated job satisfaction with a decreased intention to quit and, as this paper will discuss in more detail, daylight, views, and personal control over the workplace have all been shown to increase job satisfaction. Leather et al. (1998) noted that a reduction in reported job stress in response to views of nature may mediate intention to quit. The specific, indirect link between access to daylight, job satisfaction, and turnover was investigated by Alimoglu and Donmez (2005) who found that nurses with increased access to daylight reported decreased burnout indicators.

Energy

While this paper will not provide a detailed discussion of the energy benefits of daylighting, we note that they are significant and direct the reader towards others' research on the subject.

HMG (2005) analyzed photocontrolled side-lighting systems in the US west coast and found that top performers averaged 51% lighting energy savings. Galasiu et al. (2007) studied combined systems featuring occupancy sensing, daylight sensing, and personalized dimming and consumed 42-47% less lighting energy compared to the previous uncontrolled condition. Daylight sensing and controllable dimming systems were installed during the New York Times building renovation and Fernandes et al. (2014) found that they decreased energy consumption by 28%. For more information about daylighting and the potential energy benefits, see Mudit (2011) and Yu and Su (2015).

PHYSIOLOGICAL RESPONSES TO THE VISUAL ENVIRONMENT

The visual environment impacts nearly every facet of our lives. It directly influences our mood and cognitive performance during the day and the quality of our sleep at night. Further research is needed to define how specific characteristics of light and views affect human behavior and health, but there is consensus that increased access to light, particularly bright daylight, and views during the day can improve productivity and well-being.

Circadian Regulation

Light regulates the human circadian system which, in turn, governs many aspects of health and physiological activity. A more detailed discussion of circadian lighting can be found in the companion whitepaper: Lighting in the Circadian Age (citation forthcoming).

There has a been a surge of interest in the effects of light on human health, particularly through its influence on the human circadian system. The circadian system can be described as a set of physiological timekeeping mechanisms, or clocks, that regulate most bodily processes. Dibner et al. (2010) state that light plays a fundamental role in synchronizing these clocks with activity cycles and supporting healthy functionality. Reviews by Smolensky et al. (2016) and Roenneberg and Merrow (2016) link the disruption of this cycle to the development of many systemic health issues.

There is consensus that the sleep-wake cycle is regulated by relatively low amounts of light, as demonstrated by Cajochen et al. (2000), and that the amount of light commonly present indoors is sufficient for entraining circadian rhythms to normal day-night cycles. That being said, exposure to more intense light during the day, particularly in the morning, may be beneficial as it can facilitate

synchronization after disruption, as demonstrated by Dijk et al. (2011), and support more robust (greater amplitude) circadian rhythms, as shown by Ancoli-Israel et al. (2002). Further evidence was presented by Phipps-Nelson et al. (2003) who found that daytime exposure to bright light (> 1000 lux) can reduce subjective sleepiness and impaired cognitive performance associated with insufficient sleep. This study restricted participant sleep to five hours a night for two nights and measured cognitive performance using a psychomotor vigilance task test. Two recent field studies used wearable sensors to expand upon these results. Boubekri et al. (2014) demonstrated that greater exposure to bright light (> 1000 lux) throughout the work day was correlated with increased quality and quantity of sleep. Figueiro et al. (2017) developed a wearable sensor tuned to detect circadian stimulus, as defined by the wavelength-dependent empirical model derived by Rea et al. (2005). Greater amounts of circadian stimulus were, once again, correlated with improved sleep quality and more robust circadian rhythms. Oh et al. (2014) demonstrated that available white LEDs can be tuned to either minimize or maximize their activating effects on the circadian system while still meeting visual needs, supporting entrainment.

The influence of color and timing

Increased exposure to bright light during the day is beneficial, but more research must be done to quantify the impacts of wavelength and timing.

There is significant public and scientific interest regarding the influence of lighting spectral composition on alertness and mood. The consensus, as stated by Cajochen in 2007, has been that short-wavelength (blue) light is more stimulating than other parts of the visible spectrum. This consensus remains regarding the effects of light on the circadian system, but more recent studies have begun to question the broad application of this generality with respect to direct alerting effects. In a 2018 review, Souman et al. (2018) concluded that consensus could not be established regarding the direct alerting effects of different wavelengths of light, although they did find a general trend of higher illuminances being correlated with greater stimulation. Other studies have tried to determine if different colors facilitate different types of cognitive function. The answer appears to be yes, but specific results are inconclusive and will not be explored in this paper. A thorough review of the subject is presented by Elliot and Maier (2014) who state that the psychological associations with color also seem capable of influencing cognitive performance, but the effects vary based on context. Further research is needed to develop guidelines for general application.

Exposure history

Physiological responses to light are influenced by long-term exposure.

Hankins and Lucas (2002) state that visual perception changes throughout the day and is influenced by long-term light exposure. Studies by Smith et al. (2004) and Chang et al. (2011) demonstrated that transitioning from dim (~1 lux) to brighter light influenced circadian rhythms more drastically than a transition from typical light levels to brighter light. Notably, a study by Leichtfried et al. (2015) had participants transition from bright light (5000 lux at 6500 K) to dimmer light (400 lux at 4000 K) and found that, while subjective assessments of alertness increased after exposure to bright light, objective assessments of sustained attention were actually worse than those of participants who had remained in the dimmer conditions. Color transitions have also been shown to influence alerting effects and circadian responses. Chellapa et al. (2014) demonstrated that light stimulus (515 nm) was more effective when preceded by orange light (589 nm) compared to blue light (461 nm).

Walmsley et al. (2015) used mouse models to show that transitions between blue (460 nm) and orange (600 nm), mimicking natural dawn/dusk transitions, reinforced circadian entrainment.

Potential for glare and negative effects

While increased daylight exposure can yield significant positive effects, care must be taken to mitigate the potential for glare.

It is important to acknowledge that exposure to daylight, particularly bright sunlight, can also have negative effects. Wienold and Christoffersen (2006) and Hirning et al. (2014) describe how daylight glare can create discomfort while a study by Van Den Wymelenberg et al. (2012) examines the negative impacts of glare on task performance. Sunlight can also overstimulate occupants with sensitivity to light, as described by Mulleners et al. (2001). That being said, Van Den Wymelenberg et al. (2010) showed that on sunny days, the vast majority of participants intentionally included sunlight in their preferred office environment. Furthermore, a series of studies by Tuaycharoen and Tregenza (2005; 2007; 2011) examine how view content can moderate glare assessments. They found that glare was more tolerable if accompanied by natural or interesting views. Higher luminance ranges were associated with more intense glare and their 2011 experiment suggests that increased image complexity may moderate glare assessments. Daylight or sunlight may not always be beneficial, but they are often desired, creating a potentially complex control problem, especially in large open workspaces.

PSYCHOLOGICAL INFLUENCES OF LIGHT, VIEWS, AND PERSONAL CONTROLS

Occupant interactions with light and views significantly influence the experience of the built environment, impacting interrelated physiological and psychological responses. Increasing access to daylight, views, and occupant control of the visual environment improves satisfaction, productivity, and social interaction.

Daylight and views

Greater access to daylight and views increases satisfaction, facilitates stress recovery, and has the potential to improve creative problem solving.

Natural light and pleasant views are highly valued by occupants. A 2001 review by Farley and Veitch describes how views of nature are correlated with increased job satisfaction while Kaplan (2001) also linked views of nature with overall satisfaction and sense of well-being. Participants in a study by aan het Rot et al. (2008) were equipped with wearable illuminance trackers and those who experienced more bright light (> 1000 lux) in their daily lives reported improved mood metrics. A similar result was reported in the aforementioned study by Zadeh et al. (2014) which found that nurses who had greater access to windows and sunlight showed improved assessments of mood and sociability. Lottrup et al. (2015) found that office workers' satisfaction with view was positively related to their reported work ability and job satisfaction.

The psychological response to views can also produce physiological benefits. Ulrich et al. (1991) found that subjects experiencing visual and audio recordings from natural (undeveloped forest scenes) settings recovered from stress more quickly than those exposed to recordings of urban

settings. Kahn et al. (2008) compared subject response to a blank wall, a window with a vegetated exterior view, and a plasma screen displaying the same live exterior view. They found that viewing the window improved heart-rate recovery from a moderate stressed state while physiological responses to the 'plasma window' were no different than those experienced by users viewing the blank wall, suggesting that simulated views cannot replicate the physiological responses to daylight and views.

Research suggests that daylight and views also have the potential to influence creative cognitive function. Participants in a study by McCoy et al. (2002) stated that complexity of visual detail and views of the natural environment increased their perceived creativity. A subsequent test found that subjects in an environment possessing these characteristics displayed greater creativity, as measured using writing and visual-collage tasks. De Dreu et al. (2008) developed and tested a psychological model which linked positive, activating moods with enhanced cognitive flexibility and inclusiveness. Recent research by Rockcastle et al. (2017a; 2017b) begins to develop empirical metrics for evaluating light in a space in the context of pleasure, interest, and excitement.

Shading controls

Shading control systems can significantly improve both comfort and energy performance but must carefully balance occupant desires for personal control with intelligently designed automatic operation.

Realizing the benefits of daylight requires responsive handling of its variability and extremes. Surveys and reviews by Galasiu and Veitch (2006) and Day et al. (2012) report that occupants desire controllable shading and lighting systems and are more satisfied when they have them. Paired experimental and modeling studies by Bessoudo et al. (2010) and Tzempelikos et al. (2010) found that shading systems can improve both visual and thermal comfort while reducing the need for active thermal control. In addition to the functional benefits, personally controllable shading and lighting systems allow occupants to personalize their workspace, which Lee and Brand (2005) correlated with improved job satisfaction.

Despite a desire for personalized control, studies by Van Den Wymelenberg et al. (2012) and O'Brien et al. (2013) have confirmed that building occupants tend to operate manual blinds infrequently. Automated systems show promise, but successful implementation is critical; Stevens (2001) found that override capability, reliability and response speed are key predictors of satisfaction with automated systems. Studies by both Reinhart and Voss (2003) and Meerbek et al. (2014) found that many automated blind systems were disabled or overridden by occupants, usually for the purposes of increasing light exposure. Interestingly, Meerbek et al. noted that manual users and automatic users expressed similar levels of satisfaction with their shading systems, suggesting the effect was due to perceived control rather than objective control. A more recent lab study by Meerbek et al. (2016) suggests that occupant satisfaction with automated blind systems could be improved with an expressive interface that communicates the status and intent of the automatic system. Further field tests are required before the potential of an intentionally designed, user-engaged blinds interface is confirmed, but these studies illustrate the potential of and desire for hybrid, human-in-the-loop control.

Electric Lighting

Personal control of lighting intensity improves satisfaction. Lighting color has the potential to influence mood, but consensus regarding generalized applications remains elusive.

Standardized electric lighting approaches have dominated the workplace scene for the last half-century, but interest in individual task lighting and personally controllable lighting fixtures is growing. One office environment study by Newsham et al. (2004) found that personalized dimming controls were associated with improved mood and satisfaction, as assessed by questionnaires, but not significantly correlated with performance on simulated office tasks. The authors of this study went on to state that the act of exercising control, not just the ability to do so, was important to occupant satisfaction and "control systems should be easily accessible, easy to understand, and able to effect substantial changes in conditions." Further studies by Boyce et al. (2006) and Galasiu et al. (2007) have supported the finding that personal dimming controls improve occupant environmental satisfaction. A laboratory study by Newsham et al. (2008) placed participants in a glare-free daylit space and found that, while they used manual dimming controls to create a preferred lighting environment, participants did not attempt to maintain constant illuminance. This result suggests that personal control to allow daylight variability may be more desirable than automated systems which typically establish relatively static light levels by limiting sun penetration.

Overall environmental satisfaction

Visual comfort is an important component of overall environmental satisfaction but attempts to improve visual comfort should account for and avoid detrimental impacts on thermal and acoustic comfort.

Visual comfort is just one component of overall environmental comfort. Veitch et al. (2007) developed a model for environmental satisfaction in open-plan offices with three primary factors: privacy/acoustics, lighting, and ventilation/temperature. Improvements to visual satisfaction must be weighed in context with their effects on aspects of environmental satisfaction. Studies by Leaman and Bordass (1999) and Leder et al. (2016) suggest that acoustic and temperature issues may have greater influence on overall environmental comfort than lighting. Kim and de Dear (2012) analyzed the effects of both positively and negatively rated interior environmental qualities and found that visual comfort was of relatively low importance compared to visual privacy, noise, and temperature. The overall amount of light (visibility) was reported as important. Interestingly, noise and temperature displayed a binary effect on overall satisfaction: they were very influential when uncomfortable but relatively unimportant once acceptable conditions were achieved. Huang et al. (2012) described noise and temperature as having a 'one-vote veto' where overall comfort would be negative if either was deemed unacceptable. On the other hand, Kim and de Dear noted that improvements to visual comfort continued to produce proportional increases in overall satisfaction even after acceptable conditions were achieved.

The relative influence of environmental factors must be evaluated in context with their assessed acceptability. Simply put, problematic factors tend to be rated as more important than acceptable factors. Lighting, in particular, is rated positively in most surveys and the human visual system is capable of adapting to a wide range of conditions, potentially moderating its assessed importance.

Satisfaction influences productivity

Environmental satisfaction has the potential to impact productivity through the positive affect mechanism.

Studies by Carlopio (1996) and Veitch et al. (2007) have found that, when controlling for other factors, environmental satisfaction is positively correlated with job satisfaction and self-reported productivity. Veitch et al. (2008) also demonstrated that positive assessments of the visual environment were correlated with improved satisfaction, mood, and engagement. This relationship suggests lighting has the potential to indirectly impact productivity via the positive affect mechanism proposed by Baron (1990) which links positive mood to increased productivity. A call center study by Miner and Glomb (2009) found objective support for this mechanism by demonstrating a correlation between positive mood and task performance, evidenced by shorter call times. Similar results were produced by large meta-analyses conducted by Judge et al. (2001) and Harter et al. (2002) which confirmed that job satisfaction was positively correlated with improved productivity at both the individual and organizational levels.

LOOKING FORWARD

When examined in isolation, the various approaches to personal and automatic control of shading and lighting systems each present unique potential benefits and complications. Implementing them in concert allows the capabilities of one system to balance the weaknesses of another, improving overall performance. Personal controls can be considered an integral part of a careful daylighting scheme that also considers building form, aperture size and orientation, interior space layouts, furniture designs, daylight and solar controls, and integrated lighting controls. We recommend a complementary approach, based on such a scheme, using a combination of automated solar and electric lighting control systems along with personal controls with automated system overrides. This approach can help modulate illumination, glare, solar gain, access to view, and circadian stimulus to produce individualized, comfortable, and healthy visual environments. New advances in dynamic facades and shading systems, such as automated and light redirecting blinds, automated shades, electrochromics, thermochromics, and spectrally selective dynamic filters can facilitate this process. Personal workstation-based shading systems also hold promise. These new tools in the designers' repertoire will help deliver optimal indoor environments and accommodate the trend towards a layered-control approach to the provision of daylight and views.

Future research should examine the mechanistic pathways through which light and views affect the human body. Specifically, studies should seek to quantify the psychological and physiological impacts of lighting intensity, spectral characteristics, exposure timing, exposure history, and view content. One of the primary challenges will be linking subjective assessments of well-being, satisfaction, and alertness to objectively measured improvements in health, mood, and cognitive performance. Establishing common metrics for subjective qualities such as mood will be a key part of this effort. Furthermore, short-term observations must be evaluated over longer periods to examine their persistence or variation over time.

We believe that enough is known about the visual environment's influence on human well-being to recommend action, particularly regarding the support of healthy circadian rhythms. However, we caution against over-generalizing what are currently highly contextual and typically discreet findings.

In practice, we recommend a measured approach to lighting utilizing natural daylight where possible and supplemented with electric lighting, patterned on the cycles of the natural environment, that reinforces the body's natural rhythms. This approach should be dynamic. Studies show occupant preferences vary drastically in different contexts and the ability to easily and intuitively respond to these changes is a key predictor of satisfaction. Finally, lighting should not be evaluated only with respect to visual task performance. The experiential qualities of daylight, as well as the natural connections fostered by views, have the potential to significantly improve aspects of mental health and mood.

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