QUANTIFYING ADAPTIVE BEHAVIORAL RESPONSES TO DISCOMFORT GLARE – A COMPARATIVE ANALYSIS OF DAYLIT OFFICES

by

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THESIS ABSTRACT

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Discomfort glare from daylight is among the most common issues in commercial offices and has been shown to negatively impact productivity, comfort, and well-being. While occupants' adaptive behavioral responses to discomfort glare can significantly alter both the energy use profile and indoor environmental quality of a workspace, little is know about the specific relationship between the environment in which discomfort glare is perceived and the subsequent behavioral response to it. This study proposes a new Glare Response Sensitivity index to evaluate the relationship between environmental parameters and behavioral outcomes in a daylit commercial office building. The results of this study show through a parametric analysis that perceptual sensitivity mediates the relationship between environmental lighting conditions and controls use behaviors. Further, the results suggest that spatial factors including office type and level of control over the environment may affect the likelihood of active lighting controls use behaviors in daylit buildings.

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CHAPTER I

INTRODUCTION

Electric lighting in commercial buildings comprises nearly 25% of total end use energy consumption in the US commercial building sector, shown in Figure 1 (U.S. Department of Energy 2009). Electric lighting in offices represents 20% of the total commercial lighting energy consumption (Navigant 2002). Successful use of daylight, along with improved electric lighting controls, have reduced total energy consumption in commercial buildings between 10-40% in experimental simulations (Bodart and De Herde 2002; Moreno et al. 2013; Roisin et al. 2008). However, these energy use reductions have seldom been realized in existing buildings due to the high frequency of electric lighting use despite adequate indoor daylight illuminance (Lindelöf and Morel 2006), poorly designed or executed automated switching regimes (Li and Lam 2001), the lack of accessible occupant controls (Day, Theodorson, and van den Wymelenberg 2011), and the duration of interior shade use that prevents sustained utilization of daylight (Mahdavi 2009). The evidence overwhelmingly highlights the importance of occupants' controls use in regards to indoor environmental quality, but architects have few tools in their repertoire to grapple with these facts. Long-term studies of occupants' controls and energy behaviors illustrate how and when occupant controls are used but they focus on transient aspects of the environment that are not readily translated into architectural design of daylit spaces such as indoor and outdoor luminance and illuminance levels (Mahdavi 2009; Correia da Silva, Leal, and Andersen 2013) or luminaire, lamp, and lighting control specification (Moore, Carter, and Slater 2003). These findings strongly suggest the need for further research on determinants of occupant controls use in daylit spaces. This study examines the spatial, environmental, social, and personal factors that influence adaptive behaviors in daylit workspaces.

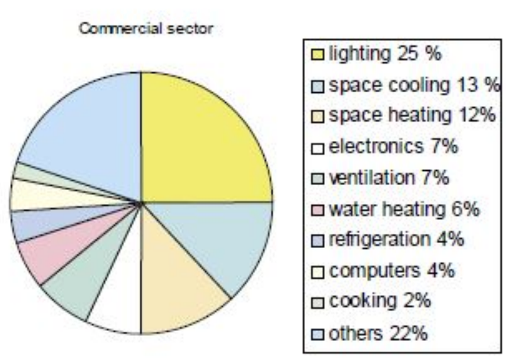


Figure 1: End use electricity breakdown in commercial buildings in the United States (U.S. Department of Energy 2009).

The lack of clear evidence-based design guidelines to improve lighting energy behavior outcomes is a particularly salient issue in regards to daylight glare in workspaces. Workspaces with too much daylight, too many windows, or improperly located windows with little or no solar control are a common feature of commercial buildings. As a result, discomfort caused by daylight glare is one of the most common indoor environmental issues in daylit workspaces. While there is disagreement regarding the most accurate ways to assess or predict discomfort glare indoors, it is universally experienced in work environments due to excessive brightness levels or contrast ratios within an individual's field of view (IESNA, 2000). People perceive varying levels of discomfort glare in the same conditions and external factors such as view quality have been shown to have a mediating effect on discomfort glare perception (Aries, Veitch, and Newsham 2010). Accordingly, glare from daylight has been a frequent target of past studies because of the potentially deleterious effect of glare on comfort, productivity, and well-being. Further, the type of behavior that is exhibited in response to discomfort glare perception, whether the occupant closes the blinds completely at first notice of glare or simply rotates their view position, can significantly impact electric lighting use, energy consumption, and internal heat gains (Jakubiec and Reinhart 2012). Despite the array of adaptive behaviors an individual could take, people will commonly act to either partially or fully occlude daylight in response to discomfort glare (P. Boyce, Hunter, and Howlett 2003). Discomfort glare can be thought of, in these instances, as negating the benefits of daylight by causing occupants to close the blinds and turn on the lights or producing uncomfortable and dissatisfied occupants. While the existing research comprehensively documents typical patterns of occupants' behaviors, it is unclear how an individual's physical environment, social environment, and personal characteristics influence adaptive behavioral responses to discomfort glare. The potential positive influence of architectural design to remediate these behaviors is unknown and architects have few tools to improve the energy and behavioral outcomes of daylight design. This research proposes a conceptual model to understand and critically examine how office design interacts with lighting, personal, and social factors in an effort to provide architects and lighting designers a more refined toolkit to reduce the energy impacts of discomfort glare in commercial offices. This thesis uses field lighting assessment, behavioral observation, and survey data, collected over a six-week period from a daylit commercial office building in Eugene, Oregon, to define lighting and behavioral parameters and construct a Glare Response Sensitivity (GRS) index that quantifies an individual occupants' likelihood of experiencing discomfort from daylight glare and prompting an adaptive behavioral response. The GRS index may offer a new analytical tool for architects during programming, schematic design of new commercial offices, or in post-occupancy evaluation of buildings-in-use in order to more closely examine how spatial and architectural factors influence occupants' adaptive behavioral responses to discomfort glare.

This thesis begins with an overview of the current state of knowledge regarding environment-behavior studies, daylighting, and visual comfort metrics in Chapter II. Chapter II includes a brief survey of existing conceptual models for environment-behavior, lighting and comfort studies in order to guide the literature search and inform the development of a new conceptual model for adaptive behavior studies. Chapter III presents the research questions, research approach and methodology of the thesis study including data collection techniques, data analysis approach, and an overview of the research setting. Chapter III also describes the rational behind proposed lighting, spatial and behavioral outcome parameters including the assumptions behind the GRS index constructed from survey responses. Chapter IV presents results of the environmental, behavioral, and perceptual parameters defined from data collected from field lighting assessment, behavioral observations, and survey data. Results, descriptive analysis and parameter definitions obtained from each of the field and survey methods are included in the Appendix. Chapter IV includes statistical analysis of behavioral outcomes that describes the relationship between environmental factors, individual perceptual and affective responses, and observed behavioral responses. Chapter V summarizes the outcomes, describes the limitations, and outlines implications of this thesis on future research. Chapter V also proposes new research questions and directions for future research that emerge from the

CHAPTER II

BACKGROUND

Existing research on the relationship between environment and behavior in general, and the impacts of daylight design on people's behavior specifically, is based on conceptual models describing the proposed interaction between space, environmental stimuli (such as brightness), and individual. This thesis proposes a new conceptual model based on the conceptual models present in existing studies of daylight in commercial buildings, discomfort glare, occupant lighting preferences, and occupant controls use behavior. Some conceptual models are explained in the existing literature but others are more implicit to the research design or assumptions and can be seen to constrain the overall generalizability of findings. The following section first gives an overview of the existing models for environment-behavior research. Next, this section discusses current state of knowledge from a number of environment-behavior subfields to identify foundational behavioral theories and specific influences on occupants' control use behaviors. Last, this section introduces the proposed conceptual model that forms the basis of this thesis study and methodology.

II.A. Existing Models

The perception-action cycle, seen in Figure 2 below, diagrams the basic neuro-physical interaction between environment, perception, and action. In daylight and glare studies, luminance levels within the field of view are the environmental stimulus. Excessive brightness or visual discomfort is the perception, which is then recognized as glare, and the adaptive behavioral response such as closing the blinds is the action. The action of closing the blinds in this example then affects the environmental stimulus by lowering luminance levels or overall illumination and creates a cycle of interaction between environment, perception and behavior. According to this framework, the same environmental stimulus does not necessarily result in the same perception or action in different individuals. There are three primary reasons for this. First, physiological differences may affect an individual's ability to perceive stimuli, such as color-blindness, or their sensitivity to stimuli, such as loss of hearing or vision with age. Second, attention influences what environmental stimulus actually reaches the neural receptor. Attention is modulated by both top-down (intentional, cognitively-driven attention) and bottom-up (unintentional, stimulus-driven attention) influences. Third, an individual's past experiences, knowledge and expectations are unintentional top-down influences on how an attended stimulus is interpreted.

Only a small portion of environmental stimuli actually reaches the neural receptors and this is usually a result of a cognitive decision about where to look or where to focus. When the individual directs attention, it is said to be top-down. When an environmental stimulus directs attention, it is said to be bottom-up. Recalling the daylight/glare example above, the brightness of light reaching the neural receptor can be so extreme that it causes reduced overall visibility, as is the case with disability glare. In this example, the salient environmental stimulus would supersede the task to which an individual is directing their attention and perception would be driven in a bottom-up manner. In less salient conditions, such as with excessive brightness that does not affect physiological vision, top-down attention can suppress the perception of discomfort. The less salient condition is quite common in daylight offices where direct sun or perimeter workspaces could be quite bright but individual's attention is likely focused on a work-related task. As a result, the nature of an individual's top-down attention influences how an environmental stimulus affects perception and behavior.

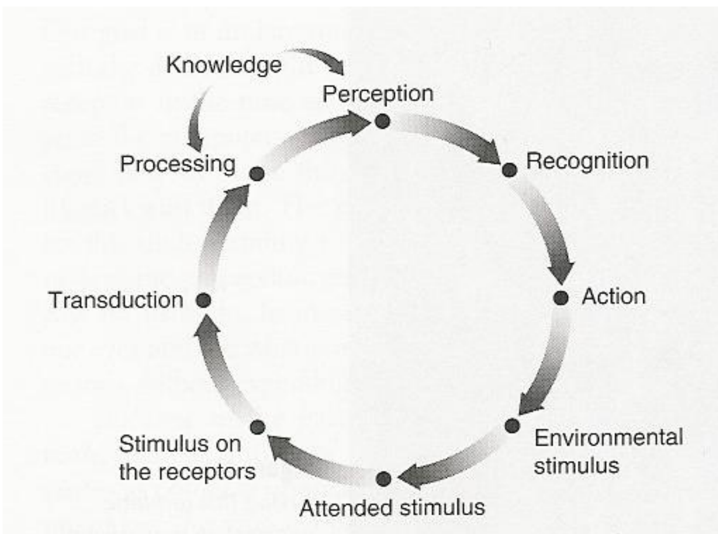


Figure 2: Perception - action cycle illustrates how environmental stimuli are received by the neural receptors, transmitted through the neural networks, processed, perceived, recognized, and acted upon in the form of a behavioral response (Goldstein 2013).

The environmental stimulus (such as luminance levels) can be measured directly using scientific equipment. The action/behavior can also be measured directly through observation techniques. The attended stimulus, perception, and recognition of a perception cannot be measured directly. Psychophysical studies, that measure the stimulus and action/response only, inevitably overlook the role of top-down influences in the perception-action cycle. Similarly, neurophysiological studies, that measure the stimulus and response at the level of the neuron, don't capture top-down influences. While the perception-action cycle neatly encapsulates the process by which things happening in the environment affect responses from people it doesn't actually offer a way to conceptualize and measure phenomenological aspects of environment-behavior studies.

A recent study of how office and individual characteristics relate to feelings of physical and psychological discomfort uses a simple conceptual model to propose a more complex series of interactions. The basic model from which the conceptual model seen in Figure 3, below, was originally developed is based on an extensive study of thousands of office workers to explain sick building syndrome (Hedge et al. 1989). The basic model shows direct effects of individual and architectural factors on physical and physiological discomfort as well as indirect effects through the lens of perceived environmental conditions. All relationships are assumed to be one-directional, however, with no indication that individual's behaviors affect their perception or feelings of discomfort. While individual factors could include the top-down influences found in the perception-action cycle, they are defined as attributes of the individual such as demographics.

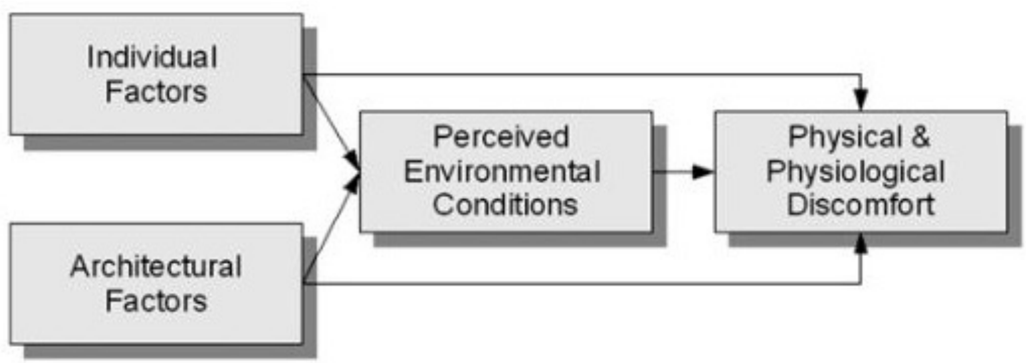


Figure 3: Original model of direct and indirect effects of physical environment on feelings of discomfort (Aries, Veitch, and Newsham 2010).

The updated model seen in Figure 3 is discussed here because it predicts direct and indirect environmental influences of spatial characteristics including distance from a window and view quality. The proposed model (Figure 4 below) uses the specific variables light quality and impression as a proxy for the perceived environmental conditions. General demographic information (the individual factors) and office characteristics are treated as completely independent factors. This model assumes that the perceived environmental conditions mediate the influence of the independent variables on the outcomes at the right side of the model, but it is not entirely clear how the mediating effect might work. As seen in the final model showing analysis results (Figure 5), the mediating influence of the perceived environmental variables on discomfort was weak or non-existent for most of the spatial factors. The next model grapples with the disconnect between the environment as measured and the environment as experienced and proposes a multi-layered system of environmental influences and filters with regards to the concept of indoor comfort.

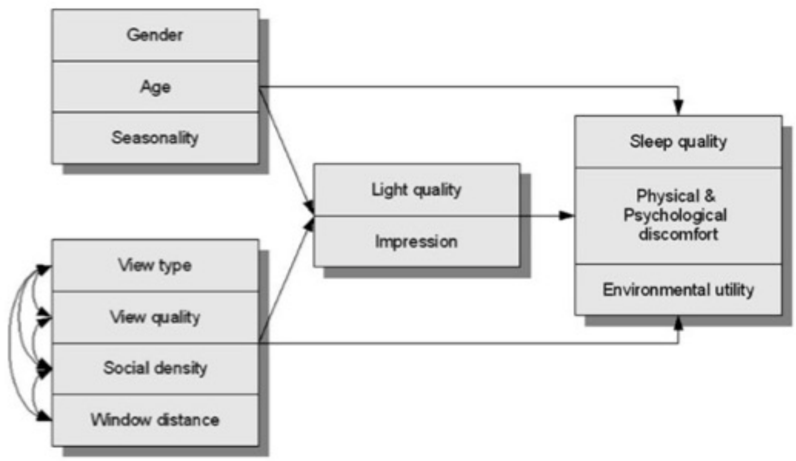


Figure 4: Proposed model of direct and indirect effects of physical environment on feelings of discomfort (Aries, Veitch, and Newsham 2010)

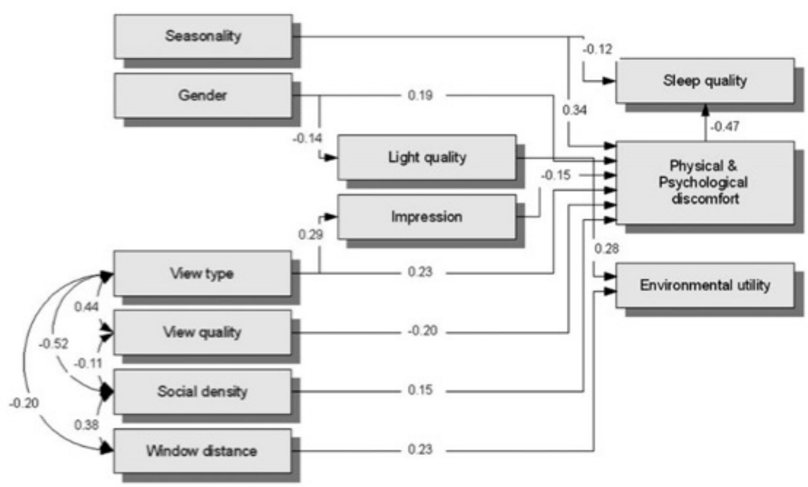


Figure 5: Final conceptual model illustrates direct and indirect effects of the physical environment on feelings of discomfort (Aries, Veitch, and Newsham 2010).

Major components of the perception-action cycle are present in the classifying model seen in Figure 6. This model does not explain behavior directly but rather conceptualizes the experience of the environment. It seeks to explain the process of how, in the context of comfort in buildings, environmental stimuli become a recognizable experience. The model is based on previous environment-behavior models that emphasize the system of interactions between different attributes including individuals, the physical environment, and social or organizational structures. These attributes comprise four dimensions of indoor comfort - physical, physiological, psychological, and social. The indoor comfort system model assumes these four dimensions are not sufficient on their own to describe the experience of the indoor environment.

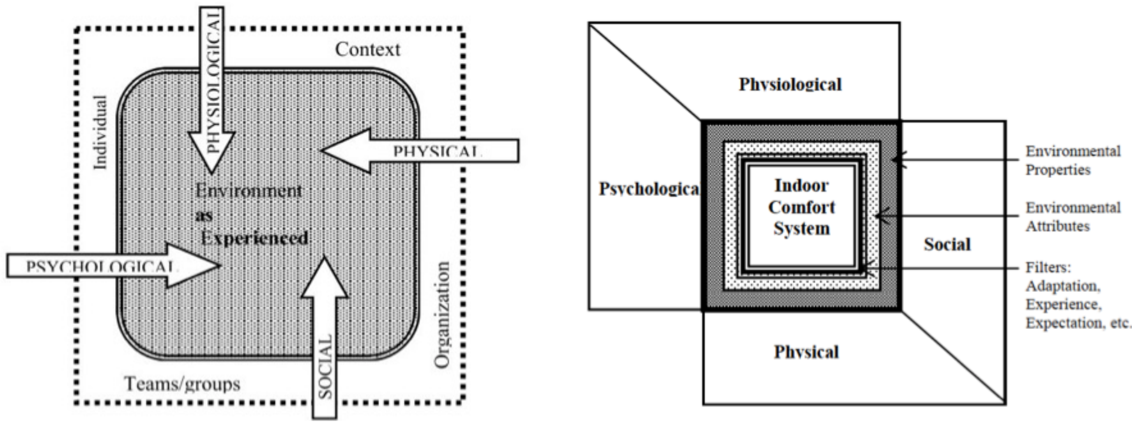


Figure 6: Environmental parameters affecting experiential qualities of the built environment as perceived by occupants, left, and four-fold model of indoor comfort includes overlapping spheres of environmental properties, attributes, and filters, right (Elzeyadi 2002).

This model includes a blanket conditional statement acknowledging the importance of top-down perceptual influences on indoor comfort. “The individual’s past experience and expectations represent his/her mechanisms of adaptation and habituation to the environment over time,” (Elzeyadi 2002, p. 3). The concepts of adaptation and habituation could imply either physiological adaptation, such as light or dark adaptation in visual perception, or psychological habituation, such as someone who works in a normally dark office and considers lower daylight levels comfortable for working. In this model top-down factors such as past experience and expectations are assumed to mediate the influence of directly measurable environmental variables. If an individual expects, and in turn accepts, brighter or more glaring lighting from daylight, then the influence of lighting factors on the individual’s comfort assessment is decreased. Attention is not mentioned in the indoor comfort system model specifically but is analogous to the role assigned to adaptation and habituation. These top-down influences, or ‘filters’, are seen in the thick borders surrounding the ‘environment as experienced’ and ‘indoor comfort system’ in the conceptual diagrams shown in Figure 6 above. While no apparent hierarchy is proposed between the four dimensions of comfort, it is reasonable to assume that the top-down factors may mediate the influence of some dimensions more than others depending on the individual or context. No organizing principles or structures are given to the top-down factors in this model and as a result it may be difficult to integrate data on top-down factors into an indoor comfort analysis based on this model. Moreover, the relationship between experience and behavior is unclear within this model. Does the adaption, experience or habituation filter affect what behaviors result from an experience? Or is the filter only between environment and experience? These questions can be addressed by the cognitive mechanism found in the next model.

The theme of a 'perceived environment' repeats in the next model, shown in Figure 7, which presents an articulated version of it to inform the study of microclimate perception in urban open spaces. The model proposes to explain how people's long-term perceptions of microclimates in urban open spaces relate to the actual microclimates. It prefaces on the notion that while there are aspects of microclimate that are easy to understand, namely the outcomes (being warmer, cooler, more windy, etc.), the actual physical and spatial qualities that generate microclimate conditions are quite difficult to conceptualize and understand. As a result, the more salient outcomes (high heat or wind for example) may bias people's understanding or expectations of the microclimate in an urban open space. The model that forms the basis of the study, seen in Figure 7 below, re-classifies the 'perceived environment' as the 'schema'. This model assumes the schema will mediate the influence of the physical environment on behavioral responses. It also identifies microclimate and spatial cues that exist in the real environment and communicate information about the environment within the schema. Spatial and microclimate cues are a measurable characteristic of the physical environment, but they are not apparent on the surface. Research using a model such as this therefore requires appropriate data collection and analysis methods in order to characterize attributes of the physical environment, microclimate conditions, as well as describe people's perceptions of the environment and behavioral responses. "If it is possible to discover spatial cues that influence people's microclimate schemata for a place, then operable design guidelines can be identified to change the cues and eventually the schemata people have developed," (Lenzholzer and Koh 2010, p. 2). The structural addition of spatial cues and perceptual schema to the existing environment-behavior models thus creates a direct line between design inputs and behavioral outcomes.

Each of these models emphasize a disconnect between the objective, measurable and quantifiable physical environment and the subjective experience or perceived environment as a way to explain the variety of different responses individuals exhibit to similar environmental stimuli. The basic structure of the perception-action cycle is present in the models described above but each conceptualizes the factors influencing perception and recognition differently. Each model integrates the role of top-down influences on perception, although the proposed model seen in Figure 7 is the only one to include a mechanism, the schema, describing how top-down influences affect perception and behavior. Further, the model ties the schema to the physical environment by identifying environmental cues that inform the development of an individual's schema. Taken together, these models can be refined further into a structure to study behavioral responses to discomfort glare. The basis for adapting these models to this research study and focusing on environmental cues and their relationship to schemata and behavior, as a way to conceptualize the interaction between environmental factors, individual characteristics, and social or cultural structures, can be found in the foundational research on perception.

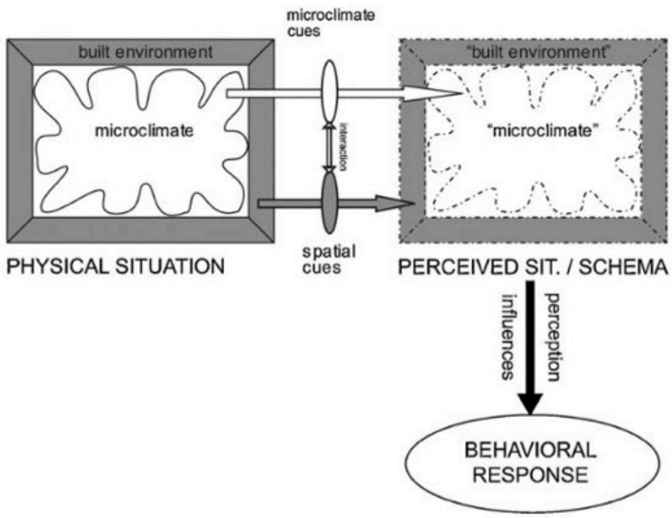


Figure 7: Conceptual model for research on microclimate perception and schematization in urban open spaces (Lenzholzer and Koh 2010).

II.A.i. Role of Schema & Heuristics in Perception & Behavior

This section provides a brief overview of foundational research on schematization and its associated mechanisms, such as heuristics, that facilitate decision-making in complex environments. The schema functions as an internal diagram of how things work within a system. It emphasizes key aspects of the system and ascribes meaning and function differently among the system's components, but most importantly, it transcribes the individual's understanding of why and how a system produces a certain outcome (Norman 1990). Gibson contended that certain stimuli act as environmental cues and are picked up by an individual's perceptual system and recognized as meaningful. Gibson postulates that these cues are processed by the perceptual system in a way that transcends rote sensation. "To see things is to see how to get about among them and what to do or not do with them. If this is true, visual perception serves behavior, and behavior is controlled by perception," (Gibson 1979, p. 223).

The schema is important insofar as it facilitates effective action. In this regard, the schema can be thought of as a mental map – a means to connect the dots (cues) and assemble a larger picture (meaning and functionality). But the schema alone cannot explain behavior. Heuristics are a manner of shortcut taken by individuals to aid in the efficiency and overall accuracy of recognition and action. Heuristics rely on information from the environment to guide perception and behavior and the schema is there to funnel meaningful information to the heuristic (Hertwig and Hoffrage 2011). "It is the interaction between a heuristic and its social, institutional, or physical environment that explains behavior," (Todd and

Gigerenzer 2007, p. 167). Heuristics are at least partially responsible for the adaptability and responsiveness of humans in new and complicated situations, but they have their limits. Heuristics, as the codified shortcuts within a schema, take on certain predictable forms. For the purposes of the study of environmental behaviors in the context of comfort or utility, heuristics that operate in pursuit of a goal and based on previous experience in a sometimes complicated or unclear situation seldom achieve the goal in the best way possible. For this reason, these types of search heuristics are referred to as 'weak methods':

> When intelligence explores unfamiliar domains, it falls back on 'weak methods' which are independent of domain knowledge. People satisfice - look for good-enough solutions - instead of hopelessly search for the best. They use means-ends analysis to reduce progressively their distance from the desired goal. Paying attention to symmetries and orderly sequences, they seek patterns in their environments that they can exploit for prediction. Problem solving by recognition, by heuristic search, and by pattern recognition are adaptive techniques that are compatible with bounded rationality. (Simon 1990)

Using a schema to orient their information search and heuristics to guide their decision-action process, an individual's rationality exists within an imperfect system with time constraints, unclear cues, and unclear results (Simon 1990). In contrast to the economic model of people as rational actors, people can be thought of as operating under a sort of ecological rationality whereby people's rationality is tied to the information contained in their environment:

> Studying ecological rationality as the fit between structures of information-processing mechanisms in the mind and structures of information in the world gives us three things to focus on: the mind (decision heuristics), the world (information patterns), and how they can match…Useful ways to describe psychologically relevant aspects of spatial structure, temporal patterns, and social environments (among others) must be developed or imported from other disciplines. (Todd and Gigerenzer 2007)

In summary, a schema is a useful way to reconcile the various types of external and internal factors that influence environment-behavior interactions. Some environment-behavior research has shown that observable differences in behavior and perception can be both measured and understood through objective field data when viewed through the lens of the schema. This study proposes utilizing the lens of the schema to organize environmental, personal, and social factors that influence adaptive behavioral responses to discomfort glare in such a way that predictable or consistent relationships between environment and behavior can be better understood.

II.B. Current State of Knowledge

The following section outlines foundational and current research in the topic areas related to discomfort glare perception and building occupants' behaviors. Existing literature on the physiological mechanisms of discomfort glare perception as well as the psychological and physical impacts of discomfort glare supports continued research into the field. Existing research on the ways people tend to use lighting and daylight controls shows a tendency toward simplistic modeling of complex behaviors to the detriment of actionable knowledge that informs design of daylit environments. This section highlights a gap in current knowledge about how the environment in which an individual perceives discomfort glare affects their behavioral response. Current research from the product design and user interface disciplines highlights new applications of the foundational research for the purposes of advancing sustainable design goals and improving behavioral outcomes through design.

II.B.i. Influences on Discomfort Glare in Daylit Environments

Discomfort glare is a product of luminance levels visible within an individual's view that exceed the existing lighting levels to which the individual's eyes are currently adapted but that doesn't impair visual perception (IESNA 2000). By its definition, discomfort glare is both physiological and psychological. This means that not everyone will perceive discomfort glare under the same physical conditions, as opposed to disability glare, which is a purely physiological phenomenon. Current research has produced a sophisticated understanding of the physiological and psychological mechanisms underlying glare perception, and a large body of research documents the deleterious impact of glare on occupant productivity, comfort, satisfaction and well-being. The existing literature does not sufficiently explain the significant variations in discomfort glare perception between individuals in different settings. A new conceptual model must address this gap in order to clarify the role of environment, stimuli, and individual on glare perception and response.

II.B.i.a. Physical Environmental Influences on Discomfort Glare Perception

Different predictive and analytical models of glare have been proposed and refined (Einhorn 1969; Hopkinson 1972; Nazzal 2005; Wienold and Christoffersen 2006) and new field methods continue to be investigated based on metrics including field of view luminance, luminance distribution, and viewing angle related to lighting source (Osterhaus 2005; Wienold and Christoffersen 2006; Van Den Wymelenberg and Inanici 2014). There seems to be a strong case that vertical illuminance, when measured at the eye level, is among the best environmental indicators of discomfort glare perception (van den Wymelenberg, Inanici, and Johnson 2010; Van Den Wymelenberg and Inanici 2014; Suk and Schiler 2013). At the same time, research by Nazzal indicates that daylight glare perception functions as a direct result of the sky luminance and vertical illuminance at the window (Nazzal 2005). As a result of the quest to find the best fit, glare models exclude many external factors that are identified within the literature. Even in highly controlled experimental settings however, such as a windowless room with non-uniform electric lighting and a single test subject, many of the existing glare models have difficulty predicting actual glare sensation in test subjects (Cai and Chung 2013). While some environmental influences have been shown to significantly influence discomfort glare perception, it is clear that additional mediating factors exist in the physical environment. The presence of a view and view quality were show to significantly affect discomfort ratings where view quality negatively predicted discomfort ratings in experimental settings (Yun, Shin, and Kim 2011) as well as in field studies (Aries, Veitch, and Newsham 2010). There is also evidence that the ability to control and the perceived degree of control significantly impacts acceptance and overall evaluation of the lighting environment and perception of glare (Moore, Carter, and Slater 2002; Moore, Carter, and Slater 2004; Day, Theodorson, and van den Wymelenberg 2011). Further, many glare prediction measures rely on static occupant locations or view orientations, belying a simple reality of how people use workspaces – that there is very often at least some freedom of movement allowed by the workspace arrangement and that there is often some degree of movement required by work-related tasks. Integrating the impacts of occupant spatial movement and adaptation into glare measures generally results in less discomfort overall and a wider range of acceptable indoor daylight conditions (Jakubiec and Reinhart 2012).

II.B.i.b. Personal Influences on Discomfort Glare Perception

A number of personal factors contribute to the general inaccuracy of glare models based solely on environmental inputs. The importance of lighting quality in the overall perception of indoor environmental quality is widely variable across cultures and individuals (Humphreys 2005). Daylight and electric lighting seem to induce different perceptual glare thresholds, perhaps owing to the positive affective and dynamic response to daylight many people express (Collins 1976; Fontoynont 2002). Appraisal of the indoor lighting environment is also seen to significantly affect reported discomfort, mood, and well-being, "People who perceived their office lighting as being higher quality rated the space as more attractive; as a result they were in a more pleasurable mood; and, in turn, they reported less overall discomfort and greater satisfaction with the work environment and with their performance on that day," (Veitch et al. 2008, p. 1). In a quasi experimental setting, more than 90% of participants who were asked to set their preferred lighting scene under sunny or partly sunny conditions chose to allow direct sunlight into the workspace despite the high incidence of glare under these conditions (van den Wymelenberg, Inanici, and Johnson 2010). These studies illustrate that personal preference, appraisal, and affect can have strong influences on discomfort glare perception.

The mismatch between physical and perceived environment found in the existing models can be explained, in part, by the individual's past experiences and expectations as well as their physical perceptive capacities, which directly affects the schema (Tversky 2003). While people generally create perceptual schemas for urban spaces, these schemas are often flawed in one manner or another leading to the conclusion that the schemas are influenced by more salient events and thus created biased expectations and behavioral responses (Lenzholzer 2010; Lenzholzer and Koh 2010). This finding is consistent with the assertion that "the initial affective and global response governs the direction that subsequent interactions with the environment will take," (Rapoport 1982, p. 14). This dynamic is represented by the presence of top-down processing in the perceptual cycle whereby the knowledge and expectations accumulated through past experiences shape an individual's perception of their environment (Goldstein 2013).

II.B.ii. Occupant Behaviors in Daylit Environments

Lighting quality has been defined as "the degree to which the luminous environment supports the…people who will use the space," and the main challenge for lighting research "is to establish what luminous conditions lead to which behaviors, and for whom," (Veitch and Newsham 1998, p. 97). This definition of lighting quality focuses on behavioral outcomes, but most studies do not include adaptive behaviors or occupants' controls use as a behavioral outcome of the lighting environment and focus instead on visual performance (Rea 1987), appraisal (Veitch, Stokkermans, and Newsham 2013), and comfort (Osterhaus 2005). Adaptive behaviors are predominantly thought to be determined by environmental discomfort alone (Boyce 2003), and are not integrated in psychological models of environmental behaviors. The body of knowledge related to the circumstances in which discomfort glare is likely to be perceived greatly outweighs the body of knowledge related to why individuals in daylit environments react to the perception of discomfort glare in the manner they do.

Occupants' control use behaviors are an important outcome of lighting design because of their direct impact on energy consumption (Bourgeois, Reinhart, and Macdonald 2006) and indoor environmental quality. The effect of variables such as work plane illuminance levels (Moore, Carter, and Slater 2003; Lindelöf and Morel 2006), and lighting control characteristics (Boyce et al. 2006; Escuyer and Fontoynont 2001) on user perception or occupants' controls use are, while frequently investigated, not clearly understood. Ameliorating discomfort is frequently described as driving occupants' control use but environmental factors such as solar radiation and solar altitude have been shown to only partially explain their use (Zhang and Barrett 2012). Further, long-term field studies show that occupants' controls use such as blinds and electric lighting is frequently set to avoid the worst possible scenarios rather than in response to any particular environmental factor (Bordass et al. 2001). In experimental and field studies, the influence of factors such as layout of workspace in relation to the occupant controls on occupants' controls use are typically not investigated (Day, Theodorson, and van den Wymelenberg 2011; Mahdavi 2009) but in one study, spatial location and orientation of the subject's workspace has been shown to influence blind use, though whether this influence is linked to glare or visual discomfort is unknown (Inkarojrit 2005).

Closing the blinds to occlude the sun is a common behavioral response to glare (Boyce 2003). In field studies, shading use and electric lighting use frequently take place as linked actions where an individual opens or closes blinds and simultaneously turns the lights on or off (Correia da Silva, Leal, and Andersen 2013). Indoor illuminance levels upon arrival at the office have been shown to exhibit a significant effect on initial electric lighting switch-on behavior, representing anywhere from 75-88% of all observed electric lighting use behaviors in long-term field studies (Correia da Silva, Leal, and Andersen 2013; Lindelöf and Morel 2006), but there is little evidence to indicate that subsequent switching events consistently result from changes in outdoor or indoor illuminance levels (Hunt 1979; Reinhart and Voss 2003). Some occupants exhibit more active control over their lighting environment in response to changing conditions, but these occupants are the exception rather than the norm (Love 1998). “People in offices rarely adjust the illuminance, presumably setting the illuminance at the beginning of the day to a level they consider adequate for the tasks they normally have to do throughout the day,” (Boyce et al. 2006, p. 368). Most of the above studies examine behaviors of occupants in enclosed, private offices rather than open office areas, highlighting a bias within the field that assumes individuals with greater degree of personal control over their environment are more likely to display environmentally deterministic behaviors than individuals in open office areas. The lighting behavior profiles used by *Lightswitch 2002*, an occupant behavior model for energy simulations, embody these trends. Occupant lighting use is described as either *passive* or *active* whereby the active occupant modifies their environment in response to external conditions and the passive occupant sets the initial lighting level and leaves it for the remainder of the day (Reinhart 2004). While the empirical basis for these profiles is well illustrated in the literature, they exclude the influence of other environmental conditions such as glare perception, view, lighting quality assessment and task requirements. Field studies show that occupants are less willing to reverse their initial adaptive behaviors after the source of discomfort has faded (Reinhart and Voss 2003). These behaviors have clear implications for the efficacy of any daylight design and these studies show the importance of preventing lighting switch-on or blind-closing behaviors in response to discomfort glare.

While the personal environment has been shown to influence the schema and resulting perceptions, Lutzenhiser points to the contextual nature of mental models as evidence that expertise and sophisticated understanding of a system is not necessary to produce positive outcomes however. “Rather than dismissing actors’ understandings as being technologically incompetent, however, cognitive researchers note that while lay models may differ considerably from formal scientific theories, they are confirmed by actors’ experience under most ordinary circumstances,” (Lutzenhiser 1993, p. 266). Individuals need not be experienced or educated in a particular system to generate positive outcomes. Rather, the manner in which environmental cues are communicated to the individuals partially determine behavioral outcomes (Lockton, Harrison, and Stanton 2009). Behaviors, in this regard, can be conceptualized as an outcome of design. The model of adaptive glare response introduces this idea whereby occupants whose workspaces are designed to allow some degree of flexibility to change view orientation or move to another seating position exhibit significantly fewer hours throughout the year where simulated predicted glare levels exceed tolerable levels of discomfort and as a result display higher daylight utilization rates throughout the year (Figure 8).“As freedom of rotation and seating position is introduced, the blinds are lowered less often as the occupant manages to avoid glare,” (Jakubiec and Reinhart 2012, p. 166) One such example of this is found in occupant reactions to automated controls for shades and electric lighting. In a study of environmental perceptions in offices, individuals often devised strategies by which they could trick or override the automated lighting controls (Lo 2012). In another study of automated shading controls in a daylit office, while 47% of all changes to the blinds were carried out automatically in response to solar irradiance exceeding 50 W/m2, nearly half of all automated blind changes were overridden by the occupants (Reinhart and Voss 2003).

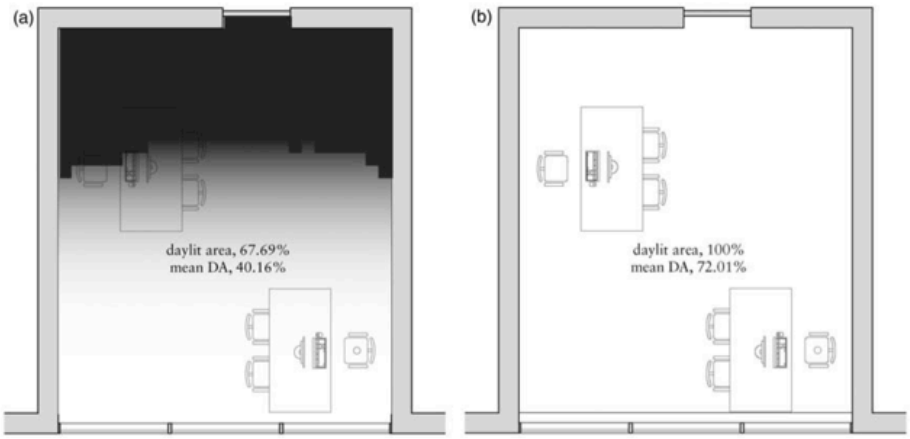


Figure 8: Daylight utilization results based on two occupant controlled blind behavioral models including a DGP controlled model (a), left, and adaptive prediction of DGP where occupant adjust seating position and rotation in order to avoid glare and keep blinds open (b), right (Jakubiec and Reinhart 2012).

II.B.ii.a. Personal Influences on Occupants' Behavior in Daylight Environments

While occupant behaviors are influenced by many different factors, environmental cues are thought to be a major factor influencing people's behavior in general. "If the design of the environment is seen partly as a process of encoding information, then the users can be seen as decoding it," (Rapoport 1982, p. 57). Rapoport uses the lens of nonverbal communication to describe the exchange of information between environment and individual as the way in which meaning is embedded in the environment. "One important function of the built environment is to make certain interpretations impossible or, at least, very unlikely – that is, to elicit a predisposition to act in certain predictable ways," (Rapoport 1982, p. 61). Indeed, more than 40 years ago, Flynn et al. reasoned that "realistic studies of lighting quality and lighting value may depend, in part, on the function of the system as a device for communicating ideas or reinforcing appropriate impressions for the user," (Flynn et al. 1973, p. 94). The success of this function hinges on the ability of the individual to read the cues contained in their environment, or an individual's criterion state, and the ability of the environment to communicate meaning effectively. "Since designers cannot change the criterion state, they need to manipulate those aspects they can control: redundancy, clear, noticeable differences, and appropriate contexts," (Rapoport 1982, p. 51). The design process should therefore establish desired behavioral outcomes (or undesired behavioral outcomes), define the particular factors contributing to the individual's criterion state, and then transmit an appropriate meaning with multiple, distinct, and reinforcing cues (Lockton, Harrison, and Stanton 2009).

An individual's schema influences behavior and decision-making as a result of experience primarily (Tversky 2003). Individuals new to or otherwise inexperienced in a particular situation behave differently than those who are experienced or experts, either because the newcomer is utilizing a schema developed for a different space or the function of the new system isn't readily apparent (Rieskamp and Hoffrage 1999). This distinction is useful to compare the awareness and behaviors of design professionals with lay people's perceptions and behaviors in indoor environments. "Experts seem to use the same number of cues but are more likely to use cues that are more useful for making appropriate decisions," (Rieskamp and Hoffrage 1999, p. 165). This example illustrates how the same physical environment can produce different behaviors among individuals who have different levels of pre-existing knowledge or experience.

II.B.ii.b. Social Influences on Occupants' Behaviors in Daylight Environments

External social factors, ranging from types of tasks to working schedule (Correia da Silva, Leal, and Andersen 2013) to informally codified practices (Lo 2012), as well as spatial requirements that are a direct result of workplace culture such as organizational layout, workspace layout, and furniture affect the individual's schema and behaviors. Further, the concept of 'energy cultures', arising from shared or organizational values, has been proposed as a way to explain the interaction between personal norms and culture that determines energy behaviors (Stephenson et al. 2010). Results from a preliminary study show that the informally-codified practice of turning all electric lights in the office on during business hours increased the participant's likelihood to leave the shades deployed during the day and decreased the participant's likelihood to turn the lights off when they left the office. This pattern is also found in a study of individual and organizational determinants of energy use behaviors in office settings, where lights were often left on in uninhabited offices to signal to co-workers that they were still in the office (Lo, 2012). In the same study, Lo et al. found that self-efficacy had the greatest impact on energy conservation behaviors. The effect of self-efficacy on energy conservation behaviors was illustrated quite potently when subjects described how their energy behaviors differed between work and home, where their perception of self-efficacy and thus their tendency to exhibit more energy conservation behaviors was much greater at home than at work (Lo 2012). The development of an individual schema can be biased by experiences that are not representative of the norm which then may lead to a skewed perception and response to environmental information in the future (Lenzholzer and Koh 2010).

II.C. Conceptual Model

The conceptual model that forms the basis of this study is an adaptation of the perception-action cycle referenced above (Figure 1), the model proposed by Elzeyadi that describes the different classifications of external factors that affect the cumulative experiential qualities and occupant perception of comfort in the built environment (Figure 2) and the model proposed by Lenzholzer and Koh to investigate microclimate perception in urban squares where the spatial schema mediates the influences of the physical environment on perception and behavior (Figure 3).

Based on the findings in the existing research that is reflected in the structure seen in the conceptual model shown in Figure 9, lighting cues (information from the physical lighting environment) are picked up by occupants to spur them to ask the first question – is this lighting uncomfortable? Whether or not the occupant picks up on the lighting cues depend on personal and social factors including attention, attenuation, expectations, and visual abilities. Personal and social factors, in the form of individual or cultural experiences, also affect how the occupant answers the next question – why is the lighting uncomfortable? But the primary contention of this research is to uncover the extent to which spatial factors, picked up by occupants as spatial cues, influence how occupants answer that question. Similarly, the decision about whether a lighting condition is uncomfortable or distracting enough to do something about depends on the personal and social factors listed above. But the more consequential decision, in terms of energy and lighting impacts, is about the response will remove that discomfort? This research seeks to uncover the extent to which spatial factors influence how occupants answer these two consequential decisions – what is the source of the discomfort, and what response is appropriate to remove the source of discomfort?

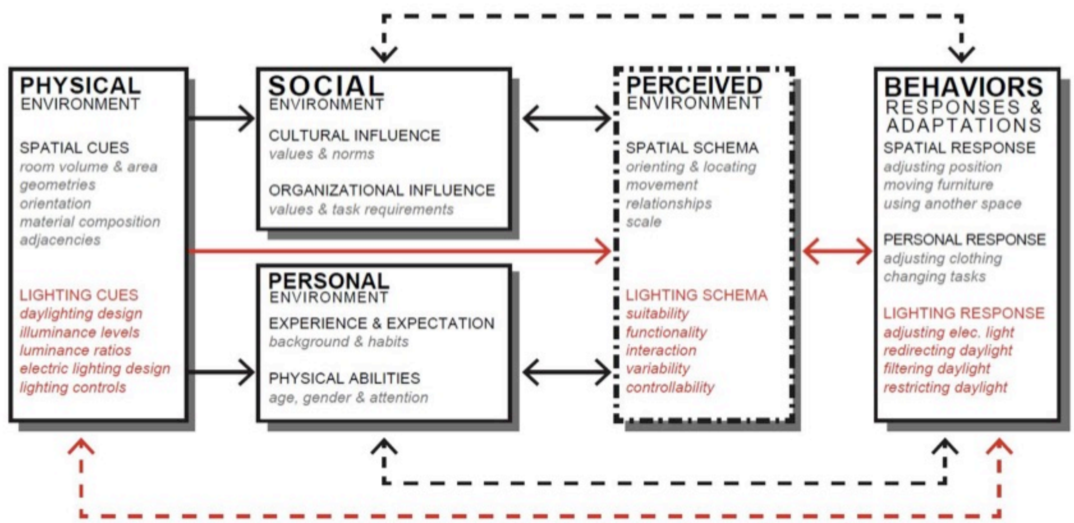


Figure 9: Proposed conceptual model for research on adaptive behavioral responses to discomfort glare in daylit offices.

Based on the findings of the existing research outlined above, the conceptual model expects numerous factors to influence adaptive behavioral responses to discomfort glare including attributes of the physical environment, lighting design, social context in which the individual is situated, as well as personal characteristics such as past experience, awareness, and visual aptitude. The physical environment is expected, in some circumstances, to directly affect perception and behavior, circumventing mediating factors as seen in the model used by Aries, Veitch, and Newsham (Figure 4). The proposed model (seen in Figure 9 above) expects the individual's spatial schema to mediate the influence of the physical, social, and personal environments on adaptive behavioral responses to discomfort glare. The schema is an individually-based psychological mechanism (Veitch 2001) including environmental cues and heuristics which directly influence the development and behavioral results of the schema. This mechanism elegantly responds to the complexity of real environments and provides a diagram of how environmental conditions are processed, interpreted, and acted upon. Research based on this model depends on a mixed methods approach to characterize disparate environmental and psychological influences on behavior.

Previous research has made it clear that some more salient factors might circumvent the schema entirely to impact perception and behavior (Aries, Veitch, and Newsham 2010; Lenzholzer and Koh 2010). In addition, the salient events are expected to shape the occupants' schema itself, which would end up biasing future adaptive behavioral responses toward preventing the extreme case as the norm. The results of that research are reflected in the model proposed herein where some factors are expected to directly influence behavior. In the context of this study, a significant glare event such as disability glare or veiling glare is expected to directly influence an adaptive behavioral response while responses to a less significant glare event, such as discomfort or barely perceptible glare, would be mediated through the schema. The type of response to disability or discomfort glare, whether the subject re-orients their view or closes the blinds for example, is expected to be mediated through the schema as well. The schema, in this study, is expected to filter the occupants' answers to the questions – is this lighting uncomfortable? Why is the lighting uncomfortable? Is it worth doing something to remove this discomfort? And lastly, what response will remove this discomfort?

These suppositions are further supported by the results of a preliminary study where participant interviews showed a conflict between the spatial, environmental, and social cues that influenced the occupants' controls use. This appeared to lead the subject to create a schema in which multiple dissimilar conceptualizations of the space and its lighting qualities existed. While the subject discussed numerous, disparate influences on their behavior, disabling glare from daylight consistently influenced adaptive behavioral responses. Interviewing the subject generated numerous insights into the subject's evaluation and experience of their workspace from which components of the subject's schema could be identified. The interview, transcription, coding, and analysis process was lengthy however. It would be difficult to scale up the interview method to cover a sufficiently large participant group. Further, relying solely on the subject to divulge accurate information about their behaviors is likely to result in biased responses. The preliminary study confirmed the utility of this model to conceptualize a multiple-research methods approach to investigate specific issues in the lighting environment. Further observations of a larger participant group's actual behavior and detailed characterization of the lighting environment and spatial attributes are necessary to draw conclusions about the relationship between the external factors and resulting adaptive behaviors.

CHAPTER III

RESEARCH METHODS

This thesis investigates the following series of questions:

- What mediating factors influence adaptive behavioral responses to discomfort glare in daylit offices?
  - Do occupants' controls use behaviors vary between offices with different spatial, daylight, and glare conditions?
  - Does an individual's workplace schema exert a mediating influence on the perception of discomfort glare in daylit offices?
  - Does an individual's reported or assessed glare sensitivity or tolerance mediate the influence of discomfort glare on adaptive behavioral responses?
  - How do spatial factors influence adaptive behavioral responses to discomfort glare?
  - How does the spatial and lighting environment influence sensitivity to or tolerance of discomfort glare conditions?
  - How does an individual's sensitivity to or tolerance of discomfort glare affect their controls use behaviors?

This study explores, in the field, the research questions above. The following statements, each corresponding to relationships proposed in the conceptual model (Figure 10), are evaluated in the course of this research. A number of sub hypotheses are also examined in the course of this thesis.

1. An individual's sensitivity or tolerance to discomfort glare influences their adaptive behavioral responses.
   a. Individuals that are more sensitive to glare are more likely to occlude their windows than individuals who are tolerant of glare.
   b. Individuals who are tolerant to glare are less likely to occlude their windows than individuals who are sensitive to glare.
2. The spatial and lighting environments influence an individual's sensitivity or tolerance to discomfort glare.
   a. Individuals whose workspaces allow them more choice about workspace orientation or location are more likely to be tolerant of discomfort glare conditions.
3. An occupants' sensitivity or tolerance to discomfort glare mediates the influence of environmental factors on adaptive behavioral responses.

a. Individuals who are more tolerant of glare are less likely to exhibit source adaptations in offices with high glare potential than individuals who are sensitive to glare.
b. Spatial attributes of the workspace show a greater influence on adaptive behavioral responses of glare-tolerant individuals than lighting environment attributes.
c. Individuals who are sensitive to glare and have flexible workspace arrangements are less likely to exhibit source adaptations than glare-sensitive individuals without flexible workspace arrangements.

4. The glare response and sensitivity index, derived from questionnaire data, will highlight behavioral and perceptual dynamics not seen in the observational data alone.
    a. Combined analysis of survey and behavioral field data shows stronger effects of spatial attributes of the workspace on occupant behaviors than individual analysis of survey or behavioral field data.

III.A. <u>Research Approach</u>

This research is divided into two main parts that investigate the question: how do the spatial and lighting characteristics of office environments influence an occupant's control use behaviors in general and adaptive behavioral responses to discomfort glare specifically? The proposed conceptual model assumes that the relationship between physical, social, and personal environmental factors and adaptive behavioral responses to discomfort glare are mediated through the schema, as represented by the occupants' glare responses sensitivity. A two-part research design tests the assumptions found in the conceptual model using a combination of field assessment, observation, and survey data. This study will not test or propose predictive models of discomfort glare but rather seeks to explain, using a robust set of quantitative and qualitative data, how the spatial lighting environment influences sensitivity and adaptive behavioral responses to discomfort glare (Figure 10).

The first part of the study is a field assessment and behavioral monitoring study that provides data on the spatial and lighting characteristics of a commercial office as well as the spatial and lighting use patterns of the building occupants. The results of the field assessment are used to group building occupants into office clusters with similar spatial or lighting attributes. Spatial and lighting use data is then evaluated within and across each cluster. Analysis of data from the first part of this study shows which spatial and lighting attributes exert a significant effect on building occupants' spatial and lighting behaviors. The relationship between overall glare potential and observed lighting and spatial use patterns is tested specifically to determine whether groups of occupants whose offices experience higher overall likelihood of glare events tend to use their blinds and electric lights in a significantly different manner than the general building population.

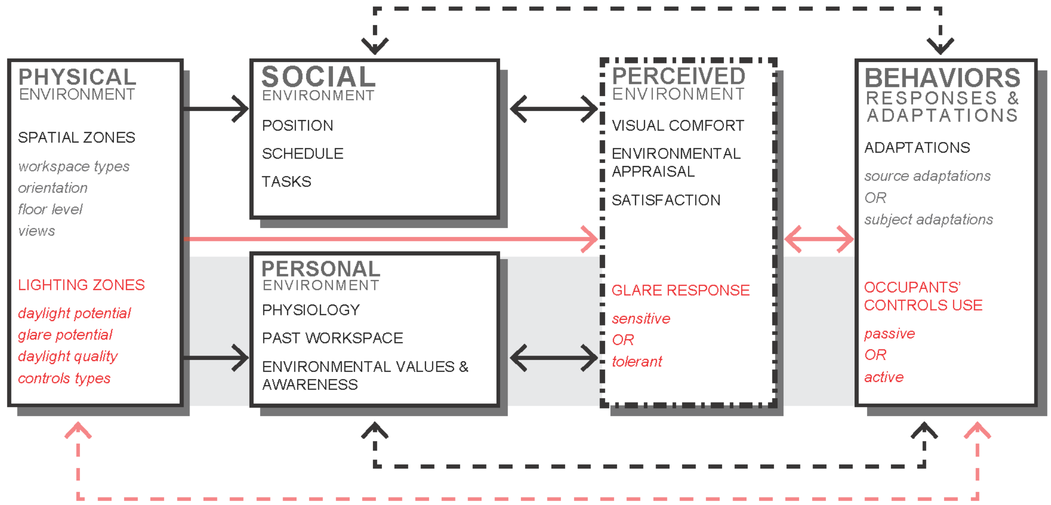


Figure 10: Proposed discomfort glare response conceptual model.

Data from the first part of the study does not provide any insight into the personal or social environmental factors found in the conceptual model. Nor does the first part of the study describe how occupants interpret the collective influence of the different external factors. The conceptual model identifies the occupants' schema as the loci wherein the influence of different external factors combines to affect an adaptive behavior. A schema, however, is not directly observable or measurable. Various methods have been proposed to describe individual's schemas of different phenomena, ranging from survey instruments, interview techniques, and cognitive mapping. Due to the scale of this study and the lack of existing studies on the topic, interview and cognitive mapping techniques were not appropriate. The second part of the study thus consists of a survey designed to elicit a deeper understanding of the operative schemas among the participant group. For the purpose of this study glare sensitivity is expected to be a primary expression of the occupants' schema, as shown in Figure 10. Survey responses and glare sensitivity index rankings are compared within and across the clusters identified in the first part of the study. Analysis results from the first part are compared with results from the survey analysis to gauge whether the apparent schemas uncovered in the survey phase can explain the differences observed between clusters. In effect, the second part of the study tests whether a diagnostic survey method can be applied to a building population in order to generate useful insights about how spatial and lighting characteristics of the work environment influence adaptive behavioral responses to discomfort glare.

Survey questions are based largely on existing building-in-use assessments and post-occupancy evaluations but focuses specifically on questions related to the occupants' perception and experience of their workspace lighting environment. The survey also gathers data on additional spatial, social, and personal factors that are thought to exhibit a direct or indirect influence on the relationship between discomfort glare and occupant behaviors. According to their responses, participants are assigned a ranking along a glare sensitivity index that indicates the overall sensitivity to or tolerance of discomfort glare conditions. Survey responses are grouped and analyzed according to a number of different criteria emerging from the initial observation phase including daylight zones, glare probability zones, workspace orientation and floor, workspace type, occupants' controls type, and workspace orientation in regards to daylight source. A multi-level cluster analysis examines how occupant schema (represented by the discomfort glare response & sensitivity index) mediates the influence of the spatial criteria listed above on adaptive behavioral responses to discomfort glare. Results are plotted a two-axis graph comparing strength of relationship between glare response (sensitive – tolerant) and occupants' controls behavior (passive – active). Correlation between glare response and controls behavior are examined using Pearson's test for correlation (*r*). Additional parameters or weighting factors can be tested based on the results of Pearson's test in order to determine glare response index construct validity.

This suite of methods thus provides a multi-faceted view of each characteristic of the conceptual model in order to draw meaningful comparisons about the relative influence of different spatial and lighting factors on adaptive behavioral responses to discomfort glare.

III.B. Research Instruments

III.B.i. Lighting Environment Assessment

Field assessment techniques provide quantitative data to describe the physical attributes of the spatial and lighting environment in an occupied commercial office building over a six-week period from September through November in Eugene, Oregon (see section III.C. below for further details regarding the study setting and specific spatial attributes examined). Table 1shows the environmental variables examined, data collection method and equipment used for field assessment of lighting cues. The variables included in the table below will in sum describe the lighting conditions of each office under observation in order to classify offices according to overall glare potential and expectation of useful illumination from daylight. Field assessment techniques are not conducted on every office included in the study. Rather, field assessments are conducted for a representative sample of offices based on office type, orientation, and workspace layout. Results from quantitative lighting assessment define glare and lighting quality clusters such that the typical behavior of the luminous environment throughout the study period is described and used to group similar workspaces together for data analysis.

Table 1: Techniques for collecting lighting data in the field.

	VARIABLE	METHOD	EQUIPMENT	INTERVAL
GLARE POTENTIAL	**Solar exposure of workspace**	In-situ measurement	*Solmetric SunEye*	Once
	Luminance distribution	High Dynamic Range imaging (HDR)	*Canon Rebel xTI + 17mm wide angle lens*	Various sky conditions & times of day
	Glare events	In-situ measurements	*Licor LI-100 light meter with LS-110 photometer*	Various sky conditions & times of day
DAYLIGHT EXPECTATION	**Indoor illuminance distribution**	In-situ measurements	*Licor LI-100 light meter with LS-110 photometer*	Various sky conditions & times of day
	Outdoor illuminance	In-situ measurement	*Licor LI-100 light meter with LS-110 photometer*	Before / After each walk-through
	Exterior shade state	Photography	*Digital camera (exterior only)*	Before / After each walk-through

While many different field and simulation-based discomfort glare prediction and evaluation methods are present in the literature, there is little consensus regarding the best indicators of discomfort glare. Most studies of discomfort glare describe it as a function of multiple environmental variables encompassing measures of incident light (illuminance) or reflected light/perceived brightness (luminance) and excess contrast within the field of view. The presence of direct sun on interior surfaces is a common cause of excess contrast, both in terms of illuminance whereby perimeter areas are much brighter than interior areas and luminance whereby surfaces with direct sun are significantly brighter than surfaces in shadow. Direct sun alone however, is not an indication of discomfort glare. For the purposes of this study, glare potential is considered the composite result of annual solar exposure on the workspace, interior luminance distribution patterns, and illuminance glare events. Annual solar access of primary work surfaces, the percentage and times of year that direct sun will reach a work surface, is calculated using Solmetric SunEye software. HDR images are taken from three different view shed locations inside each sampled office, referred to herein as the 'daylight source', 'overview', and 'workstation' views and seen in Figure 11. Daylight source and overview images are taken from a standard viewing location in relation to the office, which is consistent throughout the sample. Workstation images are specific to the arrangement of the particular office. Luminance maps and glare analysis of HDR images of actual and typical occupant viewsheds are created using best practices protocols (Van Den Wymelenberg and Inanici 2014), compiled using Photosphere (Ward 2014), and analysed using HDRscope (Kumaragurubara 2012). Illuminance glare events, marked by an indoor illuminance ratio in excess of 10:1 compared to work plane illuminance

(Reinhart, Mardaljevic, and Rogers 2006), are derived from field illuminance measurements under various sky conditions and times of day in a representative sample of offices.

Expectation of useful illuminance from daylight is described in terms of indoor illuminance distribution and typical exterior shade state. Illuminance levels are measured the work plane as well as at three other locations throughout the depth of the office and corridor to illustrate the effective depth of useful daylight (see Figure 12). Outdoor illuminance measurements taken at the ground level and the top floor of the building provide useful context for lighting adaptation levels and site-level obstructions. Photographs of the exterior of the building supplement direct observations taken during walkthroughs to document exterior shade state. This data is collected in a representative set of offices throughout the study period under a range of sky conditions (sunny, overcast, mixed) and times of day (morning, mid-day, afternoon). Field assessments were also taken under a range of exterior shade and electric lighting states in order to characterize the impact of different occupant behaviours on the indoor luminous environment and visual comfort.

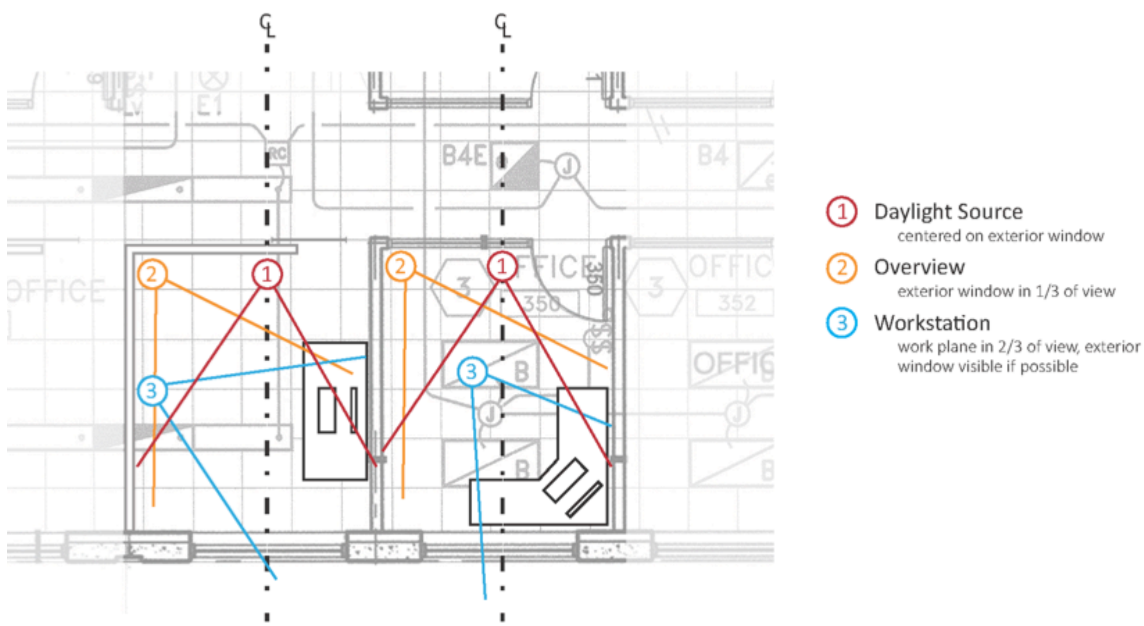


Figure 11: Typical view shed locations for High Dynamic Range Images.

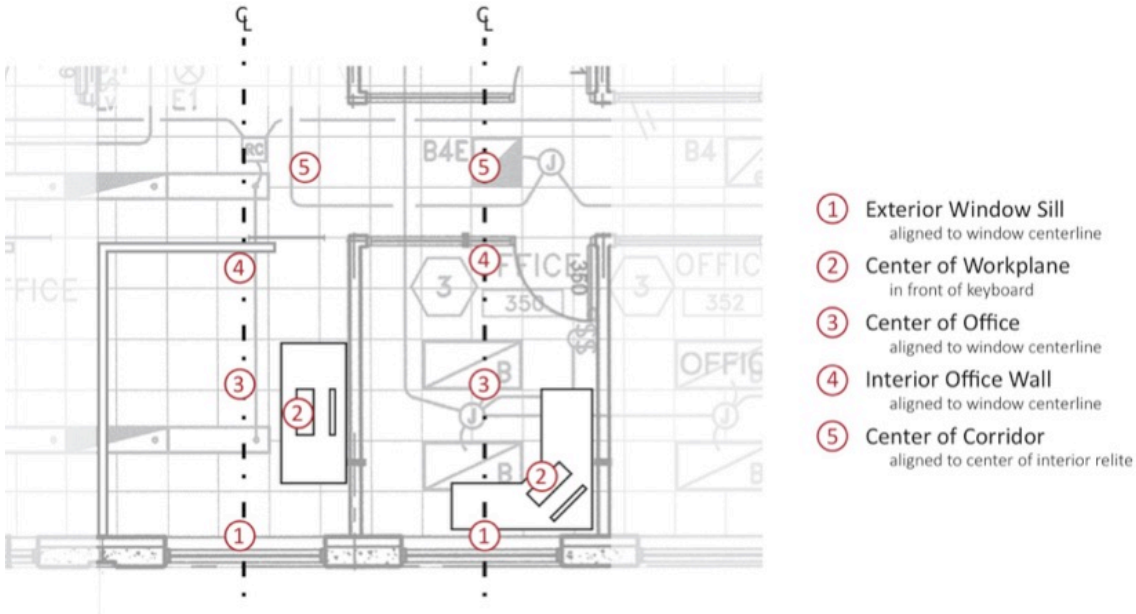


Figure 12: Horizontal illuminance measurement locations in typical open office cubicle and enclosed office.

III.B.ii. Spatial and Lighting Behavior Observations

Observation techniques provide quantitative and qualitative data on occupant behaviors throughout the study period. Past studies of occupant controls use focus on one to two overt behavioral outcomes, such as shade or lighting state, and often rely on continuous monitoring protocols to capture fine-grain details regarding those outcomes. As a result, behavioral outcomes are viewed as affected only by certain factors and not affecting other aspects of the office environment. To overcome this, quantitative environmental data is supplemented by direct observation of occupants' behaviors, physical traces, and environmental modifications. In a study of blind use behaviors under different automated lighting control schemes, weekly observational walkthroughs supplemented quantitative data to document occupant lighting use behaviors that could not be captured easily through remote monitoring protocols such as task lighting state and exterior shade state (Pigg, Eilers, and Reed 1996). In response to the concept of the adaptive zone for discomfort glare, spatial use patterns and workspace characteristics that support or inhibit the freedom of movement within an office are recorded during walkthrough observations. Observations are transcribed on behavior maps and coded into a quantitative dataset in order to identify overall patterns of lighting use, patterns of interaction between occupants and their environment, and establish a range of adaptive behavioral responses. Direct observations help capture a larger range of adaptive behaviors than is feasible with alternate methods and may uncover inconsistencies between the quantitative environmental data and survey responses. Observations of the following attributes are recorded two to three times weekly throughout the study period during unannounced observational sweeps or walkthroughs:

- Exterior shade state
- Interior shade state
- Electric lighting state
- Occupancy state
- Workspace arrangement (standing or sitting position)
- Occupant orientation
- Task
- Behavioural traces - office cleanliness, presence of plants, type and location of furniture, and semi-permanent lighting or shading modifications.

Observational data describes the spatial and lighting use patterns of occupants under normal working conditions. Observational sweeps are limited due however to their temporal nature as well as the size of the building – it is impossible to observe behaviors in more than one discrete part of the building at a time as a solitary researcher. As a result, the behavioral data will require some interpretation and this data may not show every adaptive behavior. A wide array of behaviors is captured in the data, but high-order behaviors that significantly affect the luminous environment are focused on throughout the study. Frequency of adaptive behaviors, both the time it takes to initiate and reverse an adaptive behaviour, is an important aspect of occupant behaviour studies that is underrepresented in the existing literature. In order to increase the likelihood that the frequency of high-order occupant behaviors such as exterior shade state are captured in the data, exterior photographs of the building are taken at the beginning and end of each observation period.

III.B.iii. Respondents Questionnaire

The questionnaire assesses participants along multiple parameters of discomfort glare perception and response in order to determine occupants' overall *tolerance* or *sensitivity* to discomfort glare. The questionnaire includes multiple item measures to measure glare sensitivity or tolerance, including reported environmental lighting conditions and adaptive behavioral responses to discomfort glare. Specific methods for analyzing questionnaire responses as well as parameter definitions can be found in section III.D.ii. below. The questionnaire collects contextual data on numerous factors that are not easily collected through observational means and are expected to influence behavioral responses. These factors are grouped into the following categories:

1. Environmental appraisal and preferences – these factors provide a baseline of occupants' perceptions and experience of their workspace environment in relation to an existing, abstract conception about workspaces in general. Survey items include:

    a. Semantic differential ratings – respondents are asked to assess the lighting environment using word-pairs that describe either a qualitative description of the environment, such as ‘bright – dim’ or a subjective assessment of environmental outcomes, such as ‘relaxed – tense’.

   b. Environmental attributes and amenities preference ranking – respondents are asked to rank order a series of environmental attributes, corresponding to the items for which satisfaction is assessed, in order of what they consider most important to their workspace environment.

   c. Environmental values and awareness – respondents are asked to indicate whether they agree or disagree with general statements about workspace environments as well as perspectives on energy consumption / conservation in the workspace.

2. Reported environmental conditions and occupant discomfort – these factors describe occupants’ assessment of the lighting and spatial qualities of their workspace and identifies attributes that may affect the occupants’ comfort, productivity, or satisfaction. Survey items include:

   a. Satisfaction with environmental conditions – respondents are asked to indicate their level of satisfaction along a 5-point scale from ‘very satisfied’ to ‘very dissatisfied’ of general environmental attributes such as ‘control over daylight’ and outcomes such as ‘glare from daylight’.

   b. Perceived level of control – respondents are asked to indicated the level of control they have over a series of environmental variables, ranging from 1 (no control) to 5 (high level of control).

   c. Environmental outcomes and desires assessment – respondents are asked to indicate whether they agree or disagree with a series of statements about the lighting qualities of their workspace, such as ‘glare from daylight is a frequent issue’, and environmental controls, such as ‘I would like more control over daylight’.

   d. Lighting conditions reporting – respondents are asked to indicate how frequently certain environmental lighting conditions, such as ‘direct sun on work surface’ and outcomes, such as ‘discomfort due to glare’, occur in their workspace.

3. Reported behavioral responses – this item describes the adaptive responses that occupants utilize when discomfort or dissatisfactory lighting conditions occur as well as the frequency with which different strategies are used.

Additional personal and organizational information is collected regarding work-related tasks, types of work and personal items in the respondent's workspace, amount of workday spent in their workspace, length of time at their current workspace, respondent age, educational attainment, and prescription lens use. The questionnaire is distributed to the entire population of the office under consideration (est. population size 150-180 occupants) in order to collect as many responses as possible. Participants complete a web-based version of the survey after the observation period. Participants are required to affirm their informed consent to participate in the study before they can access the questionnaire. The final online questionnaire distributed to the study population can be found in the aggregate results included in Appendix G.

III.C. Research Setting

III.C.i. Selection Criteria

The conceptual model and approach outlined above assume personal, social, and environmental contextual factors affect the expression of adaptive behavioral responses. Differences between individual occupants are expected to affect resulting glare responses and behaviors. In turn, this research is situated in a real working environment with various personal, interpersonal, and social characteristics that complicate the relationship between environmental stimuli, perception, and behavioral response. The setting for this study is a commercial office building that meets a minimum baseline of daylight performance in addition to spatial criteria. Situating the study in a single organization's offices minimizes organizational influences on occupant behaviors, stemming from intra-office power dynamics, schedule or work task requirements. The four criteria listed below are original guidelines informing site selection for studies of adaptive daylighting behaviors. If all four criteria are met, the selected office site is considered a daylit office where a significant portion of electric lighting use is either optional (personal choice) or in response to some extenuating environmental condition such as glare.

1. *Continuous Daylight Autonomy* - daylight illumination levels meet a minimum work plane illumination for typical office tasks, as observed in field studies to be between 150-300 lux, or could be maintained with the use of a small task light throughout the majority of the typical workday (Lindelöf and Morel 2006; Reinhart and Voss 2003). For these purposes 150 lux measured or simulated or a minimum design calculated 2% daylight factor at the work plane is considered suitable. The purpose of this requirement is to establish a shared baseline of electric lighting demand based on the ability of the spaces to use a commensurate amount of daylight.

2. *Manual Occupant Controls* - each individual office will use occupant-accessible lighting and daylighting controls and no daylight-integrated or photosensor-controlled automated systems. This requirement is meant to establish similar expectations of agency/self-efficacy among the occupants of each office to control their personal environments.

3. *Perimeter Offices/Cubicles* – there must be multiple perimeter offices/cubicles, each with autonomous occupant control over the lighting and daylighting systems. This requirement is meant to reduce the presence of interpersonal dynamics or social concerns associated with lighting controls that affect multiple occupants such as would be the case in open-plan or shared office spaces.

4. *Orientation* - offices must face multiple orientations, so as to compare offices with high possibility of dynamic daylighting conditions throughout the day (west, east, and south) with offices with low possibility of glare (north) (Mahdavi et al. 2008).

Time, access, and resource constraints necessitate a local study site. Choosing a study setting solely because it is located nearby can result in a poor fit between setting and objectives. In this case, the use of pre-determined selection criteria enhances the selection process and increases the likelihood that the study requirements will be met by a local setting. Further, no aspect of this study disqualifies local settings from participating. Future studies of these topics however, may benefit from a multi-site investigation in order to identify outliers among study sites and research populations.

An important side-note to the research described herein has to do with the relative hesitation among many building managers, developers, and architects to participate in research of this nature. The presence of a researcher inside an operational commercial space is generally regarded as an inconvenience for tenants. The prerogatives of a building manager, developer, or architect do not necessitate their active cooperation with or participation in outside research studies. It is prudent to emphasize then, the importance of building relationships with key agents in order to narrow the search for research settings. If not for the pivotal input of a few building and real estate professionals, this research may not have progressed in a manner appropriate to a thesis study.

III.C.ii. Research Site

A regional search of commercial buildings in the central Willamette Valley identified an 80,000 ft^2 commercial office building in Eugene, Oregon. The building was built in 2012 and has been fully occupied for two years. The building is located in a suburban office park setting with nearby green space and waterways to the north and south. Three different tenants occupy the building. To control organizational influences on occupants' behaviors, only those spaces occupied by the primary tenant are included in the study. As a result, this study setting encompasses approximately 30,000 square feet of leasable commercial space on the 3rd and 4th floors of the building including 110 individual offices for approximately 130 employees. The building satisfactorily meets the selection criteria listed above in the following:

1. *Continuous daylight autonomy* – design calculations estimate an average indoor daylight factor of at least 2% in all primary office zones.

a. For a typical structural bay: 0.2 x (window area - 120 square feet / floor area – 900 square feet) = 2.67% DF avg. (Robbins 1985)

b. The average daylight factor calculation does not include the impact of interior partitions, furniture, or maintenance. The equation above does not factor daylighting depth. When applied to the direct perimeter zone (within 15 feet of the daylight source), average daylight factor rises to 4.7%. This suggests that those spaces more than 15 feet from the daylight source do not meet the 2% minimum daylight factor requirement. For this reason, workspaces located more than 15 feet from the daylight source are included in the baseline (low) daylight expectation group.

2. *Manual Occupant Controls* – each office and occupant has access to at least one of the following daylight (n=100) or electric lighting controls (n=110) – horizontal venetian blinds on the exterior window (n=65), horizontal venetian blinds on the interior window (n=68), interior translucent partition door (n=35), zoned overhead lighting control (n=67), and stepped/dimmable overhead lighting (n=45). All offices have a supplemental task light and many occupants have multiple task, table, and/or floor lamps in their office. There are no existing covenants or agreements regulating the use of lighting or shades within the office.

   a. While all occupants have access at least one of the manual occupant controls listed above, not all are equally accessible. Most offices have lighting controls within the office (n=71). Some offices in open plan areas have lighting controls either outside the door (n=3) or a short distance down the hall (n=38). Lighting controls are inaccessible in only one office due to boxes that are stacked on a low file cabinet and this office is not regularly occupied. Shade controls are inaccessible in multiple offices due to cubicle partition layout (n=) or occupant influences such as clutter or furniture placement (n=).

   b. The building was designed to utilize photo sensor controlled automated dimming for overhead lighting in open office areas but this system was deactivated shortly after initial occupancy due to performance deficiencies and occupant dissatisfaction.

3. *Perimeter Offices/Cubicles* – the building is laid out in two concentric rings of offices along a double loaded corridor that traverses along the perimeter. As a result, three distinct office types are present: perimeter enclosed office (n=29), perimeter open office (n=35), and interior enclosed office (n=39). A small number of interior open offices (n=7) are present in the building but do not represent a sufficient sample size to include in the study.

   a. The layout of the building creates a primary daylight zone at the perimeter and a secondary daylight zone along the interior that relies on uninterrupted daylight transmission through the perimeter space. This implies that the lighting and shade use behaviours of perimeter office occupants have a direct effect on the lighting environments of the interior offices as well as their own.

4. *Orientation* – the floor plan of the building is a rectangle with the long ends facing north and south. The majority of the offices in this study face south (n=68) and north (n=33) while a small number of offices face east (n=4) and west (n=5). Due to the current division of space within the building, the primary tenant occupies the whole fourth floor (n=60) and part of the third floor (n=50).

As a result of the characteristics listed above, the building was deemed suitable for the study methodology.

III.C.ii.a. Research Population Characteristics

Office occupants regularly perform typical professional-level office tasks. Occupants' daily work relies heavily on computers for a number of tasks including proposal writing, data entry, coding, report writing, and accounting. Occupants are required to on occasion meet with clients in designated areas of the building away from their offices. Organizational structure is decentralized, with numerous small working groups scattered throughout the floor plan. Individuals may be involved with multiple different working groups simultaneously. Some staffing assignments are filled on an as-needed basis so certain offices remain available (or empty) to accommodate additional staffing needs should they arise. Some upper level staff members, such as work-group supervisors, are required to travel periodically and so it is not uncommon for offices to be unoccupied for multiple days or weeks at a time. As a result of this organizational structure, many occupants regularly conduct a portion of their work outside of their primary workspace.

To some degree, occupant workspace preferences influence the current workspace assignments. Many occupants, particularly those who have worked for the organization for a long period of time or who hold permanent or senior positions, had the opportunity to choose their office. Decentralized working groups have some flexibility to assign offices and workspaces between occupants. There is also a process by which individuals can request to move to different offices. In turn, many occupants have used more than one workspace. In consideration of this aspect of the organization as well as the fact that the building has only been occupied for two years, occupants are not expect to display long-term attenuation effects to a particular office.

III.C.ii.b. Research Site Characteristics

Site Conditions

The setting for this research is an 80,000 square foot commercial building in Eugene, Oregon. The building is located on a previously undeveloped parcel between two existing, smaller commercial buildings (seen in Figure 13 below). The site is suburban in character and scale but offers close access to high-quality pedestrian amenities as well as nearby major waterways and recreational areas. Views from the building generally include varying degrees of buildings, surface parking, green open space, and forested areas.

Views from the third floor feature significantly more green open space and forested areas than the lower floors. Views from the fourth floor include sweeping vistas of the surrounding region above the nearby tree line. There is a three story building located to the west of the research site that significantly impacts solar access and views of the sky dome to the first and second floor. A grouping of large oak trees along the bike path to the south of the building also impacts solar access and views of the sky dome to a portion of spaces on the first and second floor. A small number of third floor windows are shaded by the oak trees at some point throughout the day near the winter solstice. No significant site obstructions limit solar access or views of the sky dome to the fourth floors.

Figure 13: Aerial view of the research site while under construction, source: Google Maps, 2014.

Building Layout

Some of the organization's primary business activities take place in spaces on the first and second floors, but these spaces are not occupied regularly. No spaces on the first or second floor are included in this study. The second building tenant occupies the west half of the first floor while the third tenant occupies a portion of the second and third floors. Due to current privacy and security needs of the second tenant, the primary tenant splits their offices between the third and fourth floors. By including only third and fourth floor offices in the study population it is unlikely that any exterior shade use behaviors would be motivated by visual privacy concerns such as could be expected in first or even second floor offices, especially given the near proximity of south facing offices to a highly trafficked, public bike path. Floor plans of the third and fourth floor are seen in Figure 14. The area occupied by the third tenant, and not included in this study, is shown in gray. As can be seen in Figure 14, the building design arranges offices in the 30 foot deep perimeter zone and locates support and service spaces, including vertical circulation, copy rooms, kitchens, and conference rooms, at the building core. There are some support spaces in the perimeter office zone on both the third and fourth floors. A resource library, with an office for the staff librarian, is located at the northeast corner of the third floor. A large conference room with an adjacent kitchenette is located in the middle of the north side of the fourth floor. A small conference room is located at the northwest corner of the fourth floor. Lastly, a large employee lounge with full kitchen and exterior terrace is located at the northeast corner of the fourth floor. Egress stairs are located in the middle of the east and west edges of the building, effectively blocking direct access to daylight or views for the interior offices oriented to the east and west. As a result, these offices are designated as private, flex use offices that any employee can use for a private phone call or other work related task that can't be completed at their regular workspace.

Office Layout

Floor plans of the typical enclosed office and open office cubicles can be seen in Figure 15. Enclosed offices are grouped in at least pairs in between open office areas that include anywhere from 3 to 5 cubicles arranged along the corridor. Interior offices are typically enclosed, similar to the perimeter enclosed offices. Typical offices measure approximately 10' wide by 12' deep, or 120 square feet, and 10' tall. There are slight variations in floor area between different offices, but these do not significantly affect the overall lighting qualities or control schemes. Some enclosed offices are slightly wider, measuring 12-14' wide instead of 10'. This change is not apparent in the design documents and must have occurred during construction. In order to accommodate the wider offices, some of the open office cubicles are made narrower than the 10' typical width, usually measuring from 8' to 9' wide. The wider offices typically include an additional seating area for 2-3 people or are shared between 2 people. The reduced width in open office cubicles most likely affects workspace layout in regard to furniture type, size, and location as well as overall storage area.

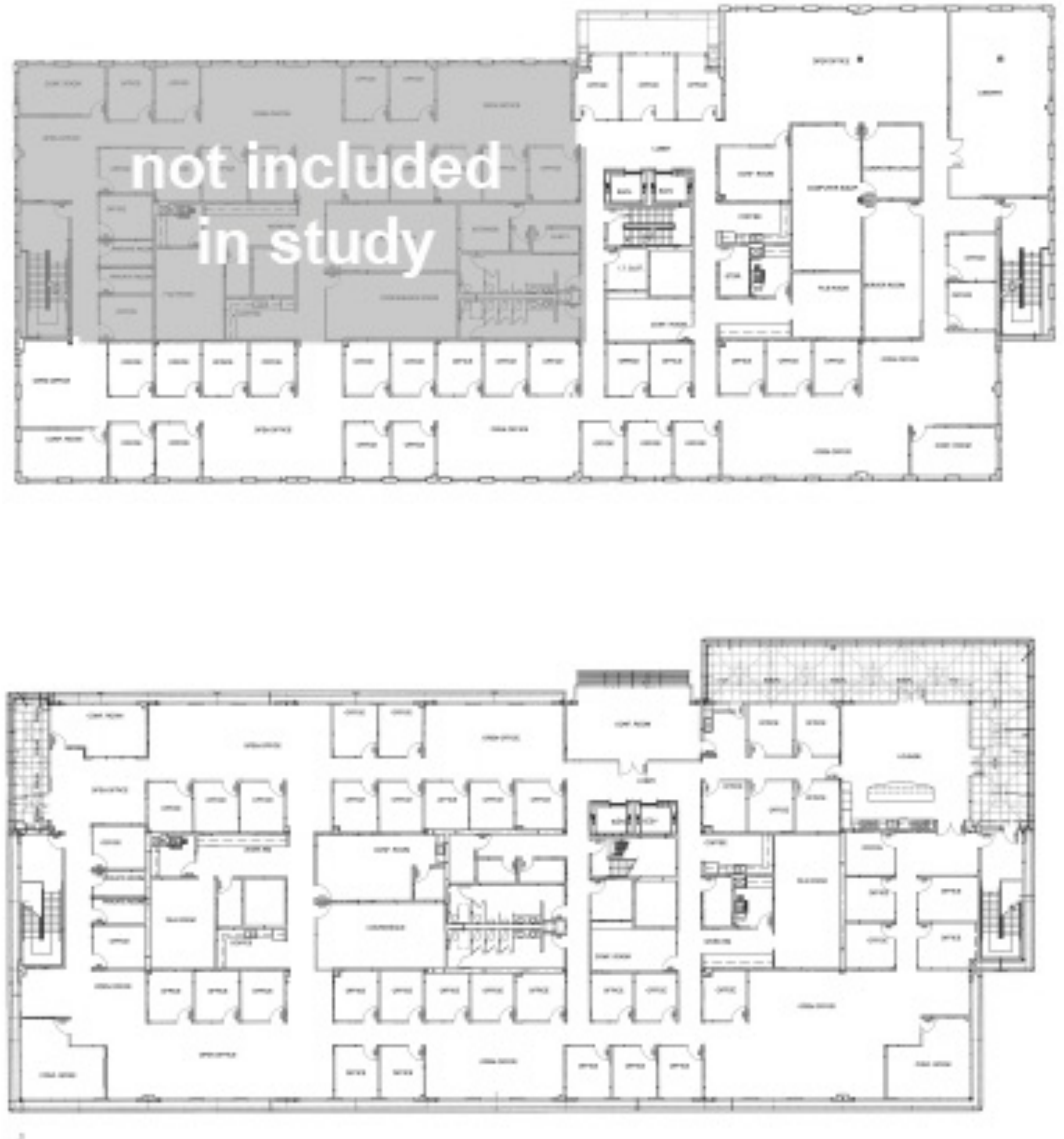


Figure 14: Study regions shown in building floor plans, 3rd floor (above) and 4th floor (below).

Exterior Window Design

Most offices have direct access to only one window from their workspace. Fenestration design for all third floor windows (shown in Figure 16) is identical to those on the first and second floor, regardless of orientation. All exterior windows use the same horizontal venetian blinds located at the interior edge of the window opening (n=65). Horizontal venetian blinds are housed at the window head and deploy continuously to the window sill. Fenestration design for fourth floor windows closely resembles that of the lower floors in terms of overall window opening area and geometric properties of the window opening but differs in three ways from the others (see Figure 17). First, there is no exterior horizontal shading because of the significant roof overhang above. Second, the windows are not divided into smaller lites within a window opening, resulting in a slightly larger glazing area on fourth floor windows. Third, the windows are not located in punched openings, rather they alternate between vision glass and opaque glass within the structural bay to achieve the look of continuous glass while preserving the same pattern of solid (opaque) wall and transparent (open) windows as the lower floors.

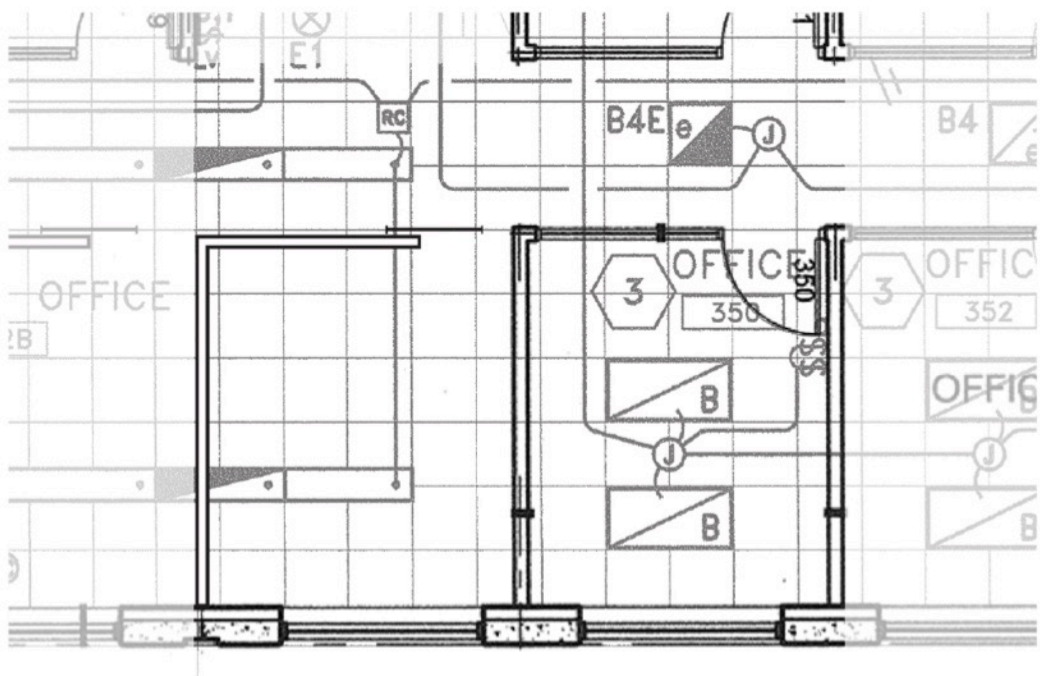


Figure 15: Typical floor plans for enclosed offices and open office cubicles.

The exterior wall appears much thinner overall as a result of these changes in the articulation of the window between the fourth and lower floors. Perhaps more importantly though, there are no horizontal divisions in vertical surface planes at the window in fourth floor offices. The effectiveness of the exterior shading strategies on both the third and fourth floors is minimal during the study period due to the low seasonal sun angle. The comparison shown in Figure 18 estimates there is a 15% shading coefficient difference between the third and fourth floors during the third week of October, the approximate mid-point of the data collection period. Any differences in shading effects between floors will also decrease toward the end of the study as the sun angle continues to decrease approaching the winter solstice. The window design may therefore only marginally affect daylight and glare conditions within third floor offices. The exterior shade is expected to slightly reduce luminance intensity in third floor offices but have no significant effects on illumination levels when compared to the fourth floor as the sky exposure angle is reduced due to the roof overhang above fourth floor office windows. Differences in exterior shade use behavior between floors may thus be seen at least partially as an effect of the difference between the minimally-shaded, articulated fenestration design of the third floor and the un-shaded, planar fenestration design of the fourth floor.

Figure 16: Typical fenestration design for windows on the first, second, and third floors showing divided lites and exterior horizontal shading surface.

Figure 17: Typical fenestration design for windows on the fourth floor showing alternating pattern of clear and opaque lites within the structural bay and roof overhang above.

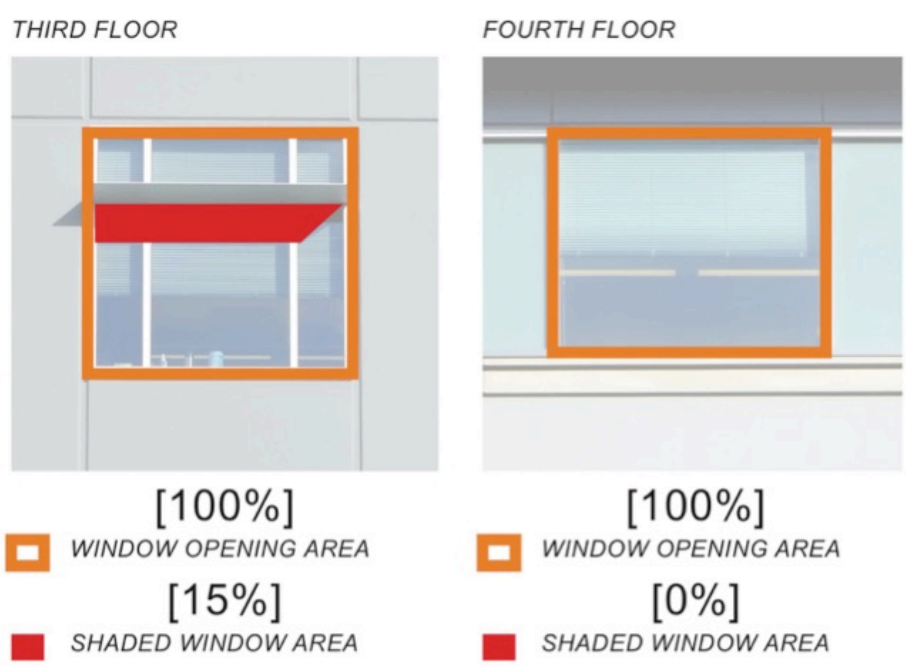


Figure 18: Seasonal exterior shading factors of third floor (left) and fourth floor (right) fenestration design, shown on October 20, 2014 (not to scale).

Interior Window / Partition Design

Enclosed offices have interior windows facing the corridor that run the full width of the office, less the door opening, and continue from the floor to the door head height (8'-0"). Interior windows use the same type of horizontal venetian blind as the exterior windows for a visual privacy filter (n=68). Offices with full width interior windows, such as is shown in the right-hand side of Figure 15 above, have solid doors with no glazing. The interior windows in these offices are the sole source of daylight transmission to the corridor and interior offices beyond. The amount of daylight that reaches interior offices located adjacent to enclosed perimeter offices are thus entirely dependent on how the occupants of the enclosed perimeter offices use their interior blinds. In those offices without interior windows (n=35), such as cubicles in the open office areas, there are sliding translucent doors that accommodate occupants' visual privacy as well as security needs. While daylight transmission through the translucent door is less than 40%, the cubicle partition height is only 6'-6" above the finish floor and there is 3'-6" clear open height above the top of the partition (see Figure 19 below). As a result, the amount of daylight that reaches the corridor and interior offices located adjacent to perimeter open office cubicles is only partially dependent on how the occupants of the cubicles use their sliding doors.

Figure 19: Open office cubicle partition layout with translucent sliding doors.

Electric Lighting Layout & Controls

There are three different electric lighting configurations found in the research setting that varies according to office type. Figure 20 shows a typical electric lighting layout for enclosed and open office areas. Each lighting configuration allows the occupant to choose between at least two distinct lighting levels in either a zoned or stepped/dimmed configuration. The type of lighting control interface also varies according to lighting configuration. All occupants are supplied with 1-2 small desk lamps and are also free to bring in their own additional task or room lighting such as table or floor lamps. Each enclosed office has two recessed 2x4 fluorescent troffers that are switched independently. The standard configuration for enclosed offices includes an occupancy/motion sensor to switch on the interior luminaire when the occupant enters the office. The occupancy sensor is set to switch-off after 15 minutes if no motion has been detected or if another lighting scene is in use. The controls interface is a two-button zone control with the occupancy sensor above the buttons. Recessed 2x2 fluorescent corridor lighting outside the enclosed offices is controlled separately from the offices. Corridor luminaires are grouped in at least pairs and can only be switched on or off.

Open office areas are lit by linear fluorescent direct/indirect luminaires hung approximately 2' from the ceiling. Each 4' linear section uses two lamps and can be set to 50% or 100% power levels in a basic far/near zone control. Linear luminaires are distributed evenly along the length of the open office area so there are two 4' or one 8' section above each cubicle. The luminaires are arranged in two lines, one close to the perimeter above the cubicles and the second at the corridor. The corridor luminaire is offset from center slightly so it is closer to the cubicle partition than the adjacent interior offices. Both rows of linear luminaires (over the cubicle and over the corridor) are controlled together. The controls interface for the open office areas uses two push buttons with small indicator lights to show what scene/setting is currently in use. One set of controls is located at the end of each open office area. In most cases, the controls are directly accessible from the corridor while in some instances the controls are located inside of a cubicle.

Re-configured offices are lit by six recessed 2x2 fluorescent troffers, similar to those in the corridor outside enclosed offices. Each of the re-configured offices has 6 luminaires evenly distributed along the length and depth of the office in a 3 by 2 grid. Lighting can be controlled in groups in order to achieve two distinct lighting scenes – 50% on and 100% on. The 50% power setting is achieved by switching on 3 of the 6 luminaires in an alternating, zigzag pattern. Both lighting scenes create uniform lighting distribution. The controls interface is a standard double-ganged manual rocker switch located near the office door.

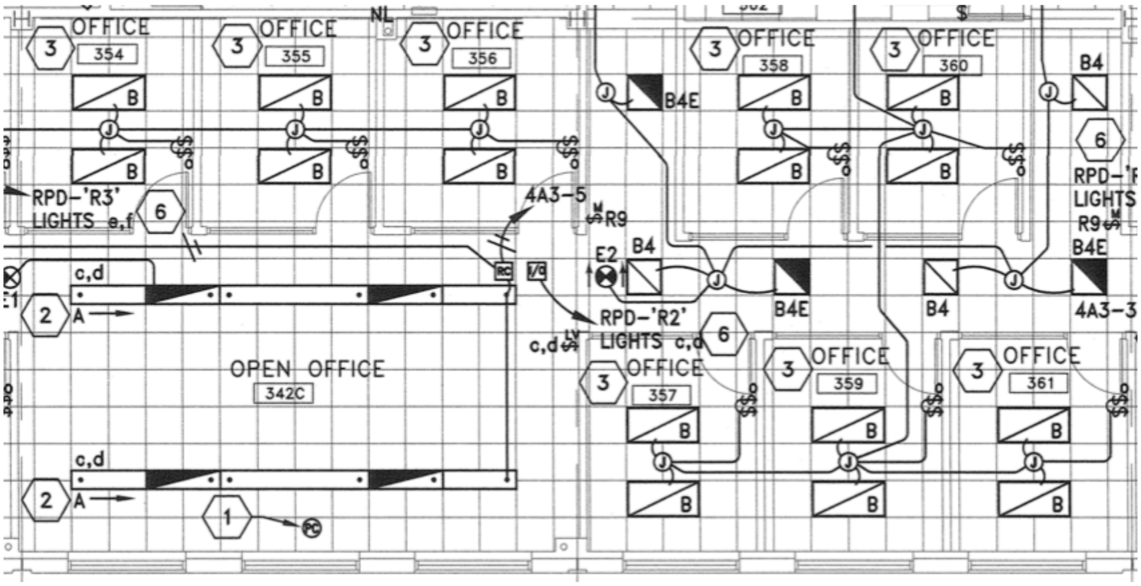


Figure 20: Lighting plan for third and fourth floor offices (typical).

III.D. <u>Data Analysis Methods</u>

In order to ultimately assess the influence of spatial factors on adaptive behavioral responses to discomfort glare, behavioral and field assessment data is first transcribed and coded into data tables. General statistics are derived from the data to characterize mean values, distribution and variation of observed lighting conditions and behaviors. Parameters group offices/occupants results along key lighting and behavioral variables, described below, into quartile-rankings. Spatial parameters group data according to spatial attributes of the office or occupant use patterns. Independence and correlation tests are then conducted on initial lighting data and spatial parameters in order to determine whether the variations observed in the behavioral data are independent of the spatial and lighting variables targeted in each parameter. For the sake of this analysis, the null hypothesis in each test included herein is as follows – *Parameter Variable and Outcome Metric are independent*. R-values are derived for bivariate measures, such as total window occlusion and mean luminance, using Pearson's correlation coefficient to determine significant linear relationships between variables. In addition, rho values are derived for bivariate measures using Spearman's test (or Pearson's correlation coefficient for ranked variables) in order to identify non-linear significant relationships between variables. The descriptive statistics outlined above are calculated as part of the parametric analysis for the behavioral data as well as the glare response profile. Parameters that fail to reject the null hypothesis for both the behavioral and survey data are not included in the final parametric analysis of the discomfort glare response profiles.

III.D.i. Parameter Definitions

Spatial, lighting, and behavioral parameters are defined based on composite results of field assessment and observation-based data collected over a six-week period. The following section outlines the techniques used to derive each parameter.

III.D.i.a. Spatial Parameters

Offices are grouped into spatial parameters based on a number of characteristics. These characteristics can be classified according to whether they are attributes of the building design, the office design, or the specific workspace layout.

1) Building design parameters

   a) Floor level

      i) Occupants/offices are grouped according to floor level (1, 2, 3, 4). This parameter compares observations between walkthrough data for the third and fourth floors as well as exterior photograph data between all floors of the building.

   b) Orientation

      i) Occupants/offices are grouped according to cardinal orientation (0, 90, 180, 270). This cluster compares walkthrough observation data and exterior photograph data between all building orientations for office spaces. East and west orientations are not reported on specifically throughout. For the purposes of the parametric analysis, east and west facing offices are included with south facing offices.

2) Office design parameters

   a) Office type

      i) Occupant/offices are grouped according to office type (Enclosed Office, Open Office Cubicle). Sub-groupings are created based on specific occupancy or spatial characteristics of the office (Shared enclosed office, shared open office cubicle, edge cubicle, middle cubicle).

   b) Degree of lighting environment control

      i) Offices are grouped according to the type of shading control (exterior only, exterior & full width interior, exterior & narrow width interior, interior only, translucent sliding partition door) and location of lighting controls (inside office, in corridor outside office, in another office/cubicle). Rank-order is determined by the sum of the following value weighting according to type of shading and lighting controls.

(1) Shading control: Exterior & full width interior – 4; Exterior & narrow width interior OR exterior only – 3; interior only – 1; translucent sliding partition door only - 0

(2) Lighting control: Inside office – 3; Immediately outside door – 2; In corridor outside office – 1; in another office/cubicle – 0

3) Workspace layout parameters

a) Workstation Location

i) Occupants are grouped according to the location of their primary workspace within the office. Primary workspace is defined as the workstation on which their computer is located due to the high amount of computer-based tasks that building occupants regularly perform. Workstation location is quantified as a function of distance from the exterior wall / daylight source distance from centerline of the exterior window/daylight source using the method seen in Figure 21. Based on this method, each occupant is assigned a value ranging from 1 – 4.

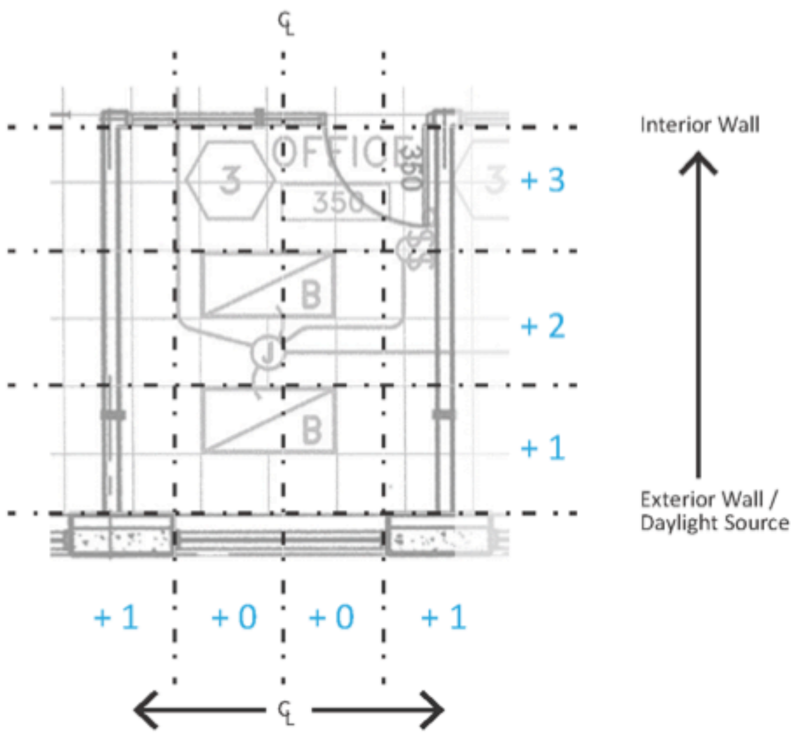


Figure 21: Method to quantify workspace location based on distance from exterior wall and centerline of exterior window or daylight source.

b) Primary workstation orientation

i) Primary workstation orientation is a single metric indicating the occupants' view orientation from their primary workstation in relationship to the daylight source (degrees from source). Values range from -180 to +180 where positive degree values indicate clockwise rotation from the daylight source and 0 degrees indicates the occupant is facing towards the daylight source (Figure 22). In the case that more than one work area is present, the workstation at which the occupants' computer is located is the primary workstation.

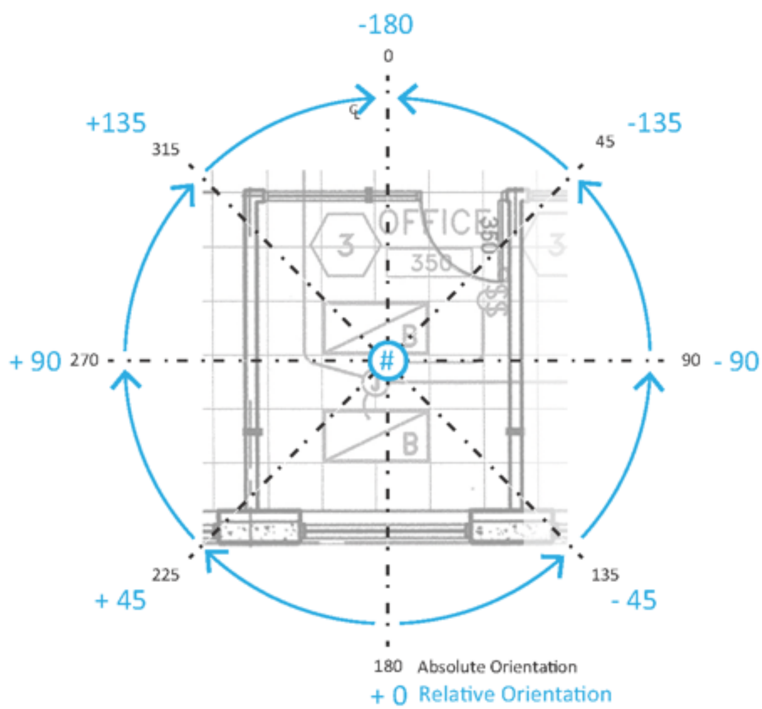


Figure 22: Diagram showing relationship between office orientation, absolute view orientation and relative view orientation.

III.D.i.b. Lighting Parameters

Glare Potential

For the purposes of this study, glare potential is considered the composite result of annual solar exposure on the workspace, interior luminance distribution patterns, and illuminance glare events. Offices are grouped in quartile rankings for each of these factors.

Annual solar exposure is measured in a sample of offices based on the orientation and desk location in reference to the window. Solar exposure is calculated over the full calendar year (annual solar exposure) as well as solar exposure during the study period (current seasonal solar exposure – September, October, and November) in order to identify current lighting environment behavior as well as long-term expectations about lighting environment behavior. Results from the sampled offices are applied to the remaining offices if they have similar orientation and desk location. Data is recorded using the Solmetric Suneye camera, which uses a fisheye lens to obtain a nearly 180-degree field of view in the image. Solar exposure is calculated automatically within the Solmetric device from a sun path chart overlay on the base fisheye image. In this study, the Solmetric Suneye is placed in the middle of the primary work plane and oriented due south. The Solmetric device and software is usually used to identify site obstructions in renewable energy applications and uses contrast within the fisheye image to determine where obstructions occur. The default contrast sensitivity is lowered however, in order to not count clouds as obstructions. As a result, the boundary area of the window opening is not well defined as an obstruction and initial solar exposure calculations are not reliable. Fisheye images are manually masked to highlight the window opening area. Solar exposure calculations are meant to characterize the impact of building geometry, office location, work plane orientation, and distance from daylight source on solar exposure at the work plane. Accordingly, images are masked around the window opening area rather than the occupants' actual obstructions. Figure 23 shows the typical solar exposure image generated automatically within the device software (left) and solar exposure image after masking the interior surfaces and exterior shading surfaces (right).

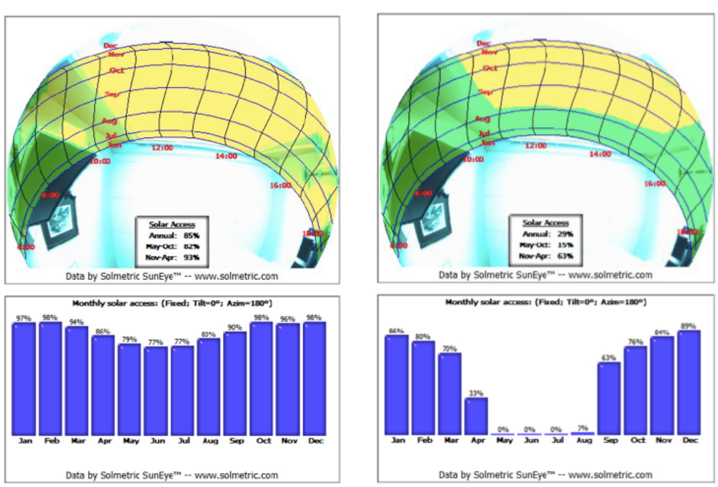


Figure 23: Raw solar exposure results (left) and edited solar exposure results with window opening masked (right). Areas shown in green represent obstructions and areas shown in yellow are included in the solar exposure calculation.

Luminance distribution patterns are quantified from HDR images and analyzed using HDRscope software (Kumaragurubara 2012). Typical results of HDR analysis are seen in Figure 24. HDRscope calculates general statistics as well as detailed analysis including Daylight Glare Probability (DGP), Daylight Glare Index (DGI), and Visual Comfort Probability (VCP). A recent study shows that mean luminance, standard deviation of luminance within a scene, and vertical illuminance at the view location are better indicators of just uncomfortable levels of glare than complex calculations like DGP, DGI or VCP (Van Den Wymelenberg and Inanici 2014). Each office/occupant is thus rank-ordered based on the measured average mean and standard deviation of luminance values within their office, as these values are easy to obtain from field data. Rankings for offices without unique HDRI / luminance data are allocated based on spatial similarities between sampled offices. Spatial attributes that indicate similar indoor luminance distribution are office orientation, occupant orientation, and desk location.

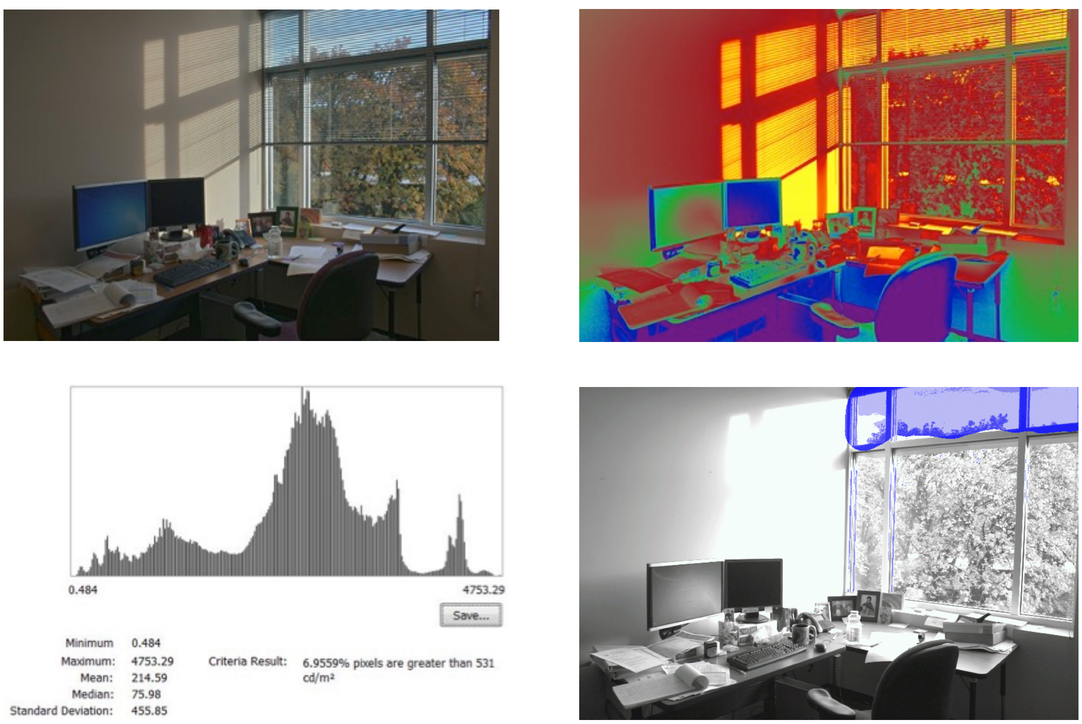


Figure 24: Example of tone-mapped HDR image (top left), false color luminance map (top right), as well as HDRI Analysis results from HDRscope including general statistics (bottom left) and Evalglare glare analysis (bottom right).

Useful Daylight Expectation

For the purposes of this study, useful daylight expectation is the result of indoor illuminance distribution. For interior offices, typical shade state of the adjacent perimeter office is a primary determinant of daylight access. Thus, for the purposes of this study interior offices are treated separately from perimeter offices in terms of daylight expectations. In a best-case scenario, interior offices may be able to support regular work activities with additional illumination provided by a task light. In a worst case scenario, interior offices may be required to significantly increase electric lighting usage in order to support regular work activities.

III.D.i.c. Behavioral Parameters

Behavioral parameters essentially group offices/occupants according to whether they exhibit *passive* or *active* behavioral outcomes. The outcomes encompass exterior shade use, interior shade use, electric lighting use and spatial movement. Shade use includes measures of window occlusion, duration and frequency. Lighting use includes measures of intensity, duration, frequency and type (overhead or task). Spatial movement measures indicate the degree to which an occupant uses multiple locations within their workspace. Offices/occupants clusters are created for each behavioral expression (lighting, shades, and movement) separately. The results of individual behavioral parameter analysis are averaged to create a final composite behavioral parameter. In the case of the final composite behavioral parameter, results from the initial behavioral parameter analysis with strong behavioral tendencies in one category may negate weak expressions in another. Behavioral data recorded during observational walkthroughs are grouped according to whether the office is occupied at the time of observation. Offices that are not occupied throughout the duration of the study period are excluded from this portion of the analysis.

Shade Use Profiles

Total window occlusion rates are quantified and compared using a method present in previous occupant behavior studies that combines two measures of occlusion, from shade deployment and tilt, into one normalized window occlusion value ranging from 0-100 (Foster and Oreszczyn 2001). Original shade deployment values (seen in Figure 25) are scaled according to shade tilt angle in the following way:

- Total Window Occlusion [0-100] = [Shade Deployment [0-100] * Shade Tilt [1-3]]/3
    - Ex: Total window occlusion for a window with shade deployed 75% and tilted up (tilt state #2) = 50%

This method results in a single value representing both shade deployment and tilt angle. The same method is used to quantify total interior shade occlusion. Window occlusion values are calculated for each observation and exterior photo record. Each office is then described according to average window occlusion, standard deviation of window occlusion states, maximum window occlusion, minimum window occlusion, and duration of time (number of records) in each window occlusion state. Lastly, an activity rating is generated for each office based on the sum difference between all observation records. The sum difference is then divided by the total number of records for that particular office to generate a normalized value representing the average change in exterior window occlusion between records. Offices are then ranked based on the average window occlusion and activity rating. Offices with lower average window occlusion and higher activity ratings are considered more *active* users than those with higher average window occlusion and lower activity ratings. In order to quantify these characteristics in one measure, an exterior window occlusion index, the activity rating is subtracted from the average window occlusion.

Interior shade use behaviors do not affect perimeter zone offices directly. Rather, they affect the interior offices and circulation spaces. In the study site building, interior shade use behaviors can effectively remove all views to the exterior from circulation spaces and from interior offices. While the analysis of occupant adaptive behaviors is primarily focused on those perimeter zones that directly experience daylight and its attending consequences, the way that an occupant uses their interior shades may shed light on other types of behaviors. In this section, interior shade use behaviors include all occupant behaviors that result in the occlusion of the interior window. The most straightforward is the horizontal venetian blinds on all enclosed offices, for which the window occlusion state is calculating using the same method as exterior shades described above. The interior blind only deploys to 75% of the total interior window height, leaving the bottom quarter panel unobstructed however, so interior shade states are scaled from the contextual 0%/25%/50%/75% definitions used in field observations to the normalized 0%/33.33%/66.67%/100% settings. In some cases, occupant modifications are observed acting in lieu of the installed horizontal venetian blinds. In these cases, the window occlusion state reflects the percentage of the window that is blocked by the occupant modification. Occupants of open office cubicles are included in this data due to the effect of their behavior on views to the exterior from the corridor or adjacent interior offices. The translucent sliding door state (open or closed) for open office cubicles is coded as 0 or 1. Due to the binary nature of the door opening behavior, however, activity rate values are likely much higher for the open office cubicles. Further, door opening or shutting behaviors are more likely to be influenced by a desire for security than interior blind use behaviors. As a result, quartile rankings for open office cubicles are calculated separately from quartile rankings for enclosed offices.

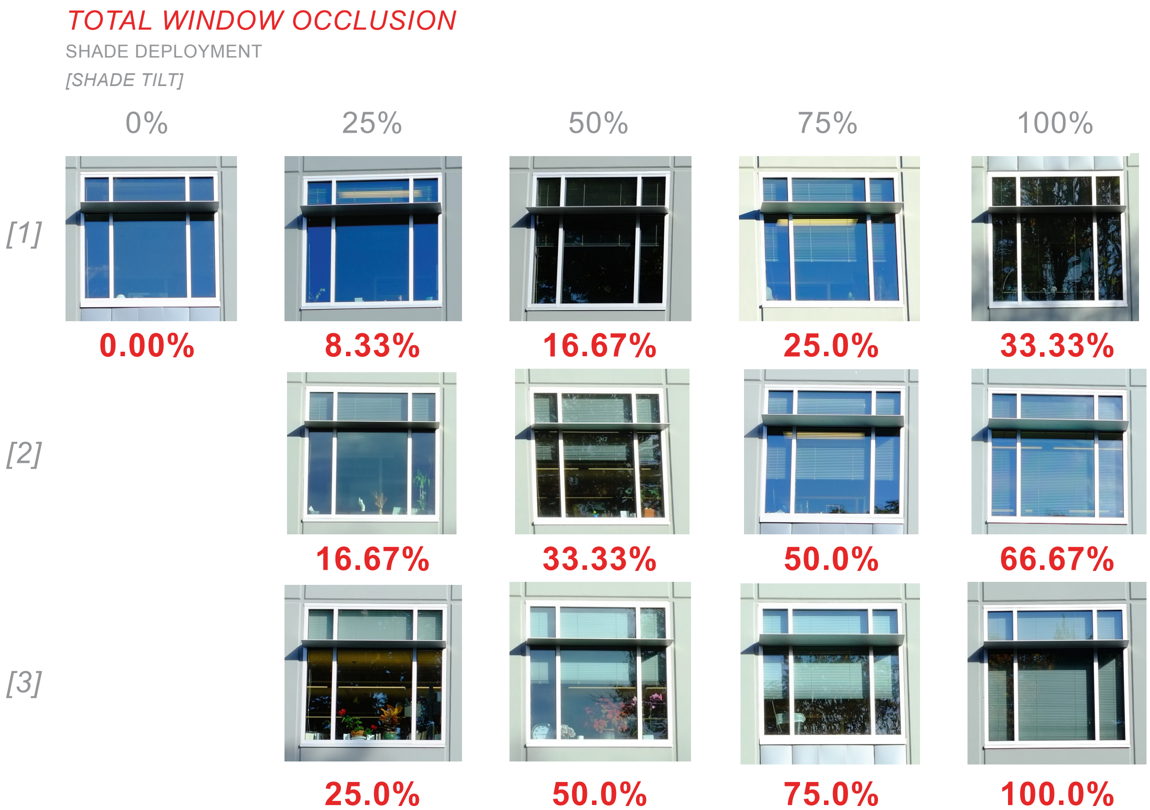


Figure 25: Total Window Occlusion values from shade deployment and shade tilt states.

Electric Lighting Use Profiles

Electric lighting use is quantified according to the amount of occupied time during which electric lighting is in use. Many occupants have electric lighting configurations for different lighting intensities or zones. Overhead lighting configurations are normalized on a scale of 0 to 2 based on the maximum installed lighting intensity in a given office. Corridor lighting state is included in the appraisal of each occupant's lighting use but it is weighted to be less significant than lighting use within the office. Task light state is also included in the appraisal of each occupant's lighting use and is weighted to be less significant than overhead lighting use. The follow method and weighting factors are used to quantify total electric lighting use during the study period in a given observation record.

- Overhead lighting: OFF – 0; one luminaire on (enclosed offices) – 1; luminaire on at 50% (open office cubicles) – 1; two luminaires on (enclosed offices) – 2; luminaire on at 100% (open office cubicles) - 2

- Task lighting: +0. 5 for each task light on

- Corridor lighting: +0. 25 if ON
- Overhead + Task + Corridor = total electric lighting state

Each occupants' lighting use is described according to average electric lighting use, standard deviation of electric lighting use, maximum electric lighting use, minimum electric lighting use, and duration of time (number of records) in each electric lighting use state. Only records showing the office electric lighting use state while the office is occupied are included in this metric. Taking the sum differences in total electric lighting state between each observation period and dividing it by the total number of records calculates the activity rate for each office's electric lighting use patterns over the study period. Activity rate represents the average change in electric lighting state between observations. Offices with the same electric lighting state during each observation period have an activity rate of 0. The activity rate is subtracted from the average total electric lighting state in order to calculate the final Electric Lighting Use Index. Offices are then ranked into quartile groupings according to the observed range of Electric Lighting Use Index values.

Spatial Movement & Use Patterns

Spatial movement and use patterns are quantified based on observations of occupants' view orientation, workspace arrangement, and behavioral traces. Occupants' view orientation describes the angle at which the occupant is seated while working during an observation. However, this metric captures only a small range of likely spatial movements that any given occupant is expected to exhibit throughout the course of a regular workday. Observations of workspace arrangement and behavioral traces suggesting use patterns are also quantified in order to incorporate these other likely, but unseen movements, into assessments of occupants' spatial use patterns. The most important outcome from the spatial use data for the purposes of this study is whether the spatial movement patterns demonstrate flexible or responsive use of the workspace to either remove discomfort or increase usability of daylight, as would be expected under the adaptive zone glare prediction model (Jakubiec and Reinhart 2012). For example, if an office is arranged in such a way that the occupant could easily transfer their work to a different work area without sacrificing daylight illumination and the occupant is observed using both of these work areas at some point during the study period, then the occupant may be said to exhibit *active* spatial use patterns. *Active* in this context is defined similarly to shade or electric lighting use behaviors in that it implies the occupant does not set up their work in one location and remain there throughout the day but rather orients themselves or their work in response to either changes in environmental conditions or task-based requirements. In this regard, an occupant's actual view orientation is not as important as the variation in view orientation that is either observed throughout the study period or observed through behavioral traces on the workspace. Offices are assigned a normalized spatial use value from 0 (not active) to 2 (active). Spatial use values are the sum of the following outcomes:

- Observed variation in view orientation – offices are ranked according to the number of unique view orientations found in the data and then assigned a weighted value from 0 (no variations) to 1 (most observed variations).

- Workspace flexibility – offices are categorized according to whether their workspace arrangement prevents them from using different work areas (0), allows them to use different work areas in a similar lighting zone (0.5), or allows them to use different work areas in different lighting zones (1).

- Behavioral traces – offices for which there are no changes in view orientation observed but whose workspaces indicate that more than one work area in the office is utilized are given an additional weighting offset (0.25).

III.D.ii. Glare Response Sensitivity Index – Assumptions & Rationale

The survey instrument serves to describe occupants' behavioral responses to and perception of discomfort glare based on a number of attributes that indicate either a tendency toward *sensitive* or *tolerant* responses to discomfort glare. Sensitive is considered for these purposes marked by the attenuation to slight changes and discomfort in the environment. For these purposes sensitive describes only glare response and thus individuals who are sensitive to glare may be overly cautious, pre-emptive, and controlling over their surroundings in order to avoid any discomfort sensation entirely. Tolerant, meanwhile, is considered both physiologically as in the *ability to endure* as well as psychologically as in the *willingness* to endure specific conditions. Simply put, discomfort glare conditions may be tolerated. While discomfort glare may be tolerated, it is highly unlikely that the discomfort would be ignored altogether. Multiple behavioral parameters describe the indicators for either 'sensitive' or 'tolerant' responses to discomfort glare (see Figure 26). These behavioral parameters include

- Preference to control environment or preserve amenities

- Willingness to report discomfort in relation the prevalence of discomfort glare conditions

- Responsiveness to perceived discomfort

- Responsiveness to relieved discomfort glare conditions

- Likelihood to modify one's environment (source adaptation) or oneself (subject adaptation) in response to discomfort glare

- Incidence of preemptive or 'permanent' responses to discomfort glare

Only a portion of the parameters listed above can be described using survey-based data. The type, frequency, and duration of behaviors, whether they are disposed toward subject or source adaptations, as well as the disposition toward environmental conditions such as daylight and view will be considered indicators of tolerant versus sensitive glare response behaviors. Personal and organizational values, environmental awareness, preferences and appraisal, as well as self-efficacy have been shown to influence discomfort glare perception and behavioral response but the extent to which they are related to glare tolerance or sensitivity is unknown. Some basic data on these attributes are created by the survey and their relationships to other parameters contributing to the index are explored. Discrete parameters have equal weighting in the initial discomfort glare response and sensitivity index although weighting factors that reflect the relative significance of each parameter may be applied to provide a better fit between survey responses and behavioral data. In this way the behavioral and environmental data provides an important verification of whether the survey data is reliable.

In sum, the parameters used to generate a discomfort glare response and sensitivity index compare among the study population each respondent’s propensity to display different type and frequency of glare response. Index results are compared graphically with behavioral outcomes as observed in field assessments using a scatter plot diagram as seen in Figure 27. Correlations between index results and behavioral outcomes are tested within each of the parameters identified above in order to determine relative significance of different physical, personal, and social factors on adaptive behavioral responses and whether the effect of those factors is amplified within the sensitive or tolerant groups. If data within a spatial parameter is seen to exhibit a stronger correlation between glare response and behavioral outcomes than the data set as a whole then the spatial factor may affect the occupants’ schematization of their workspace and is included in the next analysis step. Parametric analysis results are then compared between the index results and the behavioral results alone. If correlations improve within the composite results then this may indicate that the relationship between the spatial factor and behavioral outcome is mediated by the occupants’ schema (represented by the glare sensitivity metric). By virtue of the nature of the parameters described above, the glare response and sensitivity index implicitly connotes occupants’ behavioral energy impacts due to glare. In this way, spatial lighting, social, or personal factors seen to significantly affect discomfort glare response outcomes are explicitly tied to otherwise unseen energy outcomes. The following sections outline the rationale behind questionnaire measures that are expected to display face validity as indicators of glare tolerance or sensitivity.

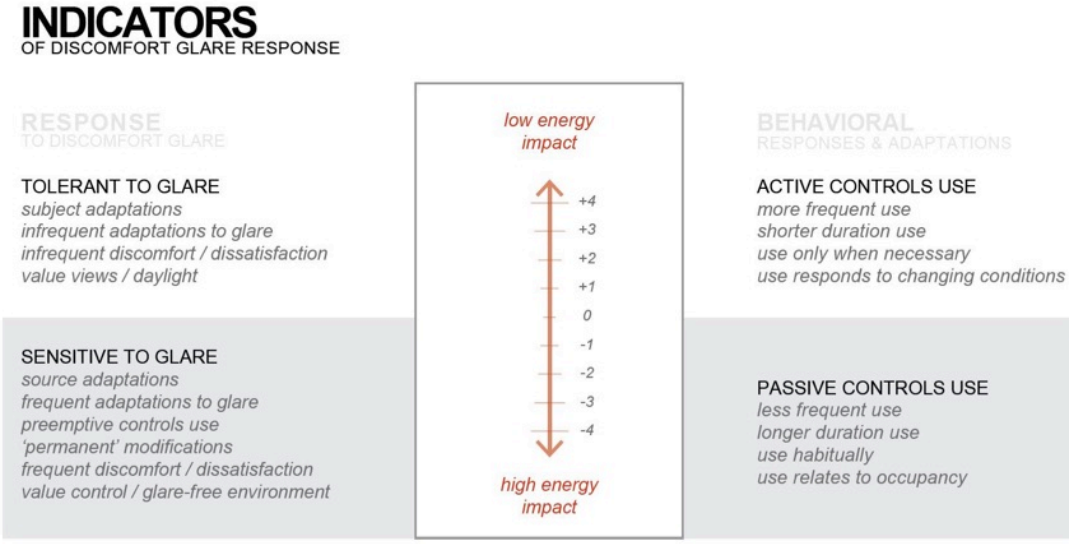


Figure 26: Discomfort glare response indicators and energy impact index

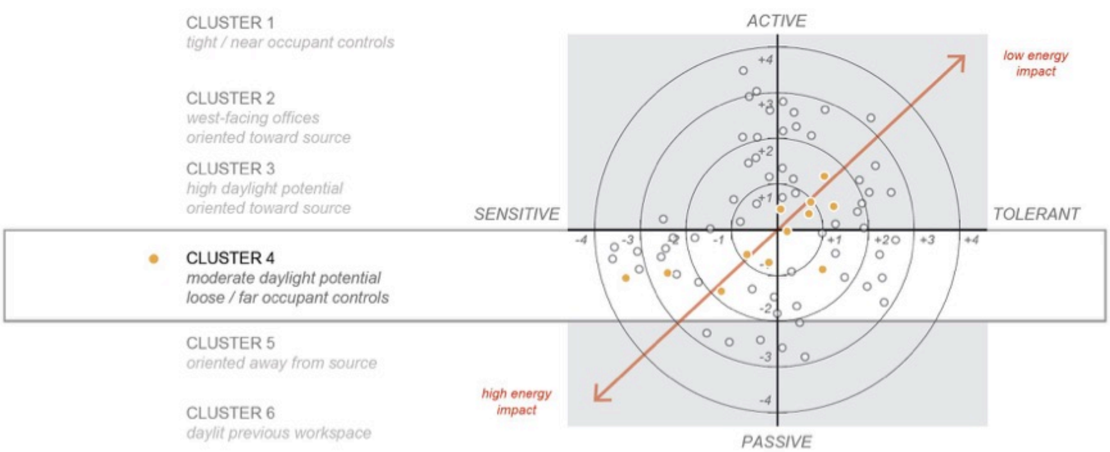


Figure 27: Example scatter plot of glare response sensitivity index and behavioral outcomes for cluster analysis.

III.D.ii.a. Indicators of Tolerant Glare Response

Types and Frequency of Adaptations

Data that shows a relatively high level of subject adaptations or low level of source adaptations are considered an indicator of tolerant glare response. The frequency of subject adaptations in comparison to source adaptations indicates a higher willingness to accept the environmental condition while mediating the perception of discomfort. These may include wearing sunglasses or a hat, adjusting one's seating position or computer monitor, choosing to work in another location in the office, or switching task. Data showing the frequency or level of subject or source adaptations is gathered from field observations and survey responses.

Behavioral Response Rate

Data that shows a low rate of behavioral response during daylighting conditions where glare is present is considered an indicator of tolerant glare response. If an individual perceives discomfort from daylight glare yet doesn't modify their behavior or environment in order to reduce or remove the discomfort, they are clearly tolerating their discomfort. Less energy is used during daylight conditions (shades open and electric lights off) as a result of delaying use of electric lighting or interior shades. An individual who reports no behavioral response to discomfort glare is considered more tolerant of the discomfort than those who take longer to initiate a source adaptation. Data indicating the absence or time delay of subject or source adaptations is gathered from field observations and survey responses.

III.D.ii.b. Indicators of Sensitive Glare Response

Incidence of Discomfort or Dissatisfaction

Data that shows a high incidence of discomfort or dissatisfaction with the lighting environment is considered an indication of sensitive glare response. Individuals who are more sensitive to glare may be more likely to report discomfort or dissatisfaction and may feel more motivated to response to or preempt/prevent of the perception of discomfort glare than someone who does not report any significant discomfort. Reporting discomfort or dissatisfaction in a spatial or lighting zone that has otherwise low median discomfort or dissatisfaction rating or no quantitative indicators of glare from the field assessment is considered a very strong indicator of sensitive glare response. This is due to the relative measure of tolerant and sensitive glare response along an index for the purposes of this study.

Types of Adaptations

Data that shows a relatively high level of source adaptations is considered an indication of sensitive glare response. The frequency of source adaptations indicates a higher willingness to modify the environmental condition and lower willingness to mediate their perception of discomfort. These may include closing the blinds or turning on electric lighting.

Preventative Environmental Modifications

Data that shows preemptive occupants' controls use or 'permanent' modifications to the workspace environment in order to avoid glare is considered an indicator of sensitive glare response. Individuals who make a modification to their workspace, such as blocking a window with paper or cardboard, or preemptively use the lighting or daylight controls to avoid glare are overtly demonstrating their sensitivity to glare. In this case, glare affects the individual significantly or frequently enough to render even the possibility of glare unacceptable. This behavior is not captured in the survey responses and is only included in glare response profiles as an illustrative outcome measure to verify the profile results. If profile results indicate an individual is likely to be tolerant of discomfort glare conditions but their observed behaviors include preventative environmental modifications, their glare response profile result is likely invalid.

CHAPTER IV

RESULTS

This chapter presents results of the lighting parameters, behavioral outcomes, and Glare Response Sensitivity (GRS) index generated from the field lighting, behavioral observation and survey response data followed by statistical analysis of the relationships between lighting parameters, behaviors, and GRS index. Specific methods for defining each of the lighting parameters, behavioral outcomes, and the GRS index parameters can be found in Appendices B through F. Results from the first phase of data collection that characterize the indoor lighting environment can be found in Appendix B (Useful Daylight Expectation), Appendix C (Glare Potential), and Appendix D (Annual Solar Exposure). Results of the behavioral observations including occupants' electric lighting use, daylight controls (shades) use, and spatial use patterns can be found in Appendix E. Results from the second phase of data collection that describe occupants' assessment of the indoor lighting environment as well as self-reported occupancy, electric lighting use, daylight controls (shades) use, and spatial use patterns and from which GRS index parameters are derived can be found in Appendix F. Offices are assigned a generic numerical ID and are referred to herein according to that generic ID.

IV.A. <u>Useful Daylight Expectation</u>

Over the course of the six-week study period, illuminance measurements were taken at 4 locations in 37 different offices resulting in 92 unique records. Horizontal illuminance measurements were taken on the exterior window sill, work plane, center of the office, at the interior wall of the office, and in the middle of the corridor outside the office. Measurements were taken in a range of exterior sky conditions and lighting and shade configurations including full daylight without shades (n=36), daylight in occupant shade settings (n=26), and occupant lighting and shade states (n=30). The sample of offices includes enclosed private offices (n=35) and open office cubicles (n=57). Exterior sky conditions under which illuminance measurements were taken include clear sunny sky (n=13), partially cloudy sky (n=31), and overcast sky (n=48). A general overview of exterior illuminance levels during measurements can be seen in Table 2 below. General statistics for interior illuminance measurements can be seen in Table 3 below.

Table 2: Exterior illuminance during measurement period grouped according to sky condition.

	Count *(n=)*	Min. *(klux)*	Max *(klux)*	Mean *(klux)*	Median *(klux)*	Std.Dev *(klux)*
Clear Sunny Sky	13	6.899	53.500	46.331	53.500	17.500
Partially Cloudy Sky	31	16.600	70.900	44.626	70.900	27.584
Overcast Sky	48	6.730	46.700	23.005	19.480	14.247

Table 3: General statistics of interior illuminance measurements (all offices).

	Count (n=)	Min. (lux)	Max (lux)	Mean (lux)	Median (lux)	Std.Dev (lux)	25th % (lux)	75th % (lux)	IQR (lux)
All Interior	**92**	**18**	**46,900**	**3,613.7**	**695**	**9,007.78**	**265**	**1,907.5**	**1,642.5**
Exterior Window Sill		38	46,900	11,685.5	5,112	14,746.3	1,796	14,737	12,941
Center of Work Plane		30	43,500	4,315.9	932.5	9,736.9	460.5	1,950.5	1,490
Center of Office		23	4,505	1,095.8	759.5	968.4	380.5	1,705.5	1,325
Interior Office Wall		18	1,915	509.3	420.5	417.5	193	767.25	574.3
Center of Corridor		20	1,293	340.1	248	290.6	93.5	530.5	437

The large range of interior illuminance levels seen in Table 3 at the exterior window sill, work plane, and center-of-office measurement locations is expected in a daylit space under varying sky conditions. Smaller variations in interior illuminance are observed at the interior office wall and the center of corridor measurement locations, which are farthest from the daylight source. It became clear as a result of early data sampling that illumination levels in the interior offices exhibit much lower intensity illumination. Illumination at the work plane in interior offices meets the bare minimum acceptable illumination recommendation found in existing research, 150 lux on the work plane (Lindelöf and Morel 2006), only when the adjacent perimeter office or cubicle were in a completely daylit (0% exterior and interior window occlusion). In addition, the daylight illumination levels inside the interior offices exhibit very little variation throughout the day. As a result, interior offices were not included in the office sample after the initial measurements.

Mean and median work plane illuminance levels greatly exceed minimum recommended illumination from daylight for typical office tasks (300-500 lux). Even the 25th percentile ranking for work plane and center-of-office illuminance, 460.5 lux and 380.5 lux exceed recommended minimum illumination levels. Illuminance levels on the exterior window sill exceed illuminance on the work plane in nearly all instances and are as much as 90 times greater than work plane illuminance when direct sun is on the window sill. Illumination levels on the work plane are seen to vary significantly between offices when compared to illumination levels at the center of the office. As seen in Table 3 above, standard deviation of work plane illuminance is more than ten times as great as the standard deviation of center-of-office illuminance. This discrepancy is likely exaggerated by instances where direct sun causes very high work plane illumination as is evidenced by the comparable 25th and 75th percentile values for the work plane, 460.5 lux and 1,950.5 lux respectively, and center-of-office, 380.5 lux and 1,705.5 lux respectively.

Based on the results described in Appendix B, it is clear that illuminance distribution varies throughout different portions of the building as well as between individual offices. Floor level, orientation, and building zone (perimeter or interior) are the primary factors seen to influence interior illuminance levels. Floor level's influence on illuminance levels and distribution, seen in Figure 28 and Figure 29, is shown to be a product of the difference between fenestration design and exterior shading strategy on the 3rd and 4th floors. The 4th floor's planar, unbroken fenestration design and projecting roof overhang exterior shading strategy leave perimeter offices on the 4th floor completely un-shaded during the study period. This was seen to result in high illuminance intensity near the perimeter and a steep drop-off in illuminance levels toward the interior as the primary mechanism distribution daylight to the interior is direct reflections off low horizontal and vertical surfaces inside the office. Despite the steep drop-off, illuminance levels remain sufficiently high enough to conclude that 4th floor offices are generally more likely to receive more of the available daylight than 3rd floor offices, as seen in Figure 28. However, the orientation of exterior windows is seen to exert a significant effect on interior illuminance such that the previous conclusion about 4th floor offices is not satisfactory. North and south facing offices display significant differences in interior illuminance levels irrespective of floor level, as seen in Figure 30. East and west facing offices are included with south facing offices due to the small population size in the study site. The last factor seen to influence illuminance significantly at the building level is the zone in which the office is located, either perimeter or interior. Interior offices are more than 15 feet from the exterior wall and thus rely on transmitted daylight through the perimeter zone.

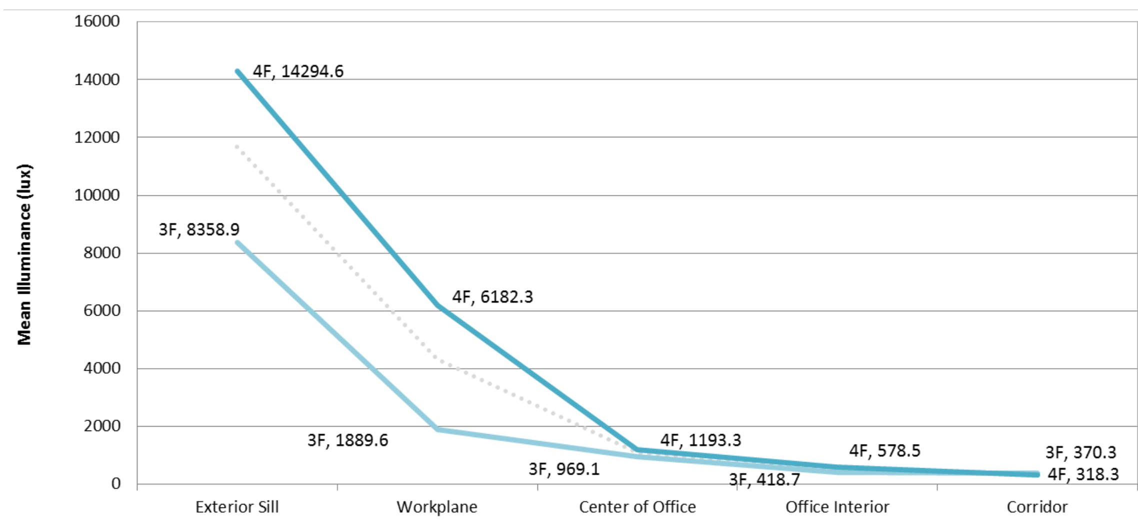


Figure 28: Mean illuminance at five measurement locations in 3rd floor and 4th floor offices. The dotted grey line represents mean values for all offices.

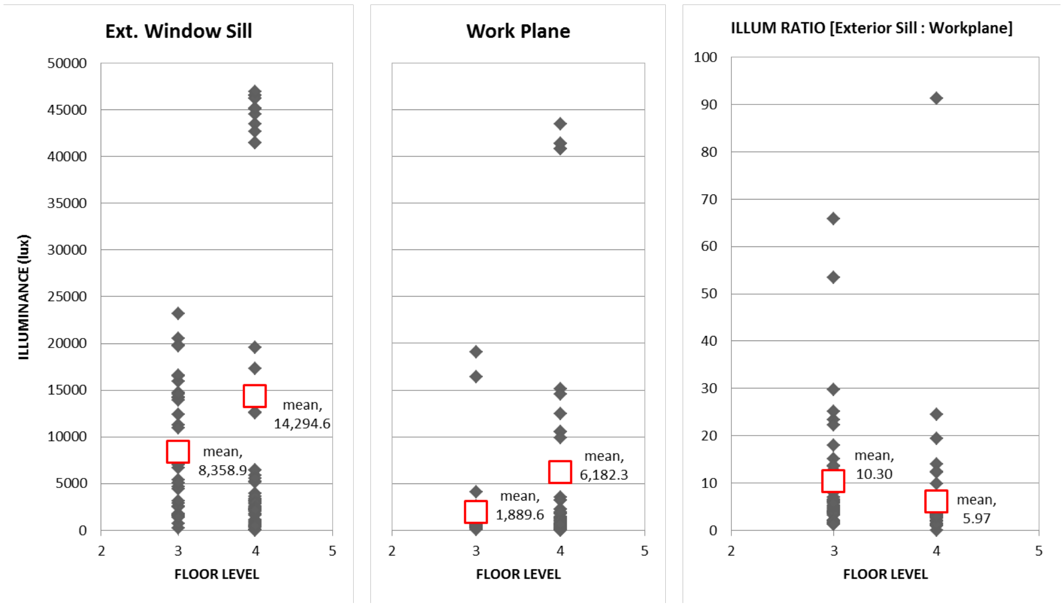


Figure 29: Scatter plots comparing measured illuminance values and mean illuminance at the exterior window sill (left), work plane (center), and the ratios of exterior sill and work plane illuminance (right) between 3rd and 4th floor offices.

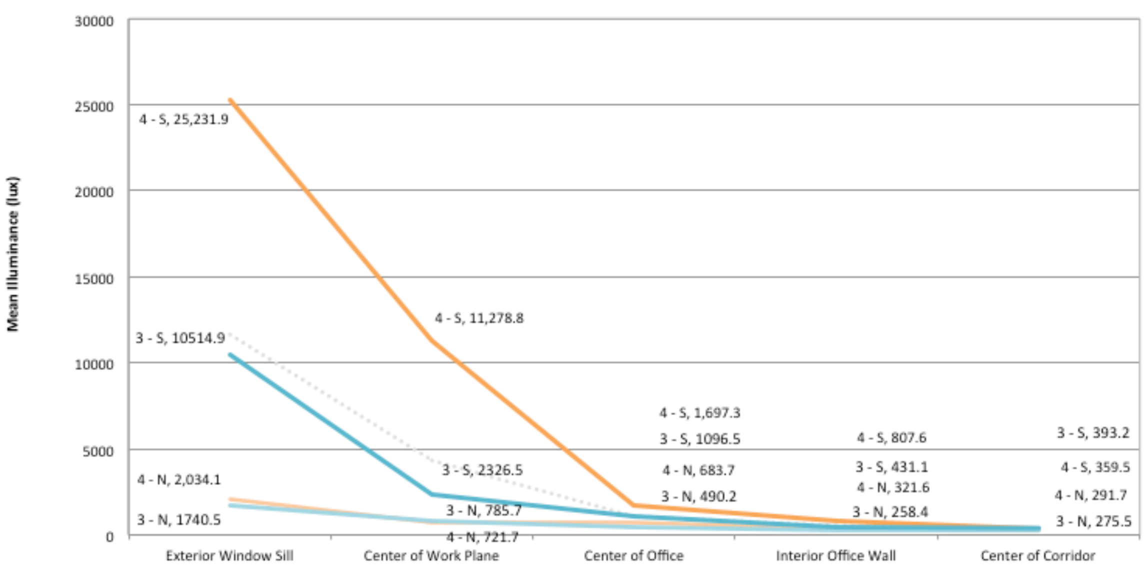


Figure 30: Mean illuminance values at five measurement locations in 3rd and 4th floor offices facing north and south. The dotted grey line shows mean illuminance for all offices.

These categories are used to define the baseline Useful Daylight Expectation values based on a ranked sum method explained in Appendix B. Appendix B also includes underlying analysis based on a series of comparative analysis of test cases identifying the influence of additional spatial attributes that are seen to affect daylight illuminance including workstation distance from the exterior wall, interior wall alignment with windows and surface properties of the interior walls. The final uDE parameter calculation protocol can be seen in Figure 31. The final uDE rankings are shown in Figure 32 mapped on top of office locations in a floor plan view based on the quartile groupings of each office (more saturated icons represent lower uDE value, or less expected useful daylight availability). The uDE values show the same variations highlighted above but feature a more or less equivalent scale factor between the major spatial groupings, thereby eliminating outliers with both extremely high illuminance and low illuminance levels. This means of comparing indoor daylight levels should capture all the variation within the building but present a more realistic picture of perceived daylight levels due to the influence of adaptation and habituation which would be expected to moderate the perception of each extreme under repeated or prolonged exposure.

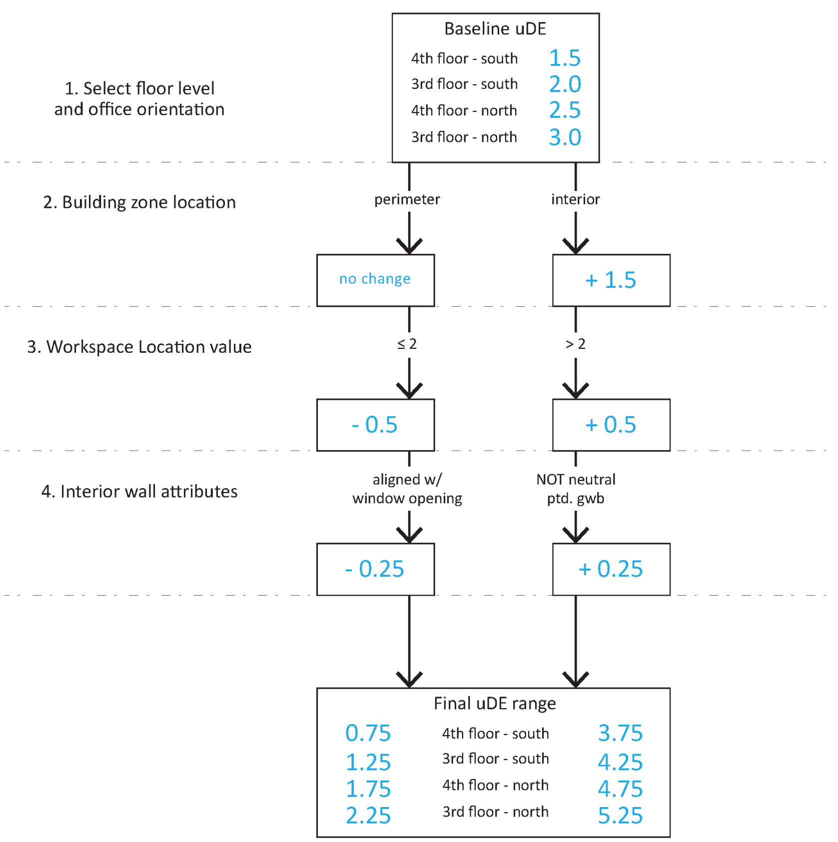


Figure 31: Diagram showing calculation procedure of Useful Daylight Expectation (uDE) based on office floor level, orientation, building zone, workspace location, and interior wall attributes.

Figure 32: Useful Daylight Expectation (uDE) results mapped onto third and fourth floor plans. More saturated icons represent offices with lower uDE value.

IV.B. Glare Potential

Over the course of the six-week study period, high dynamic range images (HDRI) were taken from 3 view shed locations in 31 different offices resulting in 169 unique records. Images were taken in a range of exterior sky conditions and lighting and shade configurations including full daylight without shades (n=64), daylight in occupant shade settings (n=71), and occupant lighting and shade states (n=34). The sample of offices includes enclosed private offices (n=62) and open office cubicles (n=107). Exterior sky conditions under which images were taken include clear sunny sky (n=19), partially cloudy sky (n=92), and overcast sky (n=59).

This section describes the resulting Glare Potential (GP) parameter definition, based on the methods describe in Appendix C that quantify the primary spatial differences and their impact on interior luminance distribution. Glare Potential is a scaled value representing the range of observed conditions in the study site. Based on the results described in Appendix C, it is clear that luminance distribution and discomfort glare probability varies throughout different portions of the building as well as between individual offices. Floor level, orientation, and building zone (perimeter or interior) are the primary factors seen to influence interior luminance intensity and distribution.

The results discussed in Appendix C show a clear relationship between floor level (Figure 33) and luminance distribution and intensity. This relationship is seen in 4^{th} floor offices where mean luminance values and variation in luminance intensity between offices are significantly higher than 3^{rd} floor offices. Office orientation is also seen to affect luminance outcomes (Table 4). South facing offices on a given floor consistently display higher mean luminance than north facing offices on the same floor. The source of high intensity luminance values differs between office orientations however, and displays an effect on other luminance outcome metrics including luminance range areas and areas outside the MGT. South facing offices that display high mean luminance are more likely to include high intensity luminance sources within the office due to direct sun or strong directional daylight, which in turn increases the luminance of nearby surfaces and reduces apparent contrast or glare within the scene. North facing offices that display high mean luminance are more likely to include high intensity luminance source outside the office, usually due to intense directional reflections of light from clouds or ambient sky condition. The high intensity exterior luminance source does not necessarily increase the luminance of nearby surfaces within the view and is frequently observed to increase contrast and glare within the scene, as shown in Figure 34. Along these same lines, the orientation of the view (or occupant) in relation to the daylight source (relative view orientation) exhibits a significant influence on luminance outcomes, Figure 35 below, particularly in north facing offices due to the effect described above. Mean luminance and luminance variation tend to decrease as the relative view orientation increases, although the rate of decrease is initially higher for north facing offices before the rate of decrease zeros out whereas in south facing offices the rate of decrease does not change as relative view orientation increases.

The final GP parameter definition can be seen in Figure 36. The sub-parameters seen in Figure 36, including building zone, relative view orientation, and workstation location, are based on a comparative analysis of test cases found in Appendix C. Figure 37 shows GP results mapped onto office locations on the third and fourth floor plans, where variations in GP between neighboring offices are seen throughout.

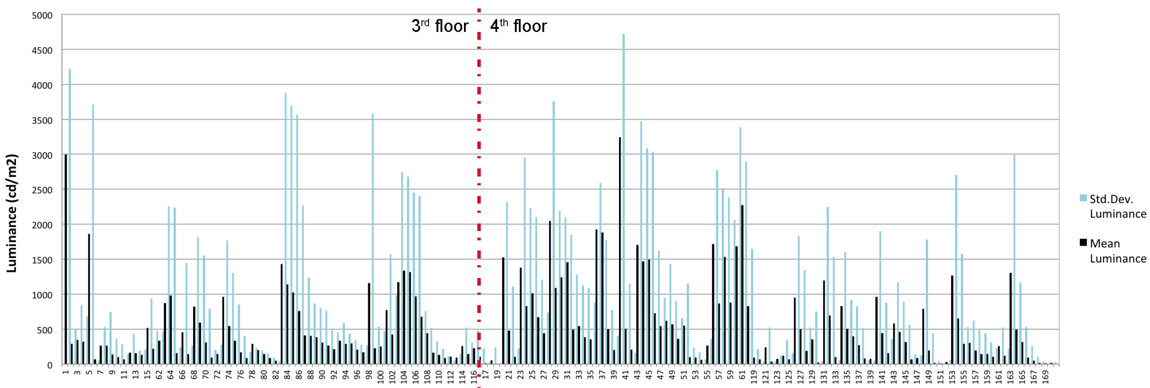
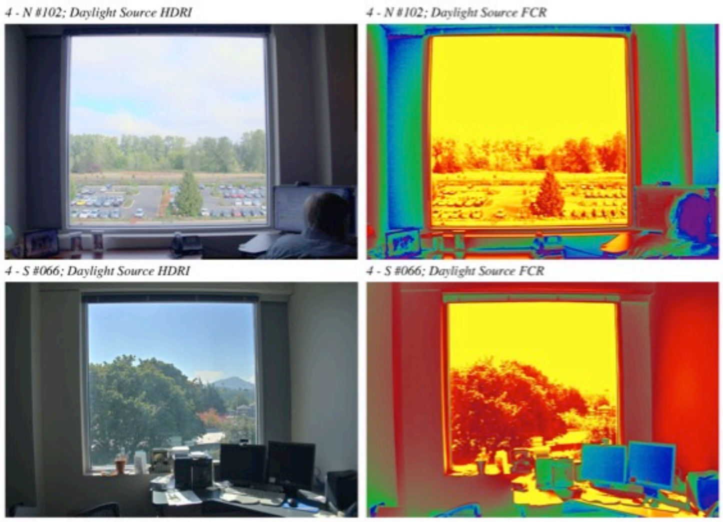
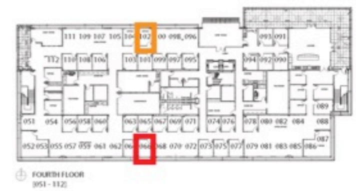


Figure 33: Mean luminance and standard deviation of all HDRI records. 3rd floor records are left of the red line, 4th floor records are right of the red line.

Table 4: General statistics of mean luminance and standard deviation values for all records grouped according to floor level and office orientation.

	Count (n=)	Min (cd/m2)	Max (cd/m2)	Mean (cd/m2)	Median (cd/m2)	Std.Dev. (cd/m2)	25th % (cd/m2)	75th % (cd/m2)	IQR (cd/m2)
ALL	**170**	**6.52**	**3,246.6**	**535.6**	**315.2**	**573.4**	**135.2**	**776.2**	**640.9**
	std.dev.	***8.8***	***4,721.6***	***1,063.7***	***604.6***	***1,069.5***	***236.0***	***1,627.3***	***1,391.3***
3 – N	8	93.1	517.1	211.1	180.0	137.2	126.1	232.3	106.2
	std.dev.	*147.5*	*939.6*	*413.9*	*394.3*	*255.8*	*218.1*	*493.1*	*275.1*
3 - S	60	46.5	1,862.8	462.1	293.1	420.4	159.3	696.5	537.1
	std.dev.	*41.8*	*3,877.2*	*1,042.6*	*522.5*	*1,091.5*	*268.3*	*1,555.4*	*1,287.1*
4 - N	36	6.5	1,523.0	359.9	212.7	374.8	72.5	499.8	427.2
	std.dev.	*10.9*	*2,318.4*	*704.3*	*523.3*	*693.8*	*124.8*	*1,121.7*	*997.0*
4 - S	56	9.7	3,246.6	779.5	541.9	701.0	243.9	1,277.3	1,033.4
	std.dev.	*13.2*	*4,721.6*	*1,446.6*	*1,149.1*	*1,158.5*	*490.6*	*2,271.5*	*1,781.0*





	Min (cd/m2)	Max (cd/m2)	Mean (cd/m2)	Median (cd/m2)	Std.Dev. (cd/m2)
4 - N #102	0.58	9,344.3	1,523	183.1	2,318.4
4 - S #066	2.61	19,159	1,705.9	240.0	3,473.4
% diff.	*+(350%)*	*+(105%)*	*+(12.0%)*	*+(31.1%)*	*+(49.8%)*

Figure 34: Comparison of view through the exterior window from south and north-facing 4th floor windows showing the impact of unobstructed exterior views on mean scene luminance and luminance distribution.

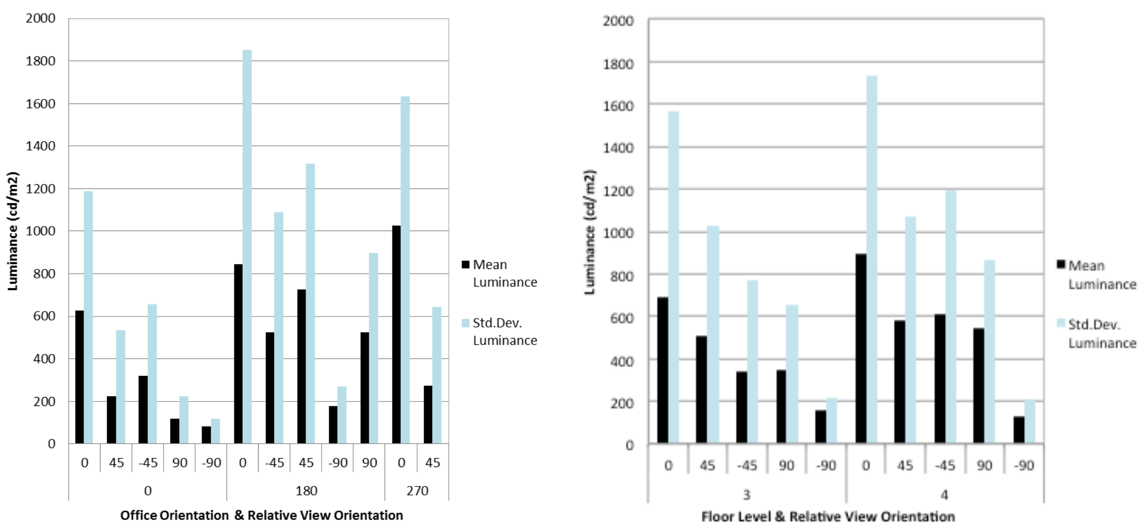


Figure 35: Mean luminance and standard deviation of luminance within the scene organized by relative view orientation and office orientation (left) and floor level (right).

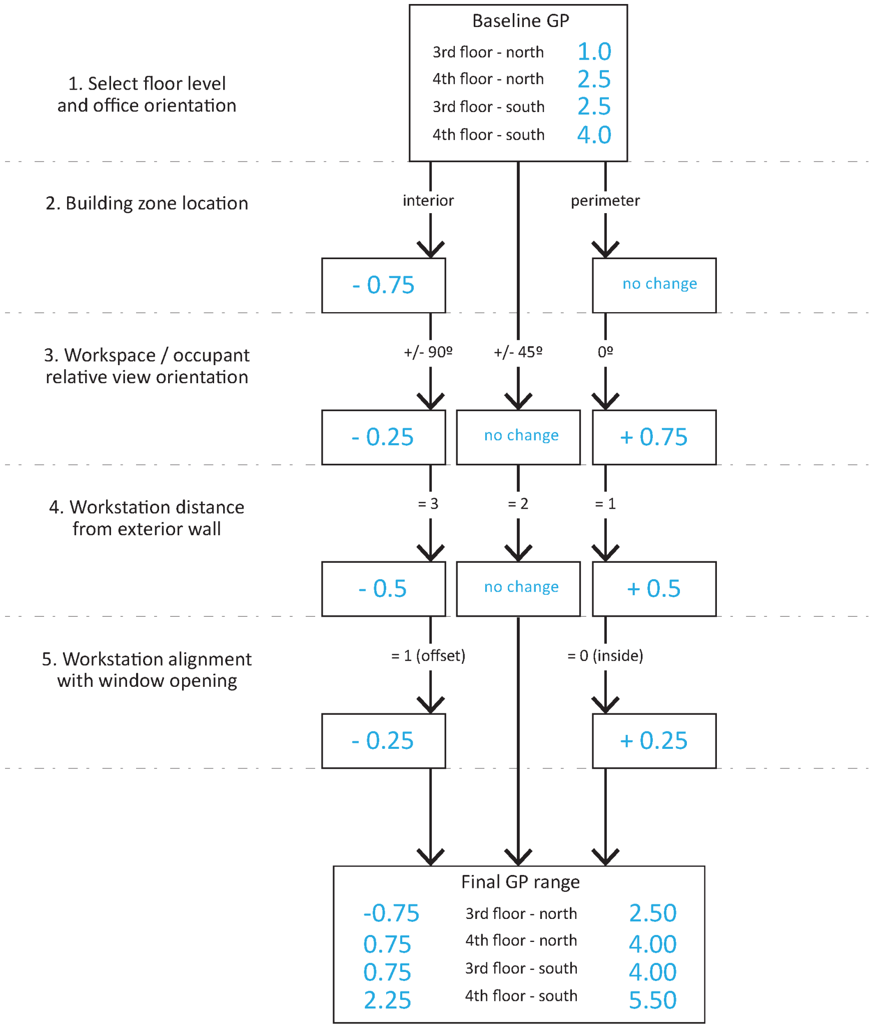


Figure 36: Diagram showing calculation procedure of Glare Potential (GP) based on office floor level, orientation, building zone, workspace/occupant relative view orientation, workstation distance from exterior wall, and workstation alignment with window opening.

Figure 37: Glare Potential (GP) results shown mapped onto third and fourth floor plans. Saturated icons represent offices with higher GP values.

IV.C. Exterior Shade Use

Exterior shade use is documented throughout the study period during walkthrough observations as well as exterior photograph records resulting in 3,891 unique records for areas within the study population, including 2,688 unique records for offices in the study population, in addition to 3,460 unique records for the remaining building areas. A general overview and detailed analysis of trends identified in exterior shade use behaviors in the study population can be found in Appendix E. The results contained in Appendix E highlight important trends in observed window occlusion states across different groups of windows or offices. In order to compare behavioral outcomes across occupants and offices in the subsequent cluster analysis the above-mentioned trends are quantified in a simple and proportional metric. This section describes results at the level of the individual-office and presents the shade use behaviors that contribute to the final exterior window occlusion index, defined in section III.D.i.c. above. Figure 38 shows observation frequency of window occlusion states for each office in the study population. Most offices exhibit a range of exterior window occlusion states throughout the study period, but for 23.1% of offices (n=15) no changes in window occlusion state are observed during the study period. 1 of these offices is not occupied throughout the study period. This behavior is referred to throughout the literature as ‘set it and leave it’ behavior. This behavior might signal undesired outcomes if the window occlusion state in which the shades are set and left significantly occludes daylight. However, as can be seen in Figure 38, the vast majority of offices that exhibit this behavior keep the exterior window 0% occluded. Despite the prevalence of individuals who display the ‘set it and leave it’ behaviors, there is a great deal of variation observed within specific offices. As shown in Figure 39, the majority of observed shade use behaviors fall within the 25%-50% window occlusion range, which accounts for nearly half of all possible shade configurations identified in this study.

Figure 38: Window occlusion state frequency for each office included in the study population.

In order to quantify the level of window occlusion as well as the frequency at which the exterior shade state changes, the activity rate is calculated for each office and subtracted from the mean window occlusion for that office over the study period. Figure 40 shows average window occlusion (in gray shown as positive values) and activity rate (in blue shown as negative values) for each office. Low average window occlusion and high activity rate are identified as desired behavioral outcomes in the literature (Reinhart 2004) and the exterior window occlusion index is structured to reflect the desired outcome. In that regard, negative values for exterior window occlusion index are expected in those offices that display low overall window occlusion but are observed varying the shade settings for short periods of time. The resulting exterior window occlusion index for each office is shown in Figure 41. Offices are grouped into quartile rankings based on the final distribution of index values.

Table 5 shows summaries of the resulting window occlusion outcome and exterior window occlusion index rankings for offices on each floor level and orientation. Resulting exterior window occlusion index rankings, shown in Figure 42, show similar trends as are described above. North-facing offices on average exhibit lower window occlusion rates as well as lower shade activity rates and as a result exhibit lower exterior window occlusion indices. Rankings for 3rd and 4th floor north-facing offices differ only insomuch as the 3rd floor offices were more likely to show higher window occlusion rates. 66.7% of the south-facing 3rd floor offices are ranked in the first or second quartile while only 26.3% of south-facing 4th floor offices rank in the first or second quartiles.

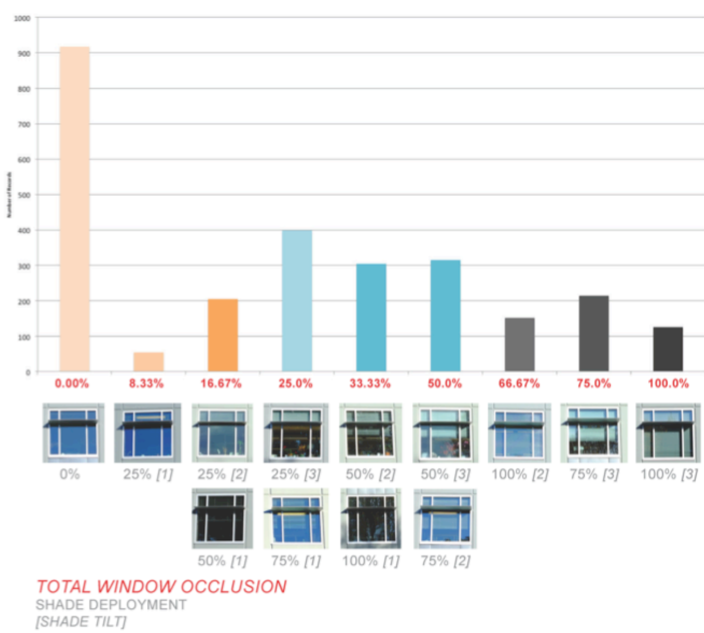


Figure 39: Number of records observed in each window occlusion state for offices in study population.

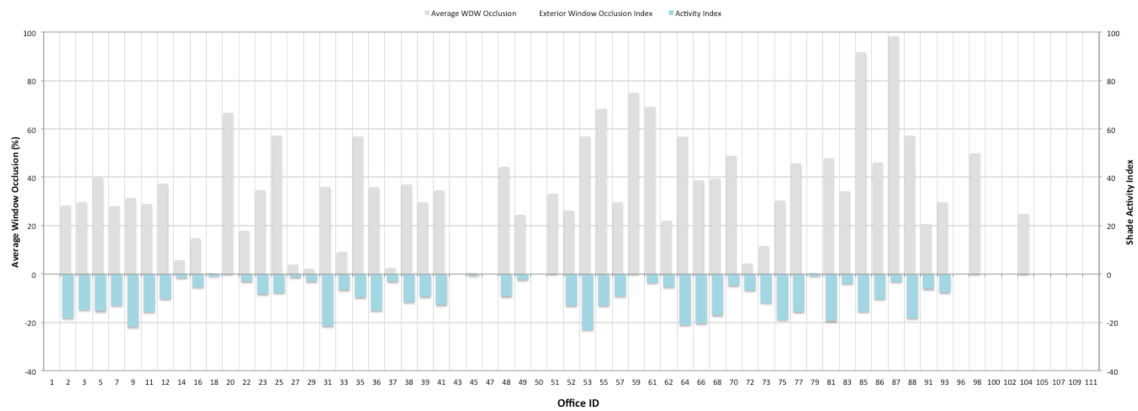


Figure 40: Average window occlusion and shade activity index for each office in the study population.

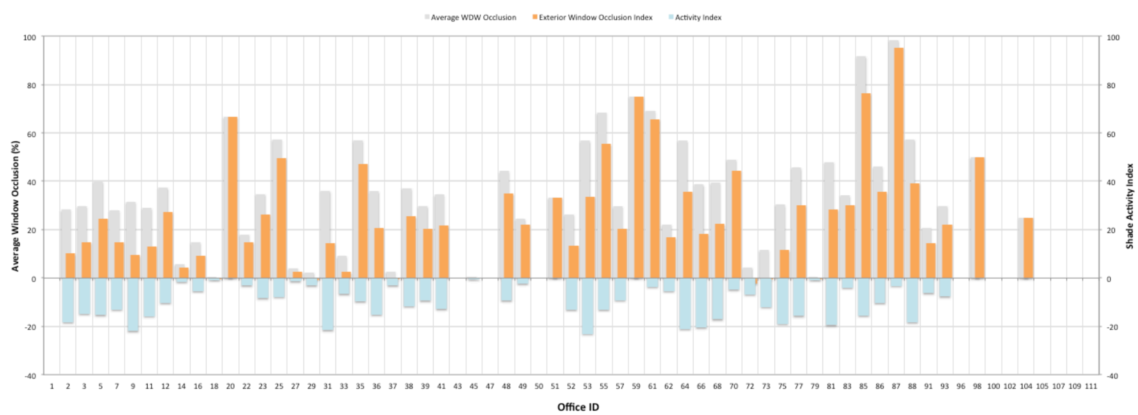


Figure 41: Final exterior window occlusion index plotted for each office in the study population.

Table 5: Summary statistics for window occlusion outcomes and exterior window occlusion index quartile groupings.

	ALL	*3rd floor*	*4th floor*	*3rd fl - SOUTH*	*3rd fl - NORTH*	*4th fl - SOUTH*	*4th fl - NORTH*
Avg. WDW Occlusion	29.18	23.83	34.06	14.67	6.56	17.45	1.82
Avg. Shade Activity Rate	7.87	7.82	7.92	8.89	4.30	11.62	1.26
Avg. Ext. WDW Occl. Index	21.31	16.01	26.15	18.96	12.37	31.39	10.16
1st Quartile (%) [< 0]		25.81%	31.43%	11.11%	50.00%	15.79%	63.64%
2nd Quartile (%) [0 < x <16.86]		35.48%	11.43%	55.56%	0.00%	10.53%	9.09%
3rd Quartile (%) [6.86 < x < 30.16]		25.81%	22.86%	16.67%	37.50%	31.58%	18.18%
4th Quartile (%) [> 30.16]		12.90%	34.29%	16.67%	12.50%	42.11%	9.09%

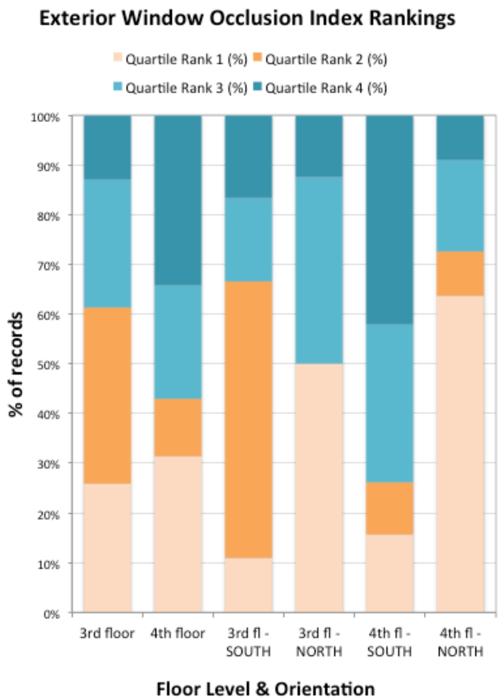


Figure 42: Exterior window occlusion index ranking results for 3rd and 4th floor offices facing north and south shown as a percentage of records within each group.

Offices in the first quartile are most likely to keep their shades fully retracted, occluded 0%, most or all of the time and if they do use the shades to only occlude the window partially and for a short period of time before fully reversing the shade use. Offices in the second quartile are likely to exhibit average window occlusion rates that are slightly higher than the shade activity rates but are likely to fully or partially reverse all observed shade use behaviors within a short time frame. Offices in the third quartile are likely to keep their windows partially occluded, are likely to exhibit numerous different shade configurations, and seldom reverse the behavior or fully retract the shade. Offices in the fourth quartile are likely to keep their windows mostly occluded, seldom change the shade setting, and if they do change the shade setting are unlikely to fully retract the shade. Figure 43 shows exterior window occlusion index rankings mapped onto the third and fourth floor plans to compare the spatial distribution of rankings.

Figure 43: Exterior Window Occlusion Index results mapped onto floor plans. Lighter saturated icons indicate offices that are more likely to exhibit active shade use and less likely to occlude daylight.

IV.D. Electric Lighting Use

An overall Electric Lighting Use Index is calculated for all occupied offices during the study period using the method described in section III.D.i.c. above. Figure 44 shows the average electric lighting use state and calculated electric lighting activity rate (in blue as a negative value) for each office. Figure 45 shows the final Electric Lighting Use Index for each office. Electric lighting use index results are mapped onto office locations on third and fourth floor plans in Figure 46. 53.9% of offices showed no variation in electric lighting state during the study period. Of those offices, they on average displayed an electric lighting state 9.87% higher than offices that varied electric lighting state during the study period. Table 6 shows that variation in electric lighting use, activity rate, and electric lighting use index results for 3rd and 4th floor offices are greatest within open offices and interior offices. On average 3rd floor open offices use electric lighting 18.8% more than 4th floor open offices while 3rd floor interior offices use electric lighting 9.85% than 4th floor interior offices. Open offices are predominantly grouped into the 3rd and 4th quartiles as a result of both higher overall lighting use and lower activity rate. 4th floor open offices showed the lowest activity rate of all groups while 3rd floor open offices showed the highest lighting use of all groups. In a surprising contra-indication shown in Table 7, 3rd floor occupants who used a task light at least once during the study period used their electric lighting more intensely than those who did not use a task light but 4th floor occupants who used a task light at least once are seen to use their electric lighting less intensely than those who did not. In these cases, at least at the aggregate level, the data suggests that act of using task lighting increases the likelihood that electric lighting overall is used more intensely.

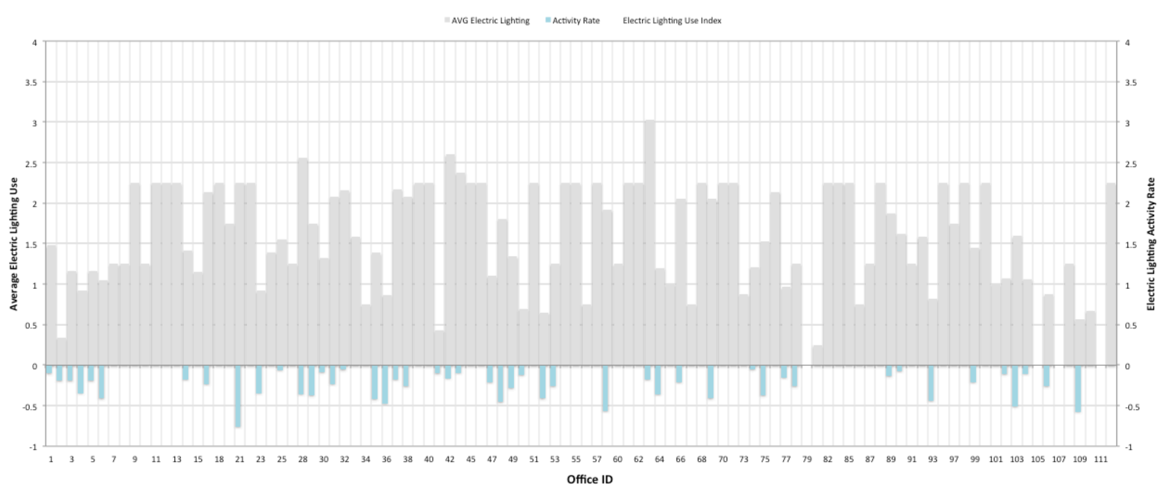


Figure 44: Average electric lighting use state and lighting activity rate for each office in the study population.

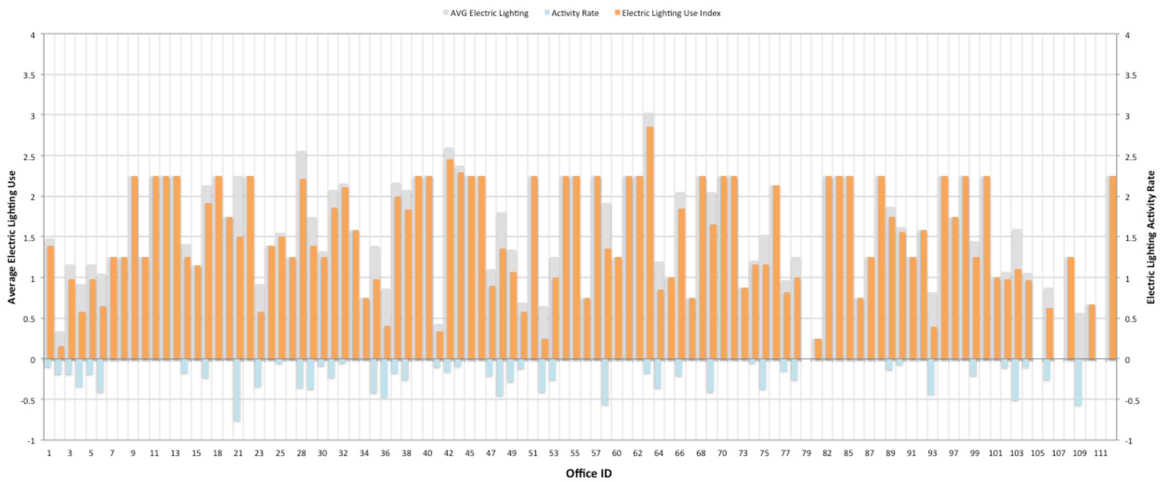


Figure 45: Final electric lighting use index plotted for each office in the study population.

Table 6: Summary statistics for lighting state, activity rate, lighting use index, and quartile ranking distribution in perimeter offices, interior offices, enclosed offices and open offices grouped by floor level.

	Perimeter Offices		Interior Offices		Enclosed Offices		Open Offices	
	3rd floor	*4th floor*	*3rd floor*	*4th floor*	*3rd floor*	*4th floor*	*3rd floor*	*4th floor*
Avg. Lighting State	1.584	1.425	1.723	1.555	1.361	1.325	2.062	1.698
Avg.Activity Rate	0.147	0.088	0.137	0.111	0.188	0.148	0.074	0.024
Avg. Lighting Use Index	1.437	1.338	1.586	1.444	1.173	1.177	1.988	1.674
1st Quartile (% <0.97)	20.69%	39.39%	17.65%	17.39%	28.57%	33.33%	5.56%	26.09%
2nd Quartile (% 0.97<x<1.36)	27.59%	15.15%	23.53%	39.13%	42.86%	42.42%	0.00%	0.00%
3rd Quartile (% 1.36<x<2.25)	48.28%	45.45%	52.94%	39.13%	28.57%	21.21%	83.33%	73.91%
4th Quartile (% >2.25)	3.45%	0.00%	5.88%	4.35%	0.00%	3.03%	11.11%	0.00%

Table 7: Summary of average electric lighting use, activity rate, and electric lighting use index for offices that do and do not use task lights.

		Avg electric lighting use	Avg Activity Rate	Avg electric lighting use index	*% diff*
Uses Task Lights	**ALL**	**1.585273**	**-0.16244**	**1.42283**	
	3rd floor	1.75753	-0.20553	1.551997	*9.08%*
	4th floor	1.434549	-0.12474	1.309809	*-7.94%*
Does Not Use Task Lights	**ALL**	**1.534304**	**-0.09938**	**1.434921**	
	3rd floor	1.581954	-0.1159	1.466059	*2.17%*
	4th floor	1.496183	-0.08617	1.410011	*-1.74%*

Figure 46: Electric lighting use index results mapped onto floor plans to show spatial distribution and variation of electric lighting use.

IV.E. Interior Shade Use

This section describes interior shade use data at the level of the individual-office and presents the shade use behaviors that contribute to the final interior window occlusion index, defined in section III.D.i.c above. The results included in Appendix E highlight important trends in observed interior window occlusion states across different groups of offices. In order to compare behavioral outcomes across occupants and offices in the subsequent parametric analysis the observed behaviors are quantified in a simple and proportional metric. Observed mean interior window occlusion rates as well as calculated interior shade activity rates are shown for each office in Figure 47. Interior shade activity rates are shown as negative values that are subtracted from the mean window occlusion state. Figure 48 shows the resulting Interior Window Occlusion Index for all offices. As can be seen, there are 8 offices that exhibit a negative Interior Window Occlusion Index result. 7 of these offices are open offices and only 1 is an enclosed perimeter office. A negative value indicates that the mean interior window occlusion was low enough to be completely offset by the activity rate that results from one or two shade use activities that are fully reversed within a short time frame (usually between observation periods). In response to these observations, quartile rankings are defined within each building zone and office type sub group (perimeter open office, perimeter enclosed office, and interior enclosed office), seen in Table 8. As a result, differences between quartile rankings of 3rd and 4th floor offices in each office type subgroup can be examined. Table 9 presents summary statistics for interior window occlusion, activity rate, and occlusion index for offices in each subgroup. Quartile ranking composition of each subgroup is seen in Figure 49.

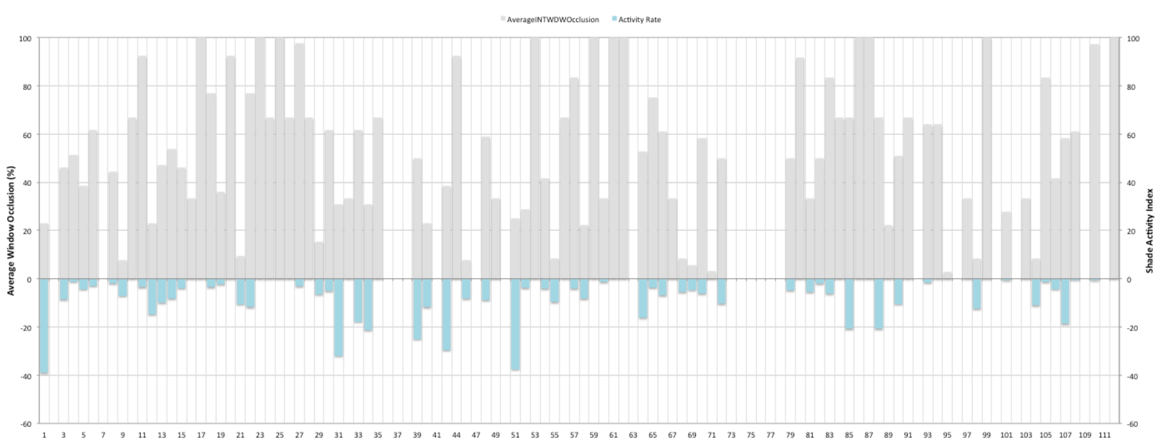


Figure 47: Average interior window occlusion and shade activity rate for each office in the study population.

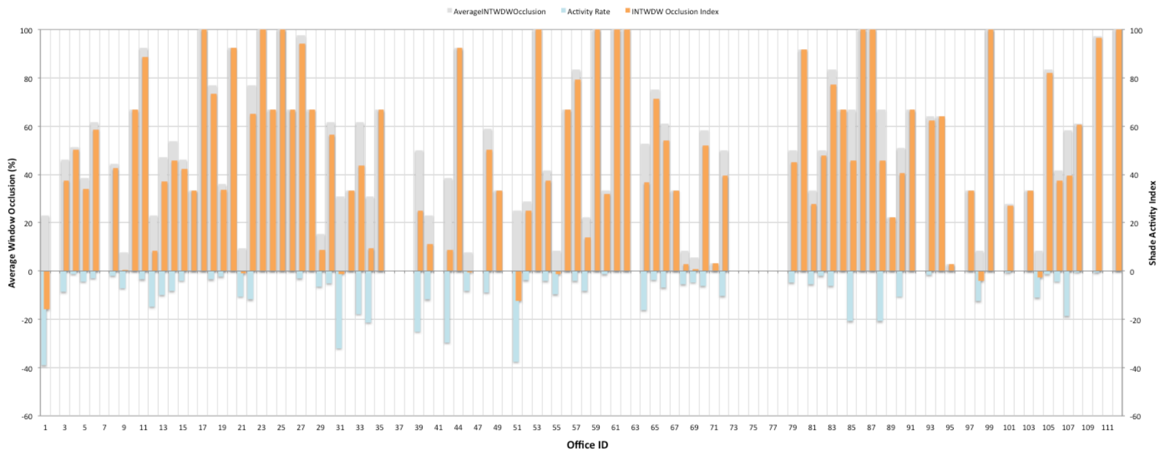


Figure 48: Final interior window occlusion index plotted for each office in the study population.

Table 8: Quartile boundary definitions of interior window occlusion index rankings for each office type subgroup.

	Perimeter		Interior
	Enclosed Offices	*Open Offices*	*Enclosed Offices*
25^{th} percentile	0	0	13.89
Median (50^{th} percentile)	34.12	38.54	37.02
75^{th} percentile	66.67	74.30	63.89

Table 9: Summary statistics for interior window occlusion outcomes and interior window occlusion index quartile groupings.

	Perimeter				Interior	
	Open Offices		Enclosed Offices		Enclosed Offices	
	3rd Floor	*4th Floor*	*3rd Floor*	*4th Floor*	*3rd Floor*	*4th Floor*
Avg. Int. Wdw Occl.	42.31	46.83	39.26	44.73	54.09	33.63
Avg. Shade Activity Index	12.39	7.84	2.08	3.06	2.72	1.51
Avg. Int. Wdw Occl. Index	29.92	38.99	37.18	41.67	51.37	32.12
Quartile Rank 1 (%)	30.77%	33.33%	37.50%	38.46%	7.14%	39.13%
Quartile Rank 2 (%)	30.77%	9.52%	18.75%	7.69%	21.43%	26.09%
Quartile Rank 3 (%)	23.08%	28.57%	25.00%	30.77%	35.71%	17.39%
Quartile Rank 4 (%)	15.38%	28.57%	18.75%	23.08%	35.71%	17.39%

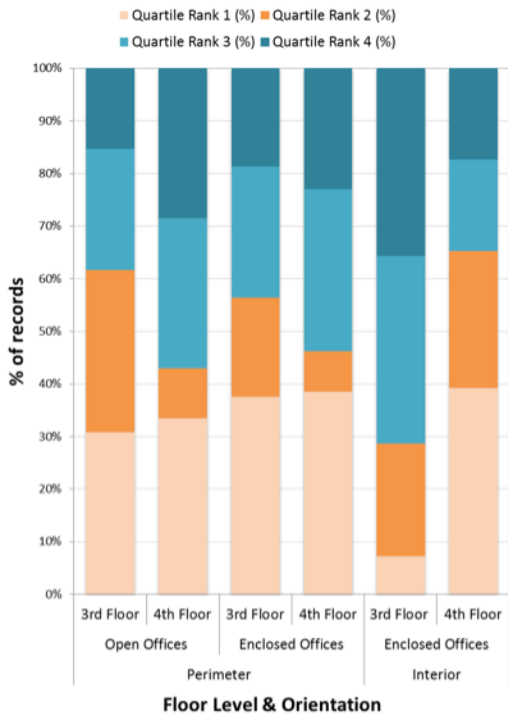


Figure 49: Interior window occlusion index ranking results for 3rd and 4th floor enclosed and open offices in perimeter and interior zones shown as a percentage of records within each group.

The results show that 3rd floor perimeter offices are more likely than 4th floor perimeter offices to fall within the 1st or 2nd quartiles while 4th floor interior offices are more likely than 3rd floor interior offices to fall within the 1st or 2nd quartiles.

IV.F. Spatial Use Patterns

This section briefly describes observations of occupants' spatial use patterns within their workspace and presents the final Spatial Use Variation index results. Many aspects of the occupants' environment are likely to influence observed spatial behaviors, but this section focuses on aspects of the workstation and workspace arrangement that allow occupants to use the space reflexively. Occupants within the study population are free to arrange their workspaces as they see fit. As a result, workspace arrangements varied throughout the building in terms of workstation type, workstation location, workstation orientation, and the presence of flexible amenities (either in the workstation or from the presence of a secondary work area) that allow the occupant to work in more than one area or configuration depending on work-related requirements or environmental conditions. In each observation period, occupants' spatial use habits were recorded using behavioral maps to note workstation location and occupant orientation (see Figure 50).

The simplest manifestation of this is the type of workstation found in each office. Four primary workstation types were identified in the study population, each of which affords different flexibility of movement and spatial use. L-shaped desks offer the occupant convenient and ergonomic flexibility to change orientation without changing location. Rectangular desks, while in and of themselves not inherently flexible, can easily be used in conjunction with another nearby work surface to achieve either the same effect as an L-shaped desk or to provide another work area in a different location within the office. Numerous occupants were also observed using standing desks, which could facilitate greater spatial use variation compared to seated desks. On many occasions where occupants were seen using a work area other than their primary work area, they were often performing a different categorical type of work-task such as reviewing documents, preparing documents, or meeting with another individual. The relationship between how the occupant uses their workspace, if they use it flexibly and if the workspace supports that type of use, and behavioral outcomes in terms of adaptive responses to discomfort are among the key research questions investigated in this study. In order to compare this relationship, spatial use patterns are quantified using the following procedure. Three measures of spatial use variation and flexibility are quantified. First, the average variation in observed occupant relative view orientation is calculated for every occupant. Due to the coarse grain observation periods, this method is not expected to accurately represent the range of spatial movement any given occupant might exhibit. In order to account for unseen variations in spatial use, two additional weighting metrics are assigned to each occupant based on workspace arrangement and observed behavioral traces. Calculation methods and weighting of these values can be found in section III.D.i.c. above. Figure 51 shows the total Spatial Use Variation index results for each office. A significant portion of the offices in the study population were arranged to support some degree of flexible use and of those, behavioral traces of actual flexible use were seen more frequently in 3rd floor offices than 4th floor offices. This same trend is also seen in the relative view orientation variation among 3rd floor offices. Figure 52 shows that 3rd floor occupants of south-facing offices vary their relative view orientation nearly twice as often as occupants in north-facing and 4th floor offices. Occupants of 3rd floor perimeter offices also vary their relative view orientation more frequently on average than occupants of interior and 4th floor offices (Figure 53). This suggests that varying relative view orientation may be related to glare or daylight conditions, but if this behavior were driven by glare incidence then occupants of 4th floor offices would also be expected to vary their relative view orientation more frequently than occupants of other areas of the building. Figure 54 and Figure 55 suggest that there may be other factors besides lighting conditions contributing to spatial use variation including the base orientation of the occupants' primary workstation and the location of the workstation in relation to the source of daylight. Despite these indications, no clear relationship between either lighting conditions or spatial attributes emerges from this data.

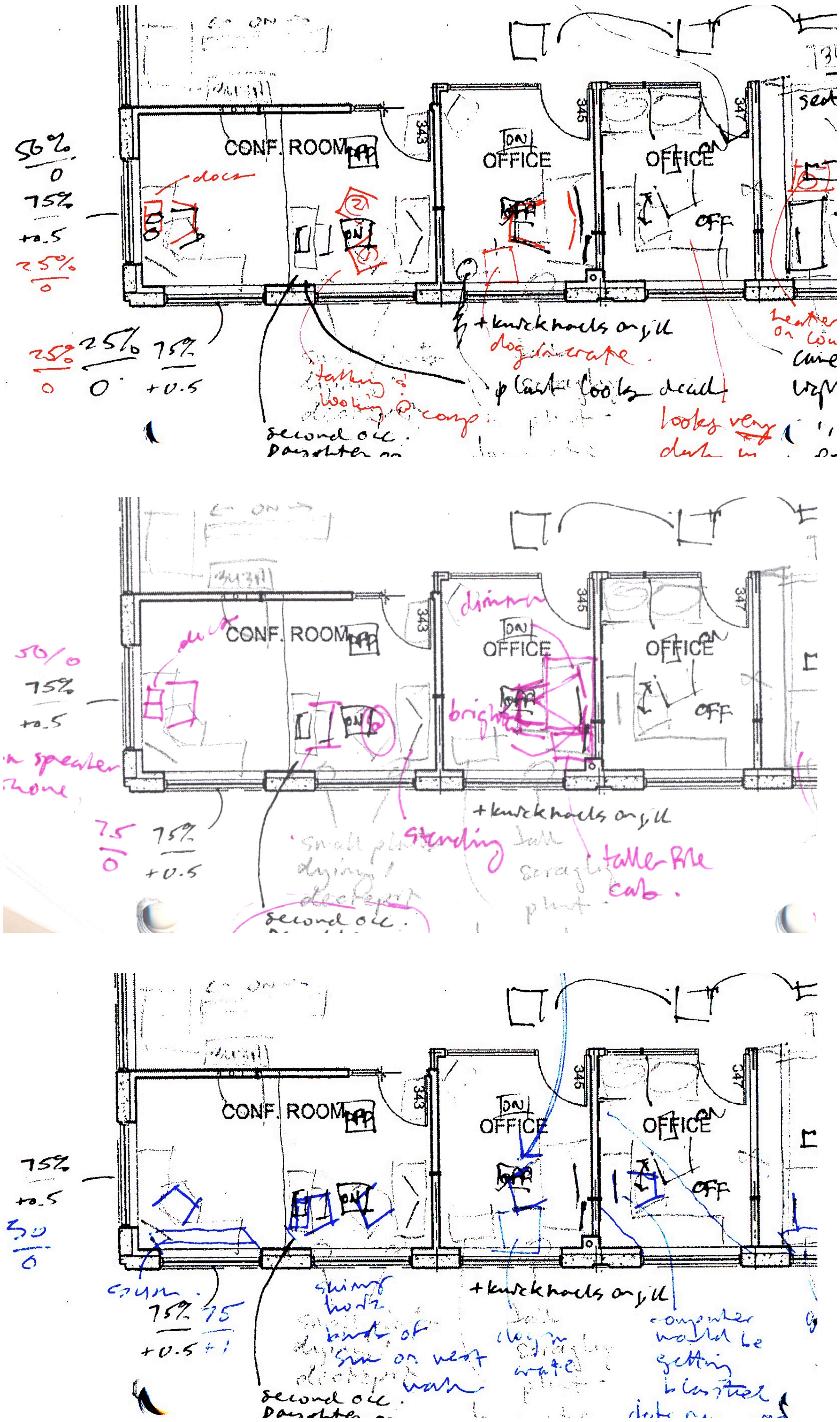


Figure 50: Example of behavioral maps showing spatial use variation mapping of offices #002, 003, 005, and 007 over three sequential observation periods

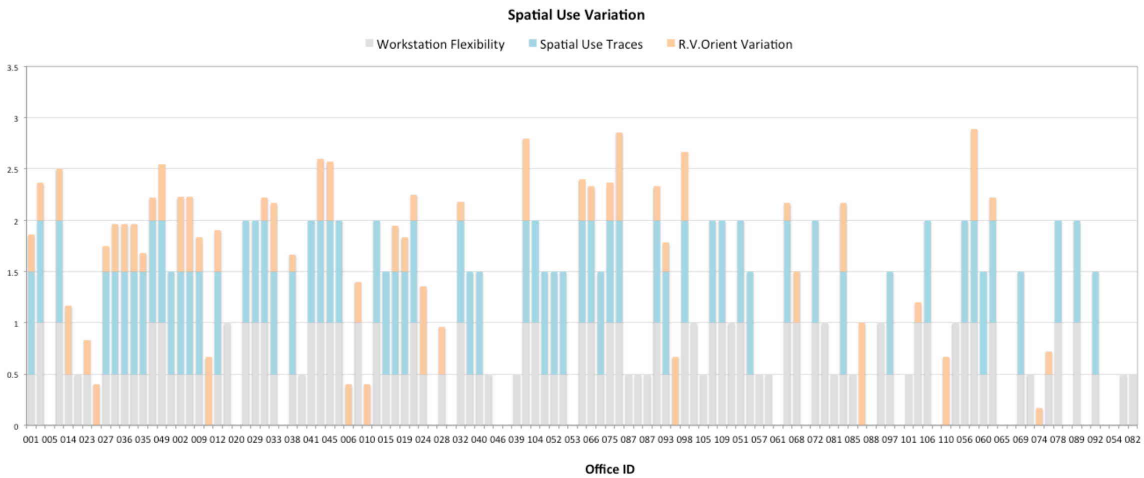


Figure 51: Spatial use variation index including relative view orientation variation, workspace flexibility, and spatial use traces for each office within the study population.

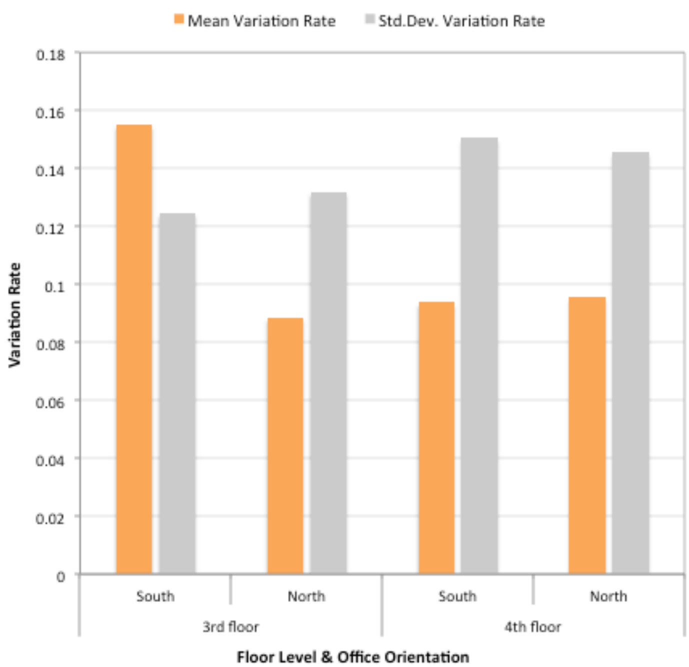


Figure 52: Mean and standard deviation of observed variation rate of Occupant Relative View Orientation according to floor level and office orientation.

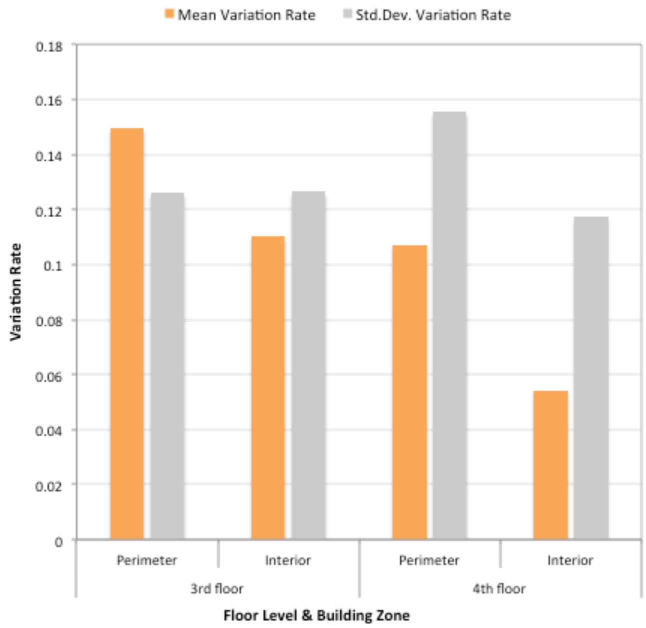


Figure 53: Mean and standard deviation of observed variation rate of Occupant Relative View Orientation according to floor level and building zone.

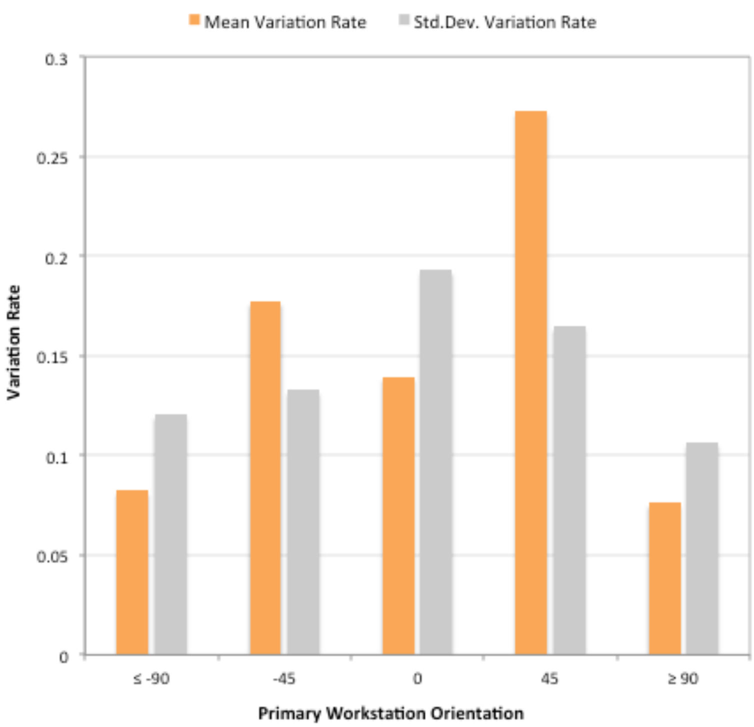


Figure 54: Mean and standard deviation of observed variation rate of Occupant Relative View Orientation according to primary workstation orientation.

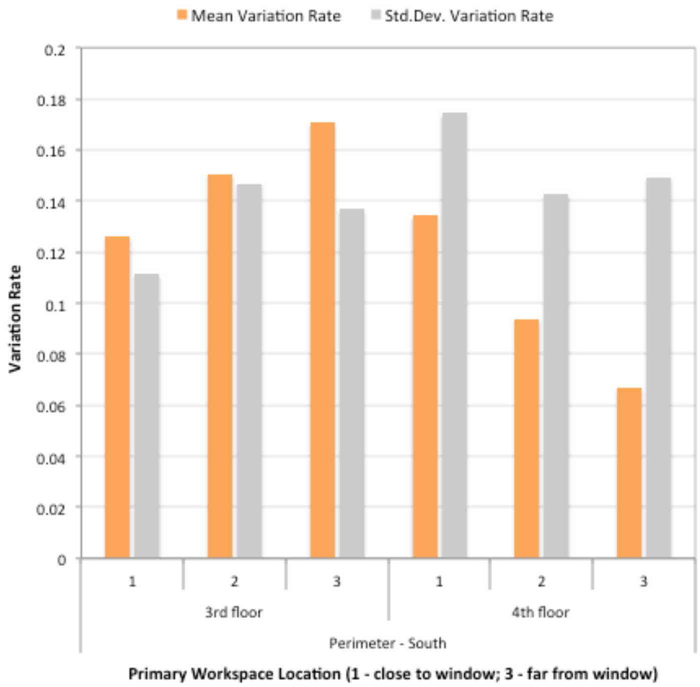


Figure 55: Mean and standard deviation of observed variation rate of Occupant Relative View Orientation in south perimeter offices grouped by floor level and workspace location relative to the exterior window (1 – close to window, 3 – far from window).

IV.G. <u>Glare Response Sensitivity Index</u>

This section reports on results of the questionnaire analysis based on the parameters established in section III.D.ii. above. 91 participants responded to the survey within the study period (77% response rate) but 4 respondents did not complete the survey and were excluded from this analysis (74% completion rate). An additional 8 responses were excluded from the results reported herein because the respondent did not have a primary workspace located within the study area. The final survey population (n=79) represents approximately 67% of the study participants who have a primary workspace within the study area. Bivariate and multivariate relationships between questionnaire item measures for the purposes of defining specific item measures to include in the Glare Response Sensitivity (GRS) index are described in Appendix F. Final index parameters based on paired item measures can be seen in Table 10. A summary of index results can be seen in Table 11. GRS index results are mapped onto floor plans showing office locations and distribution of GRS index results in Figure 56. While some patterns are apparent in the initial GRS index results, they do not appear to overtly correspond to any of the major spatial sub-groupings or lighting parameter results. Respondents from 4th floor offices show greater variation in GRS index results and tend to be more sensitive on average than 3rd floor respondents. Within nearby office adjacencies, GRS index results on occasion show significant variation.

Table 10: Final index parameters based on paired item measures indicating sensitivity or tolerance to glare.

	Sensitive		Tolerant	
	+ 0.75	+ 1	+ 0.5	+ 0.25
[P2] Q29 Number of report sources of discomfort	*≥ 3*	*< 3*	*< 3*	*≥ 3*
[P2] Q14-1 Frequency of problematic glare	*Frequent*	*Frequent*	*Infrequent*	*Infrequent*
[P3] Q49-3 Perceived Control over Glare from Daylight	*Low / None*	*Mod / High*	*Mod / High*	*Low*
[P3] Q14-2 Desire more control over Daylight	*Agree*	*Agree*	*Disagree*	*Disagree*
[P4] Q52-11 Open/close shades partially	*≥ sometimes*	*≥ sometimes*	*Rarely/Never*	*Rarely/Never*
[P4] Q52-4 Adjust seated position	*Rarely/Never*	*≥ sometimes*	*Rarely/Never*	*≥ sometimes*

Table 11: Summary table of Glare Response Sensitivity Index rankings across respondent groupings.

		3rd floor				**4th floor**				
			Perimeter		Int.		Perimeter		Interior	
	ALL	ALL	South	North	South	ALL	South	North	South	North
Sample (n=)	79	33	15	4	8	46	14	9	16	9
Tolerant (≤1.5)	40	20	8	3	5	20	4	5	7	5
Tolerant (%)	*50.6%*	*60.6%*	*53.3%*	*75.0%*	*62.5%*	*43.5%*	*28.6%*	*55.6%*	*43.8%*	*55.6%*
Sensitive (>1.5)	39	13	7	1	3	26	10	4	9	4
Sensitive (%)	*49.4%*	*39.4%*	*46.7%*	*25.0%*	*37.5%*	*56.5%*	*71.4%*	*44.4%*	*56.3%*	*44.4%*
Mean Value	1.709	1.598	1.650	1.438	1.625	1.788	1.946	1.861	1.672	1.861
Median Value	1.5	1.5	1.5	1.375	1.5	1.75	1.875	1.5	1.75	1.5
Std.Dev.	0.419	0.369	0.376	0.239	0.482	0.438	0.440	0.639	0.326	0.639

Figure 56: Glare Response Sensitivity (GRS) index results mapped onto floor plans to show spatial distribution of GRS index results.

IV.H. Parametric Analysis of Occupants' Behavioral Outcomes

This section first details cluster analysis results for study participants in each previously defined lighting and spatial cluster. Results of the initial analysis of lighting and spatial clusters will then be compared to multi-level cluster analysis including results of the Glare Response Sensitivity Index in order to determine whether the index results improve correlations between environmental factors and behavioral outcomes, as is expected by the conceptual model. Statistical tests for correlation between environmental factors and behavioral outcomes include Pearson's correlation coefficients (r), Spearman's correlation coefficient for ranked values (ρ), and linear correlation coefficients of scatter plot data (r^2).

IV.H.i. Lighting Parameters

This section provides an overview of final correlations between the lighting clusters identified in previous sections and behavioral outcomes – exterior window occlusion, interior window occlusion, electric lighting use and spatial use. Results of correlation tests for bivariate measures including P-value (r) and Spearman's ranked correlation coefficient (ϱ) for the entire study population are shown in Table 12.

Table 12: Summary of correlation between lighting clusters (annual solar exposure, glare potential, and useful daylight expectation) and behavioral outcomes (exterior window occlusion index, interior window occlusion index, electric lighting use index, spatial use variation index, and average controls use).

		Exterior Window Occlusion Index	Interior Window Occlusion Index	Electric Lighting Use Index	Spatial Use Variation Index	Average Controls Use
90% confidence		*±4.499*	*±7.879*	*±0.064*	*±0.115*	*±2.586*
ASE	(r)	0.289	0.287	0.021	-0.142	0.292
	(ϱ)	0.212	0.309	0.078	-0.150	0.290
GP	(r)	0.458	0.094	-0.084	0.044	0.238
	(ϱ)	0.389	0.083	0.022	0.024	-0.168
uDE	(r)	-0.417	-0.053	0.096	-0.144	-0.214
	(ϱ)	-0.401	-0.044	0.079	-0.132	-0.154

IV.H.ii. Spatial Parameters

This section provides an overview of correlation results between the lighting clusters and behavioral outcomes within each of the spatial clusters in order to identify how correlations vary within each spatial cluster. The results of this analysis, seen in Table 13, Table 14, and Table 15 below, support observations from initial behavioral data showing that higher incidences of exterior window occlusion in 4th floor offices than 3rd floor offices as well as in south-facing offices than north-facing offices. 4th floor offices show stronger correlations between exterior window occlusion and ASE (r_{ASE}=0.176) as well as GP (r_{GP}=0.445) compared to 3rd floor offices (r_{ASE}=0.140, r_{GP}=0.290). Similar results are obtained for south-facing offices (r_{GP}=0.415) compared to north-facing offices (r_{GP}=0.154).

Table 13: Summary of correlation between ASE & observed behaviors in 3rd and 4th floor offices.

ASE		Exterior Window Occlusion Index	Interior Window Occlusion Index	Electric Lighting Use Index	Spatial Use Variation Index	Average Controls Use
3rd Floor	*90% confidence*	*±5.336*	*±12.570*	*±0.103*	*±0.156*	*±0.069*
	(r)	0.140	0.234	-0.583	0.142	-0.062
	(ϱ)	0.129	0.286	-0.480	0.116	0.009
4th Floor	*90% confidence*	*±9.309*	*±12.511*	*±0.105*	*±0.182*	*±0.083*
	(r)	0.176	0.068	-0.288	-0.043	-0.039
	(ϱ)	0.078	0.019	-0.211	0.037	-0.082

Table 14: Summary of correlations between GP & observed behaviors within 3rd floor, 4th floor, interior, perimeter, north, and south office groupings.

GP		Exterior Window Occlusion Index	Interior Window Occlusion Index	Electric Lighting Use Index	Spatial Use Variation Index	Average Controls Use
3rd Floor	*90% confidence*	*4.487*	*7.934*	*0.068*	*0.120*	*0.039*
	(r)	0.290	-0.003	-0.287	0.104	0.051
	(ϱ)	0.248	-0.017	-0.221	0.071	0.040
4th Floor	*90% confidence*	*7.690*	*7.473*	*0.064*	*0.118*	*0.045*
	(r)	0.445	0.114	0.008	0.132	0.303
	(ϱ)	0.405	0.152	0.080	0.100	0.276
Interior	*90% confidence*	-	*7.605*	*0.062*	*0.132*	*0.032*
	(r)	-	-0.149	0.058	0.080	-0.124
	(ϱ)	-	-0.122	0.063	0.048	-0.091
Perimeter	*90% confidence*	*4.721*	*7.558*	*0.064*	*0.105*	*0.046*

	(r)	0.458	0.283	-0.067	-0.189	0.315
	(ϱ)	0.389	0.282	-0.034	-0.169	0.271
North	*90% confidence*	*5.682*	*9.619*	*0.090*	*0.172*	*0.038*
	(r)	0.154	0.016	-0.332	0.182	-0.130
	(ϱ)	0.133	0.023	-0.276	0.194	-0.079
South	*90% confidence*	*5.811*	*6.497*	*0.054*	*0.097*	*0.039*
	(r)	0.415	0.039	-0.050	0.012	0.221
	(ϱ)	0.386	0.027	-0.016	-0.013	0.167

Table 15: Summary of correlations between uDE and observed behaviors within 3rd floor, 4th floor, interior, perimeter, north, and south office groupings.

uDE		Exterior Window Occlusion Index	Interior Window Occlusion Index	Electric Lighting Use Index	Spatial Use Variation Index	Average Controls Use
3rd Floor	*90% confidence*	*4.487*	*7.934*	*0.068*	*0.120*	*0.039*
	(r)	-0.212	0.033	0.263	-0.166	-0.008
	(ϱ)	-0.252	0.077	0.306	-0.140	0.058
4th Floor	*90% confidence*	*7.690*	*7.473*	*0.064*	*0.118*	*0.045*
	(r)	-0.429	-0.092	-0.012	-0.168	-0.320
	(ϱ)	-0.401	-0.086	0.017	-0.150	-0.232
Interior	*90% confidence*	-	*7.605*	*0.062*	*0.132*	*0.032*
	(r)	-	0.173	-0.123	-0.063	0.088
	(ϱ)	-	0.125	-0.110	-0.097	0.050
Perimeter	*90% confidence*	*4.721*	*7.558*	*0.064*	*0.105*	*0.046*
	(r)	-0.417	-0.341	0.068	0.203	-0.327
	(ϱ)	-0.401	-0.338	0.041	0.180	-0.285
North	*90% confidence*	*5.682*	*9.619*	*0.090*	*0.172*	*0.038*
	(r)	-0.357	0.183	0.410	-0.538	0.276
	(ϱ)	-0.342	0.247	0.371	-0.557	0.252
South	*90% confidence*	*5.811*	*6.497*	*0.054*	*0.097*	*0.039*
	(r)	-0.309	-0.047	0.028	-0.022	-0.244
	(ϱ)	-0.334	-0.059	0.035	-0.008	-0.200

IV.H.iii. Glare Response Sensitivity Index

This section describes the results of final correlation tests between lighting/spatial clusters and behavioral outcomes. Aggregate results of correlations for GRS index values of all survey respondents can be seen in Table 16. The GRS index shows stronger correlations to the lighting clusters than to observed behaviors and on most measures the ranked values are more strongly correlated than the unranked values. This seems to indicate that the GRS index captures a relatively accurate representation of environmental conditions. Individual index parameters tend to show stronger correlations with observed behaviors than the combined GRS index. Ranked interior window occlusion and electric lighting use behaviors show the strongest relationships with GRS index results. Contrary to expectations however, many of the behavioral correlations are negatively related to the GRS index and GRS parameters, suggesting that respondents rated as more sensitive by the GRS index or parameters tend to display more *active* behavioral responses than those rated as tolerant. The scatter plots show in Figure 57-Figure 60 below display the overall tendency of observed behaviors to negatively relate to GRS index parameters. Considering the stronger correlations between individual index parameters and behavioral measures, this result may suggest a flaw in the construction of the GRS index or in its assumptions about how glare sensitive versus glare tolerant individuals respond to discomfort glare.

Table 16: Summary of correlations between Glare Response & Sensitivity Index (GRSI) results/GRSI Parameters with lighting clusters (annual solar exposure, glare potential, and useful daylight expectation) and behavioral outcomes (exterior window occlusion, interior window occlusion, electric lighting use, and spatial use variation).

		Annual Solar Exposure (ASE)	Glare Potential (GP)	Useful Daylight Expectation (uDE)	Exterior Window Occlusion Index	Interior Window Occlusion Index	Electric Lighting Use Index	Spatial Use Variation Index
	90% confidence	*±1.042*	*±0.235*	*±0.189*	*±3.608*	*±5.826*	*±0.051*	*±0.096*
	correlation							
GRSI	(r)	0.132	0.279	-0.292	0.051	0.074	-0.155	0.054
	(ϱ)	0.173	0.241	-0.284	0.069	-0.614	-0.465	-0.127
Parameter 2	(r)	-0.094	0.004	0.001	-0.095	-0.045	-0.116	0.094
	(ϱ)	-0.108	-0.0319	-0.003	-0.689	-0.729	-0.645	-0.128
Parameter 3	(r)	-0.056	0.158	0.015	0.041	0.035	-0.023	-0.082
	(ϱ)	-0.068	0.155	0.015	-0.705	-0.729	-0.697	0.024
Parameter 4	(r)	0.378	0.335	-0.550	0.169	0.134	-0.161	0.110
	(ϱ)	0.488	0.331	-0.587	-0.569	-0.016	-0.216	-0.150

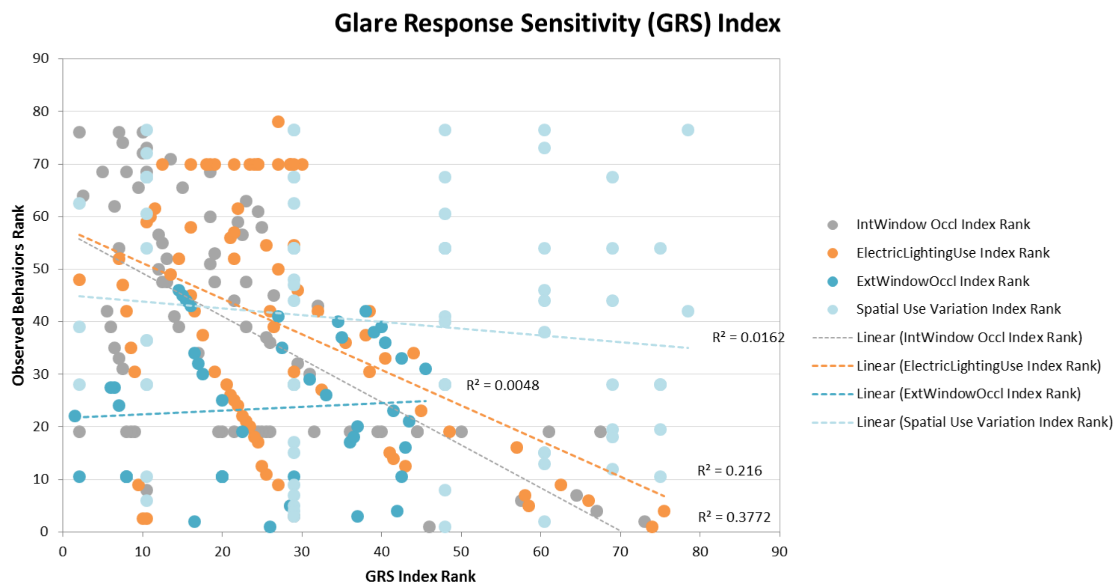


Figure 57: Scatter plot showing linear correlations between ranked values of Glare Response Sensitivity (GRS) index and observed behaviors.

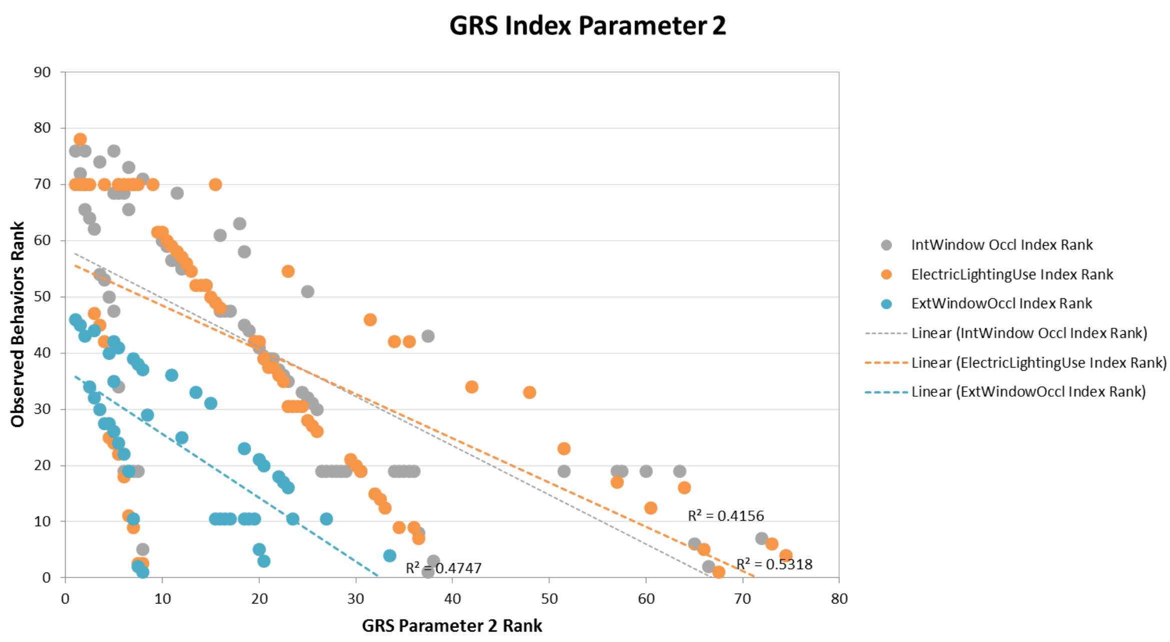


Figure 58: Scatter plot showing linear correlations between ranked values of GRS parameter 2 and observed behaviors.

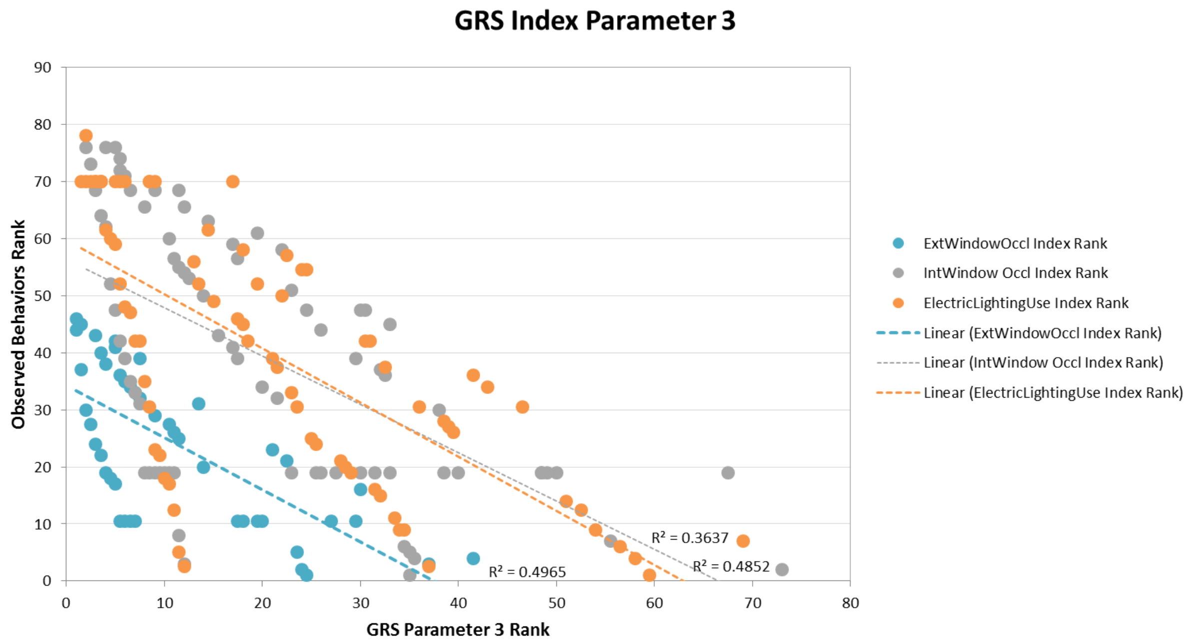


Figure 59: Scatter plot showing linear correlations between ranked values of GRS parameter 3 and observed behaviors.

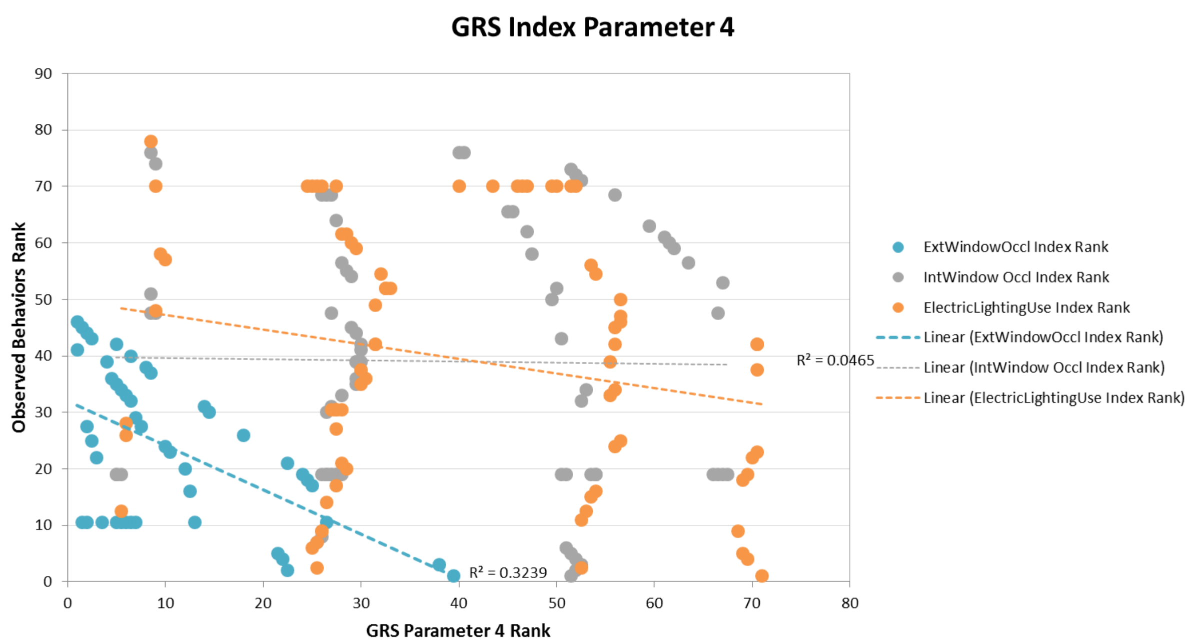


Figure 60: Scatter plot showing linear correlations between ranked values of GRS parameter 4 and observed behaviors.

Due to the moderately to high correlations seen between GP / uDE clusters and observed behaviors in the previous section, the question remains whether the relatively weak correlations between GRS index results and observed behaviors can be explained by a partial correlation between lighting clusters, GRS index, and observed behaviors. Results of the partial correlation test show the estimated impact of the correlation between GRS index and observed behaviors on the correlation between lighting clusters and observed behaviors. As seen in the results below (Table 17 and Table 18), the relationship between lighting clusters, GRS index, and observed behaviors is not consistent across different behavior types. Factoring out the effects of the GRSI from the correlation between GP & exterior window occlusion (0.41179), the partial correlation between GP & exterior window occlusion is 0.45404. The partial correlation is slightly higher than the observed correlation between GP & exterior window occlusion indicating that the GRSI may have a dampening effect, if any, on the relationship between GP & exterior window occlusion. Similar results are obtained regarding electric lighting use and spatial use variation with regards to GP. The partial correlation results, factoring out effects of the GRS index, between GP and interior window occlusion (r=0.071) is lower than the originally observed correlation between GP and interior window occlusion (r=0.088) indicating that the GRS index results may have a small positive effect on the correlation between GP and interior window occlusion. This suggests that individuals who are rated as more sensitive according to the GRS index results are more likely to occlude their interior window more frequently as glare potential increases. Contrary to expectations, a similar result is seen regarding spatial use variation whereby individuals who are rated as more sensitive according to the GRS index results are more likely to vary their orientation more frequently or have a flexible workspace arrangement in areas with higher glare potential. Similar results are seen in the partial correlation analysis of uDE, GRS index and behavioral observations, and once again dampening effects of the GRS index are observed within exterior window occlusion and electric lighting use behaviors while amplifying effects of the GRS index are observed within interior window occlusion and spatial use variation behaviors.

Table 17: Results of multiple & partial correlation tests between Glare Response Sensitivity (GRS) index, Glare Potential (GP), and behavioral outcomes.

Glare Response Sensitivity Index (x) + Glare Potential (y)		Exterior Window Occlusion	Interior Window Occlusion	Electric Lighting Use	Spatial Use Variation	Average Controls Use
Pearson's r	r_{xz}	*0.051*	*0.074*	*-0.155*	*0.054*	*0.035*
	r_{yz}	**0.412**	**0.088**	**0.005**	**0.145**	**0.242**
	r_{xy}	*0.279*	*0.279*	*0.279*	*0.279*	*0.279*
Multiple correlation	r	*0.417*	*0.102*	*0.163*	*0.146*	*0.245*
	r^2	*0.174*	*0.010*	*0.027*	*0.021*	*0.060*
	adj. r^2	**0.368**	**0.129**	**0.006**	**0.067**	**0.188**

Partial correlation						
	$r_{z(x,y)}$	*-0.066*	*0.052*	*-0.163*	*0.015*	*-0.034*
	$r_{z(x,y)}^2$	*0.004*	*0.003*	*0.027*	*0.000*	*0.001*
	$r_{z(y,x)}$	*0.414*	*0.070*	*0.051*	*0.135*	*0.242*
	$r_{z(y,x)}^2$	*0.171*	*0.005*	*0.003*	*0.018*	*0.059*
	$r_{zx,y}$	*0.082*	*0.052*	*0.161*	*0.015*	*0.036*
	$r_{zy,x}$	**0.454**	**0.071**	**0.051**	**0.137**	**0.250**

Table 18: Results of multiple & partial correlation tests between Glare Response Sensitivity (GRS) index, Useful Daylight Expectation (uDE), and behavioral outcomes.

Glare Response Sensitivity Index (x) + Useful Daylight Expectation (y)		Exterior Window Occlusion	Interior Window Occlusion	Electric Lighting Use	Spatial Use Variation	Average Controls Use
Pearson's r	r_{xz}	0.051	0.074	0.074	0.054	0.035
	r_{yz}	**-0.367**	**-0.072**	**0.056**	**-0.183**	**-0.221**
	r_{xy}	-0.292	-0.292	-0.292	-0.292	-0.292
Multiple correlation	r	0.372	0.091	0.110	0.183	0.223
	r^2	0.138	0.008	0.012	0.033	0.050
	$adj.\ r^2$	**0.293**	**0.138**	**0.122**	**0.090**	**0.158**
Partial correlation	$r_{z(x,y)}$	-0.059	0.056	0.095	0.001	-0.031
	$r_{z(x,y)}^2$	0.003	0.003	0.009	0.000	0.001
	$r_{z(y,x)}$	-0.368	-0.052	0.081	-0.175	-0.221
	$r_{z(y,x)}^2$	0.136	0.003	0.007	0.031	0.049
	$r_{zx,y}$	0.068	0.056	0.095	0.001	0.032
	$r_{zy,x}$	**0.396**	**0.053**	**0.081**	**0.178**	**0.226**

Despite the lack of clear significant relationships between lighting clusters, GRS index results and observed behaviors, there may still be trends in observed behaviors within subgroups of both the GRS index results and the lighting clusters. At least 4 distinct sub-populations emerge from the exterior window occlusion and electric lighting use data seen in the scatters plots above (Figure 57 through Figure 60). Each sub-population behaves similarly in regards to the GRS index and index parameters, but displays markedly different trajectories. This suggests additional factors, perhaps driven by personal, social, or spatial differences, affect the strength of the relationships between GRS index results and observed behaviors. Table 19 shows the different exterior window occlusion and electric lighting use outcomes among individuals rated as sensitive (GRS index >1.5) and tolerant (GRS index <1.5). Sensitive individuals on average occlude the exterior window less than individuals rated as tolerant but among the ranked window occlusion results tolerant individuals are more likely to be ranked lower (occlude the window less) than sensitive individuals. Consistently however, sensitive individuals on average use the electric lights less frequently and less intensely than tolerant individuals.

Table 19: Average exterior window occlusion and electric lighting use among respondents with GRS index results 1.5 or less (tolerant) and greater than 1.5 (sensitive).

		Average Exterior Window Occlusion (Rank)	Average Exterior Window Occlusion (#)	Average Electric Lighting Use (Rank)	Average Electric Lighting Use (#)
GRS index	< 1.5 (tolerant)	22.95	19.36	40.12	0.34
	> 1.5 (sensitive)	24.00	17.12	38.88	0.32

Differences in behavioral outcomes among sensitive and tolerant individuals could be driven by lower intensity shade / electric lighting use or higher frequency shade / electric lighting use. Activity rates for both exterior shade use and electric lighting use are positively correlated to GRS index results indicating that individuals rated as more sensitive by the GRS index are more likely to vary their exterior shades and electric lights more frequently than individuals rated as tolerant (Table 20). This relationship can also be seen in the scatter plots shown in Figure 61 and Figure 62. This result is supported by the positive correlation seen between spatial use variation and sensitivity, which indicates that individuals rated as more sensitive are also more likely to vary their viewing orientation or have workspaces that support flexible space use than individuals rated as tolerant (Figure 57).

Table 20: Correlation between GRS index and exterior shade use activity and electric lighting use activity.

Glare Response Sensitivity (GRS) index	Ext. Window Occlusion Index	Exterior Shade Use Activity	Electric Lighting Use Index	Electric Lighting Use Activity
confidence	*±3.608*	*±1.708*	*±0.051*	*±0.033*
Pearson's (r)	0.051	0.012	-0.155	0.072
Speaman's (ϱ)	0.069	0.103	-0.465	0.248

While sensitive and tolerant individual display different behavioral outcomes overall, whether these differences are a product of lighting conditions and what commonalities exist between the subpopulations identified above is as of yet unknown. The series of scatter plots shown in Figure 63 through Figure 70 seem to indicate that these differences are not driven solely by differences in GP or uDE nor are they a result of the GRS index itself. If the subpopulation groupings were a result of large differences such as between floors or building orientations, comparisons between GP and uDE (seen in Figure 63 through Figure 66) should show emerging sub-populations. There are no trends observed in the data to suggest that differences in environmental lighting conditions can explain the sub-population groupings.

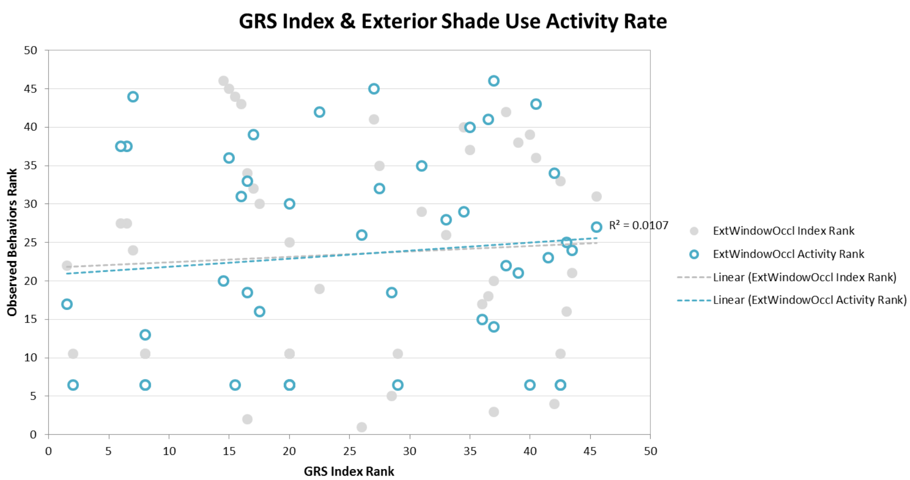


Figure 61: Scatter plot of Exterior Shade Use Activity rate and GRS index results.

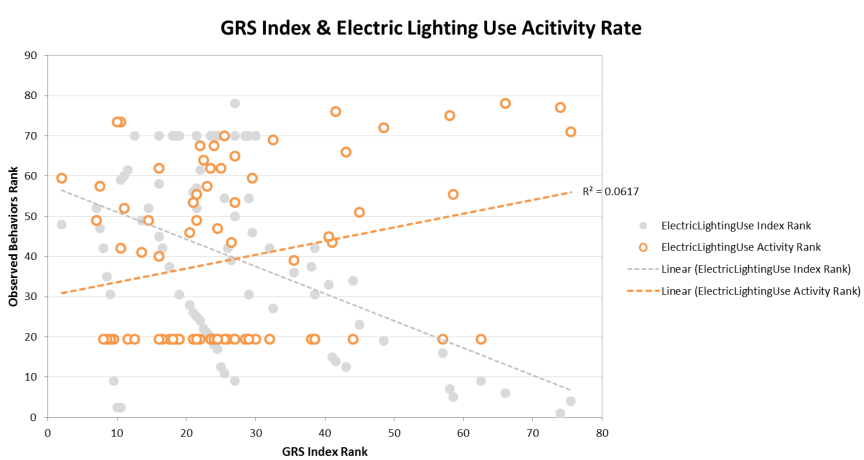


Figure 62: Scatter plot of Electric Lighting Use Activity rate and GRS index results.

Figure 63: Scatter plot showing relationship between exterior window occlusion & GRS index rankings within sub-50th percentile (<2.75) and over-50th percentile (>2.75) glare potential groupings.

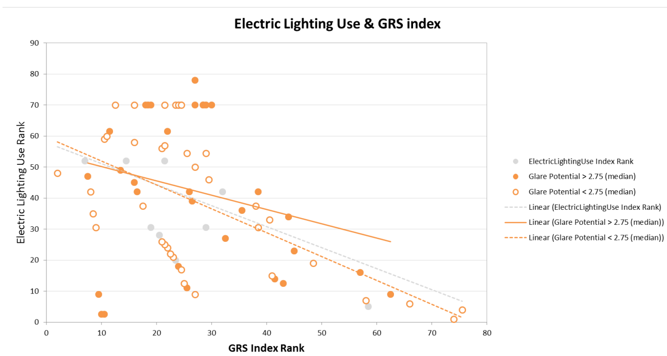


Figure 64: Scatter plot showing relationship between electric lighting use & GRS index rankings within sub-50th percentile (<2.75) and over-50th percentile (>2.75) glare potential groupings.

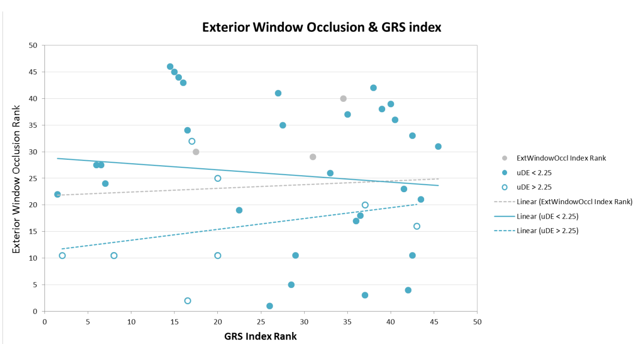


Figure 65: Scatter plot showing relationship between exterior window occlusion & GRS index rankings within sub-50th percentile (>2.25) and over-50th percentile (<2.25) useful daylight expectation groupings.

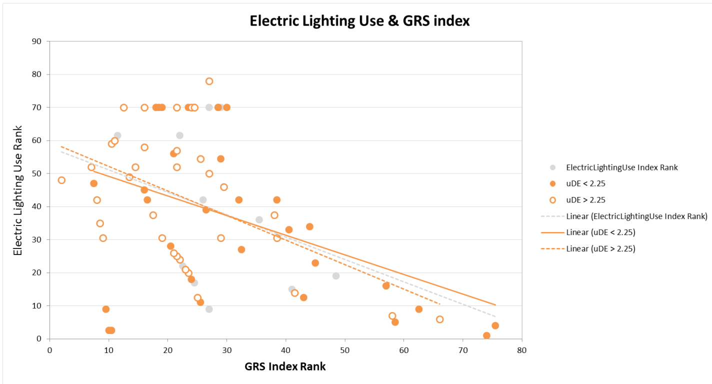


Figure 66: Scatter plot showing relationship between electric lighting use & GRS index rankings within sub-50th percentile (>2.25) and over-50th percentile (<2.25) useful daylight expectation groupings.

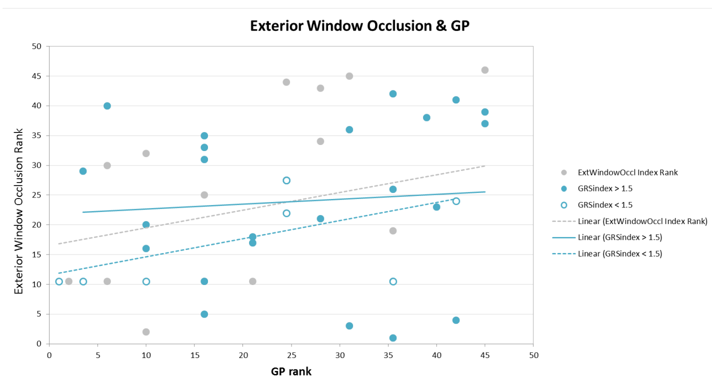


Figure 67: Scatter plot showing relationship between exterior window occlusion & glare potential (GP) rankings within tolerant (<1.5) and sensitive (>1.5) GRS index groupings.

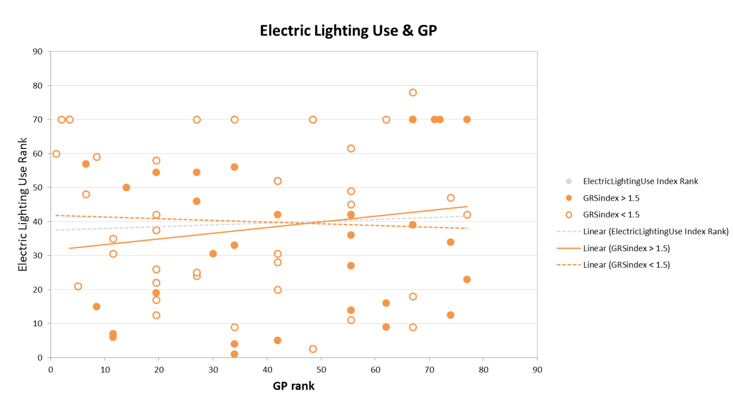


Figure 68: Scatter plot showing relationship between electric lighting use & glare potential (GP) rankings within tolerant (<1.5) and sensitive (>1.5) GRS index groupings.

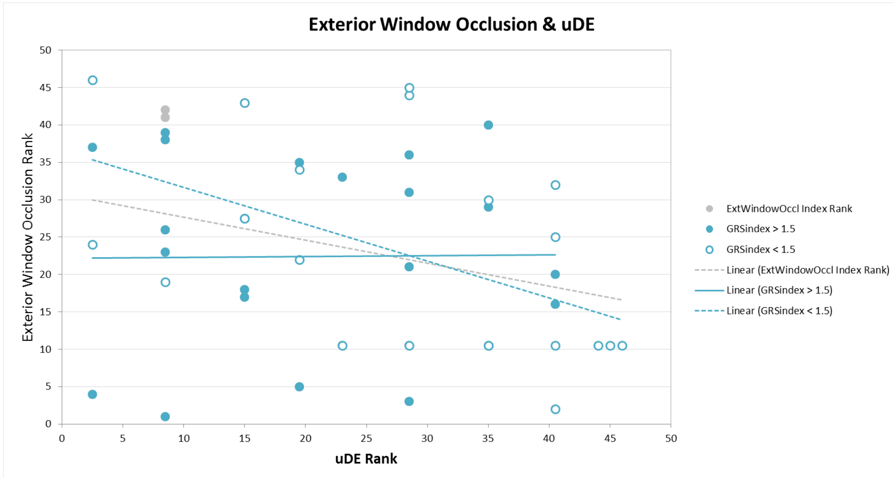


Figure 69: Scatter plot showing relationship between exterior window occlusion & useful daylight expectation (uDE) rankings within tolerant (<1.5) and sensitive (>1.5) GRS index groupings.

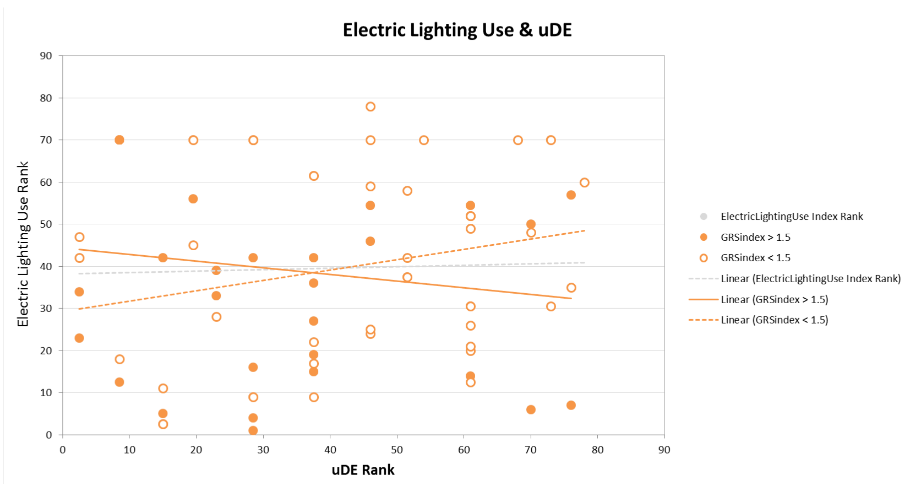


Figure 70: Scatter plot showing relationship between electric lighting use & useful daylight expectation (uDE) rankings within tolerant (<1.5) and sensitive (>1.5) GRS index groupings.

The results suggest that either personal differences between respondents, structural social differences between respondents, or spatial differences in the workspace environment may account for subpopulation grouping. While there is insufficient data to examine the personal or social aspects of the sub-populations, the effect of spatial differences can be seen in Figure 71 through Figure 76, which show the effect of office type of correlations between GRS index and GP on electric lighting use, exterior window occlusion, and activity rates. Electric lighting use and electric lighting use activity rates both show moderate correlations to sensitivity for occupants of open office cubicles and little to no correlation for occupants of enclosed offices. This is contrary to expectations because open office cubicles do not have individualized control of electric lighting yet sensitive individuals display more active electric lighting use behaviors in open offices than they do in enclosed offices. This result suggests that spatial factors influence the controls-use behaviors of sensitive individuals and may account for the sub-populations seen in the GRS index and index parameter results shown in Figure 57 through Figure 60 above.

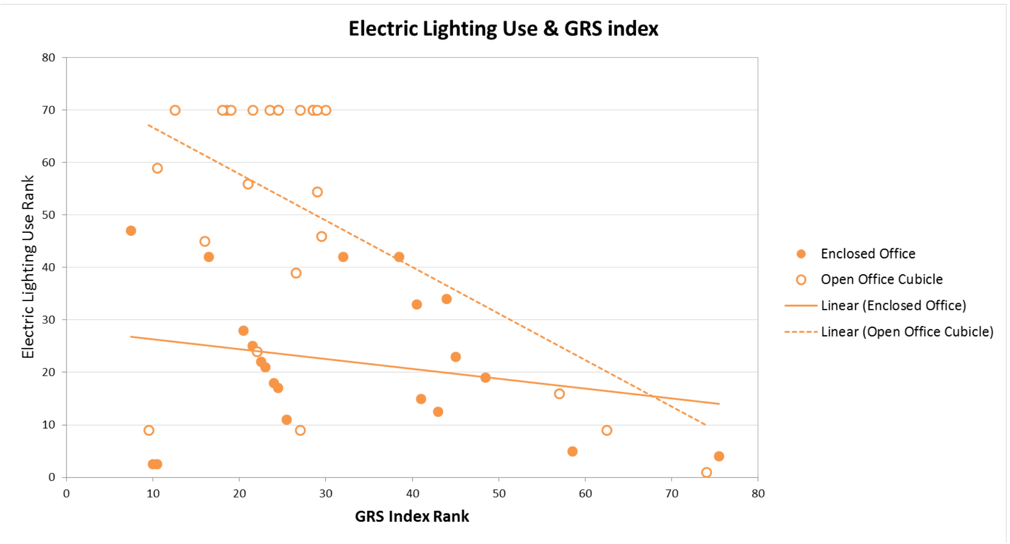


Figure 71: Scatter plot of ranked electric lighting use and GRS index results for enclosed offices and open office cubicles.

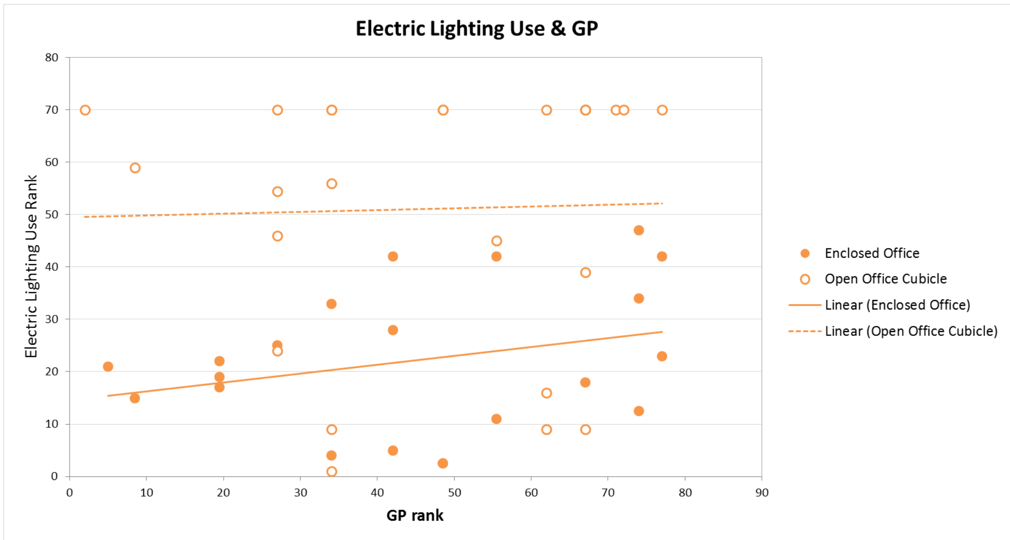


Figure 72: Scatter plot of ranked electric lighting use and GP values for enclosed and open office cubicles.

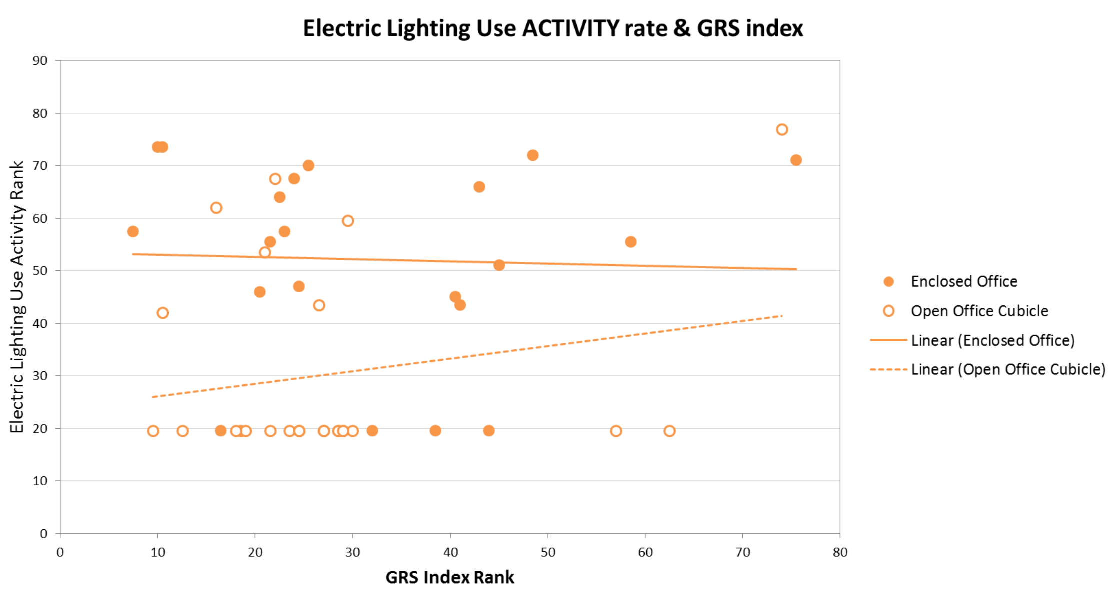


Figure 73: Scatter plot showing ranked electric lighting use activity rates and GRS index results for enclosed offices and open office cubicles.

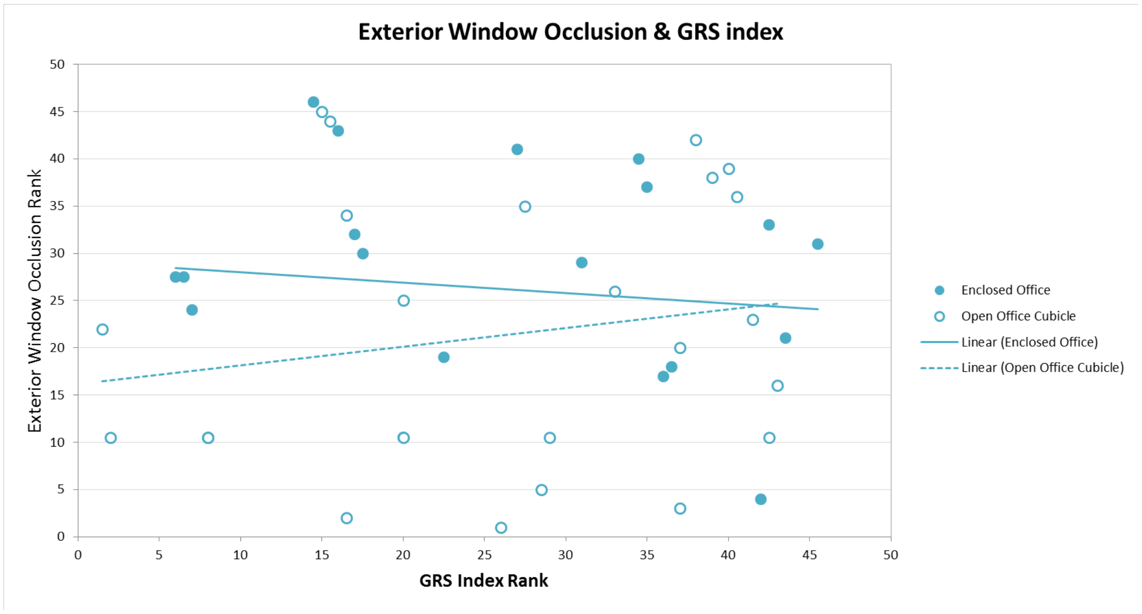


Figure 74: Scatter plot showing ranked exterior window occlusion and GRS index results for enclosed offices and open office cubicles.

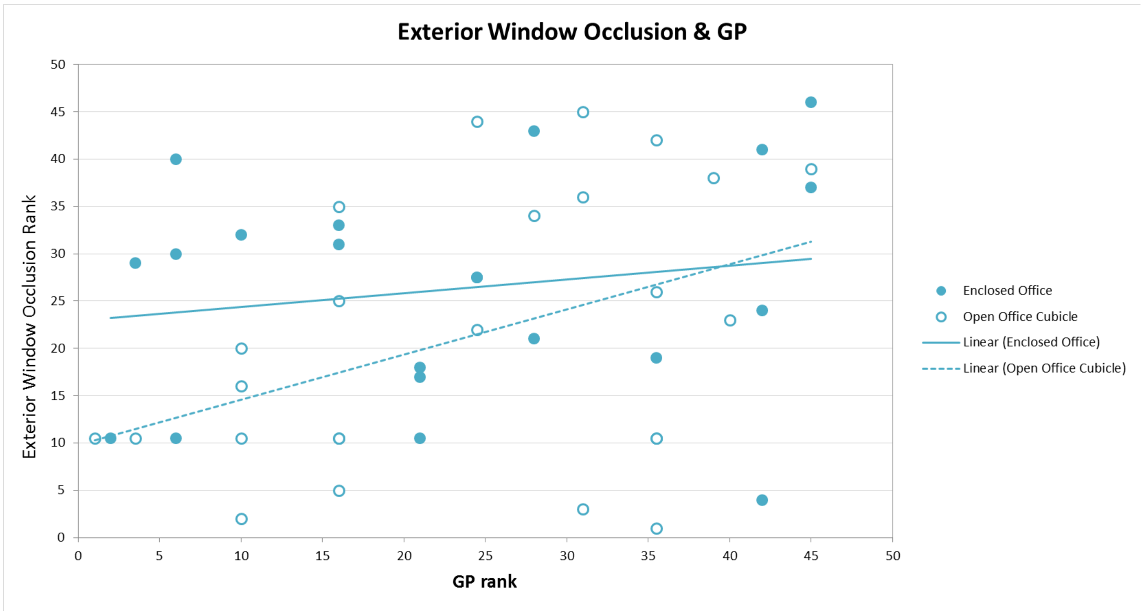


Figure 75: Scatter plots showing ranked exterior window occlusion and GP values for enclosed offices and open office cubicles.

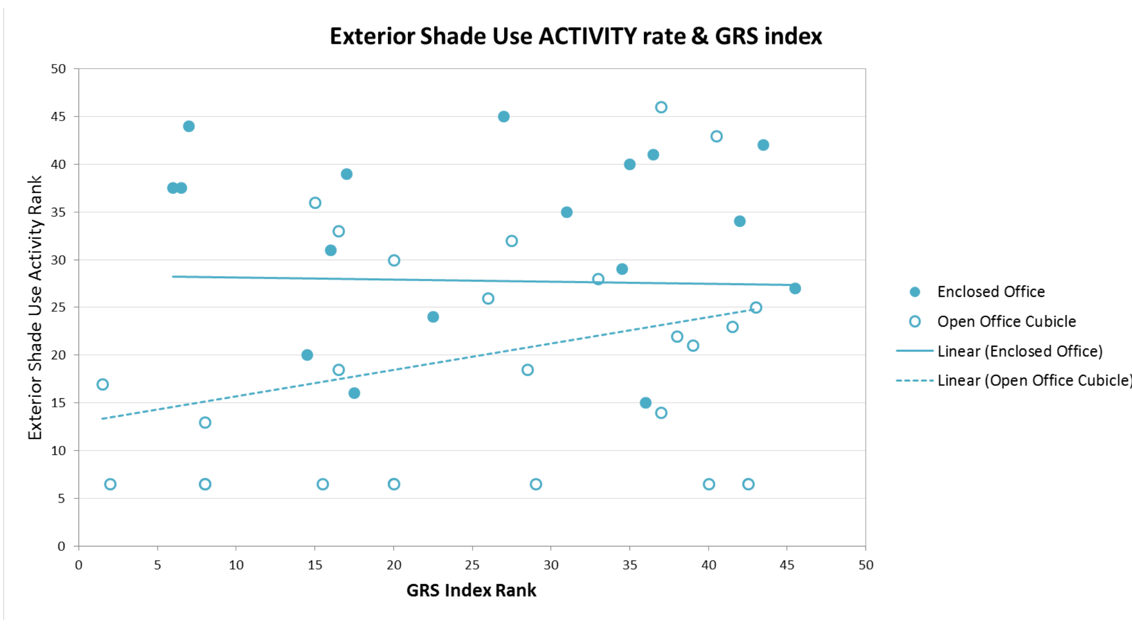


Figure 76: Scatter plot showing ranked exterior shade use activity rate and GRS index results for enclosed offices and open office cubicles.

CHAPTER V

CONCLUSIONS

The results of this study provide new information to help answer the research questions proposed at the beginning of the thesis. From the results of field lighting assessment and behavioral data, it is clear that occupants' controls use behaviors are influenced by both spatial and lighting conditions, but that the degree to which those behaviors directly relate to physical environmental conditions is mediated by the occupants' sensitivity as assessed by the Glare Response Sensitivity index. The mediating effect of sensitivity is evidenced by the partial dampening effect of the GRS index on the relationship between Glare Potential ratings and exterior shade use behaviors and the moderately strong relationships observed between GRS index results and electric lighting use and interior shade use behaviors and the moderate relationship with spatial use variation. The GRS index results show that it isn't just glare, or just daylight levels, that explains occupants' controls use behaviors, but that additional spatial factors as well as personal and social attributes mediate the relationship between lighting conditions and behavioral outcomes.

Many of the assumptions regarding expected relationship between glare sensitivity, environmental conditions, and behavioral responses were not directly supported by the data however. The conceptual model for this thesis assumes that if an individual is tolerant to glare, that is, if the Glare Response Sensitivity index ranks an individual as more tolerant to glare, then that individual is more likely to exhibit positive energy behaviors associated with *active* daylight and electric light controls use. This assumption was not supported by the data. The results show that tolerant individuals, as assessed by the Glare Response Sensitivity index, are less likely than sensitive individuals to occlude the interior and exterior windows, use electric lighting, and vary their spatial use patterns. This result does not invalidate the GRS index in so much as it fails to support the definitions of sensitive and tolerant glare response proposed in this thesis. The results suggest that sensitive glare response is marked by lower intensity and more frequent variation of shade use, electric lighting use, and spatial use patterns. While the GRS index results are not strongly correlated to observed behaviors in general, the individual index parameters show moderately strong correlations to observed behaviors. This suggests that while the index construction is flawed, the paired item measures in each parameter are consistent indicators of the target behavioral responses.

The results of the parametric analysis of GRS index results suggests that the GRS index measures perceptual sensitivity rather than sensitivity to discomfort. Higher perceptual sensitivity, in the context of this study, correlates to increased controls use frequency. In this regard, individuals rated as sensitive by the GRS index are more likely to display *active* controls use behaviors, while individuals rated as tolerant are more likely to display *passive* controls use behaviors. The data seems to indicate the key mechanism separating these two types of behaviors, *active* and *passive*, may be attention modulation. If an individual displays heightened perceptual sensitivity to discomfort glare conditions, as the results of the GRS index indicate, it follows that environmental stimuli is more likely attended to by the individual and that changes in environmental conditions are more likely to result in behavioral modifications. From this reading, it may be more accurate to describe individuals who are rated as tolerant by the GRS index results as 'insensitive' or 'inattentive' in that they are less likely to exhibit behavioral modifications in response to environmental changes. This conclusion is supported by the moderately strong positive correlation between controls use activity rate and GRS index sensitivity. In addition, this conclusion is supported by the high proportion of respondents who at least sometimes modify their seated position in response to discomfort as well as use the shades in response to discomfort. The higher likelihood of behavioral responses to discomfort conditions, indicating more frequent attention modulation, also appears to be related to the *active* behavioral pattern exhibited by individuals rated as sensitive by the GRS index.

The results of this study highlight an incongruity between actual level of environmental control, perceived level of environmental controls, and behavioral outcomes. The relationship between GRS index sensitivity and *active* controls use behaviors was stronger among occupants of open office cubicles than enclosed private offices, suggesting that higher levels of control over the environment may result in less frequent or more intense controls use. The stronger correlation between *active* controls use and GRS index sensitivity among open office occupants was only apparent after the parametric analysis of GRS index results, as the initial analysis of behavioral observations indicated that occupants of open office cubicles on average occluded their windows and used their electric lighting more than occupants of enclosed offices. This result indicates the usefulness of the GRS index to discern subtle patterns or trend of behaviors among a building population and validates continued research to determine the spatial factors that contribute to more *active* controls use behaviors.

V.A. Questions for Future Research

The results of this research may inform future studies of how and why building occupants control the lighting and spatial conditions in their workplace environments. Each of the questionnaire item measures and individual lighting / GRS index parameters need additional testing and verification to refine their applicability to other buildings or populations, but as a parametric analysis this study sets the stage for future research. Many questions emerge from the results of this study and distinct research paths could be taken to answer these questions. First, current GRS index results show defined sub-populations along the tolerant – sensitive rating scale and each exhibits markedly different behavioral patterns. This observation suggests that a crucial parameter may be missing from the current GRS index. The question then remains as to what parameter(s) link the sub-populations seen within GRS index results? Both experimental and quasi-experimental approaches could be taken to answer this question. Experimental approaches that target the extremes of the GRS index may seek to define the threshold between perceptual sensitivity that correlates to *active* behaviors and perceptual sensitivity that correlates to *passive* behaviors. Quasi-experimental approaches may seek to describe a population along a refined GRS index under multiple different scenarios in a factorial or longitudinal research design in order to identify the relationship between changes in the lighting and spatial environments and their effect on perceptual or behavioral outcomes. A quasi-experimental approach could be undertaken as part of a building retrofit or renovation that utilizes existing best practices and evidence-based workplace design methods. Quasi-experimental approaches could also outfit test-case offices within existing building populations to modulate specific spatial or lighting attributes and examine the relationship between changes in the physical environment and behavioral outcomes among individuals with known GRS index ratings.

An additional question emerging from this study is about the relationship between perceived control, actual control, and behavioral outcomes. The results of this study suggest that the relationship between sensitivity and *active* behavioral outcomes is stronger among occupants of open office cubicles than occupants of enclosed private offices. . Is there a threshold of actual control whereby the positive benefits associated with perceived control drop off? Comparative field studies of populations in open office arrangements with varying levels of control over daylight, electric lighting, and workspace arrangements could utilize the parametric approach of this study to control for daylight expectations and glare potential to hone in on the relationship between GRS index sensitivity and behavioral outcomes among the different populations.

V.B. Limitations

Many of the assumptions made in the course of constructing the different indices used to compare different environmental and behavioral metrics are based on objective, quantitative measurements obtained in the field but are interpreted solely through the study author's lens. External validation of index construction through means such as expert panel opinion or focus group survey could help to improve the objectivity of these indices particularly if these methods are repeated in a future study. As is, the procedures through which the Glare Potential, Useful Daylight Expectation, and Spatial Use Variation indices are created are highly site-specific. While some of the conclusions regarding observed relationships between these indices and behavioral outcomes might be found in other settings, the repeatability of these methods are limitations to the generalizability of findings. Despite these limitations, any errors in the creation of lighting and index parameters are systemic and thus do not negate the relationships observed between environmental / perceptual parameters and behavioral outcomes. The GRS index results show respondents fall along the full spectrum of tolerant to sensitive glare response but the distribution pattern of respondents along that index is perhaps a result of the index construction itself rather than a characteristic of the study population. Additional regression analysis is required to determine the precise relationship between components of the conceptual model.

The questionnaire used in this thesis is designed to accompany field observations and lighting assessment data but the methods used to corroborate questionnaire responses to specific offices were not robust. The balance between a questionnaire that produces a robust data set and a questionnaire that is convenient enough to ensure high response and completion rates is very difficult to achieve in a comparatively small sample size. There were numerous detailed questions about the respondent's workspace that were edited from the questionnaire during the revision process due to a concern about overall length and redundancy between survey responses and field data. In order to demonstrate the utility of a glare response profile, as its own behavioral assessment method, the questionnaire needs to be a free-standing assessment tool. Descriptive spatial responses, such as the one labeled 'discomfort glare' in Figure 77 below, could help produce a robust data set without burdening the respondent with tedious or confusing word-based questions. Further, the method used to gather spatial location data for each respondent's office was not as straightforward as planned. The questionnaire first asked for which floor the occupants' office was on and then displayed an image of the floor plan for them to click on the specific location of their office. Each response would be coded both as pixel coordinates and graphically as a cursor location or heat map over the floor plan. Some respondents had trouble reading a floor plan and often erred in marking the correct office either by switching north and south or selecting an adjacent office. This issue forced responses to be re-coded and corroborated manually whereas the whole point of this strategy was to simplify the coding process. A mistake only an architect would make. In addition, some item measures that are meant to be directly compared oscillated between statements about general phenomena, for example 'Glare from daylight is a frequent issue', and statements about specific attributes, such as 'Discomfort from lighting interferes with my work'. As a result, these measures did not produce consistent results and often produced contradictory results. This oversight had an inflated effect on comparability of certain item measures in this study population because many people had significantly divergent, often negative, feelings about the electric lighting. Future item measures intended to assess a perception or response to daylight specifically should reference daylight consistently within the question text. The above limitations regarding questionnaire responses emerge from the bivariate and multivariate item measure analysis and thus are not seen to impact the veracity of GRS index results.

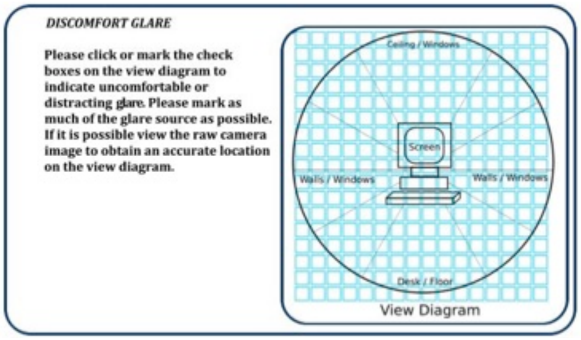
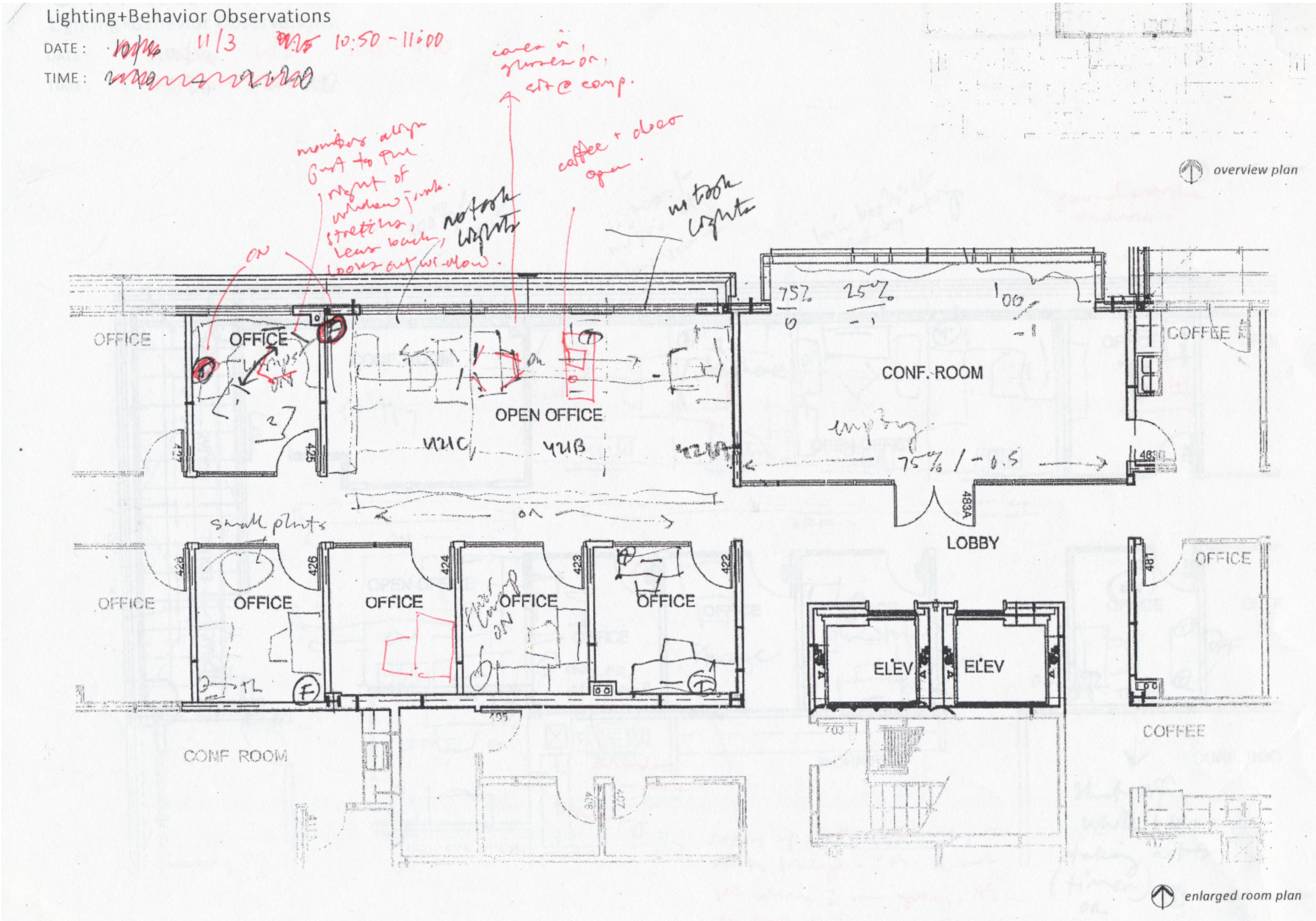


Figure 77: Post Occupancy Evaluation for lighting glare assessment (Hirning et al. 2013).

A further limitation of this study may result from the chosen study setting. The study setting had demonstrable deficiencies with regards to daylighting and controls integration that may have had a dampening effect on some of the relationships this study is designed to explore. Many confounding factors with regards to the layout of workspaces and differences between individual occupants exist. While these confounding factors are not expected to completely obscure any of the relationships between environmental parameters, perceptual parameters, and behavioral outcomes they limit any further reading of the results to ascribe causality to spatial attributes. While the confounding aspects of the study site perhaps limit the scope of conclusions possible, it underscores the possibility of the GRS index as a robust analytic tool for future field studies of how people behave in buildings.

APPENDIX A

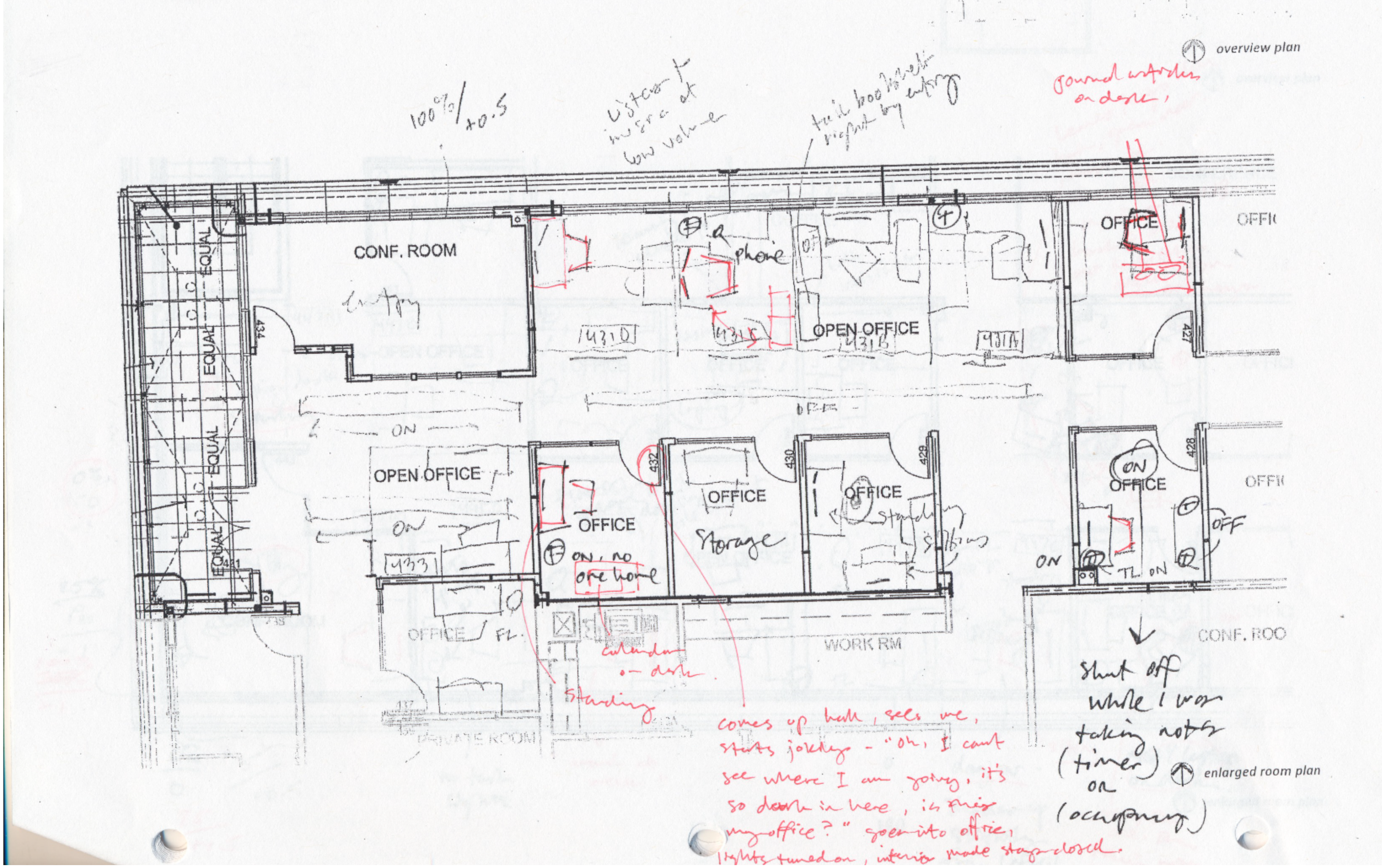
SAMPLE OF FIELD DATA INTAKE SHEETS & BEHAVIORAL MAPS

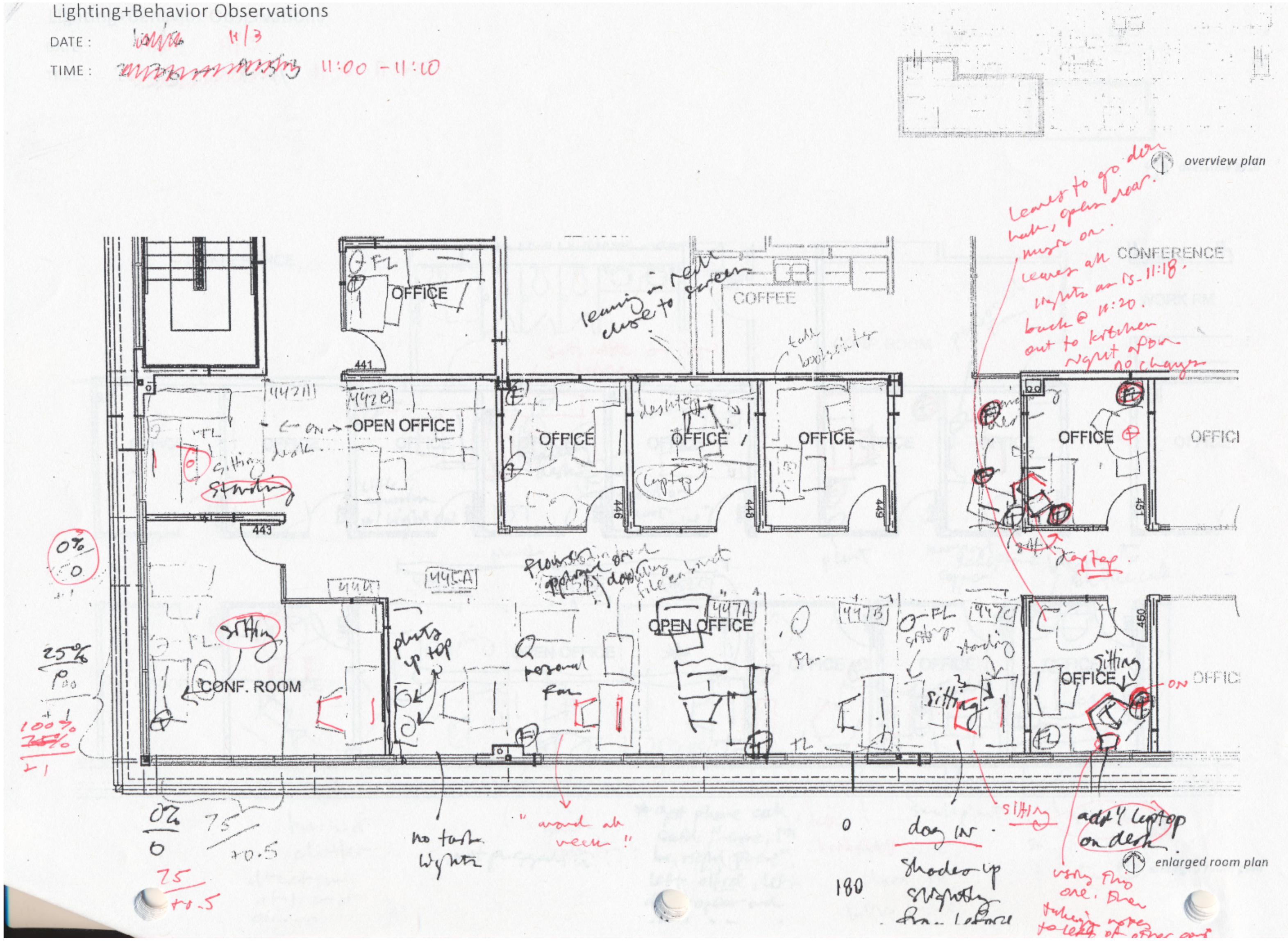

Lighting+Behavior Observations
DATE :
TIME :
overview plan
OFFICE
OFFICE
OPEN OFFICE
CONF. ROOM
COFFEE
LOBBY
OFFICE
OFFICE
OFFICE
OFFICE
OFFICE
OFFICE
ELEV
ELEV
COFFEE
CONF ROOM
enlarged room plan

Lighting+Behavior Observations

DATE : 1/13 11:00 - 11:10

TIME :

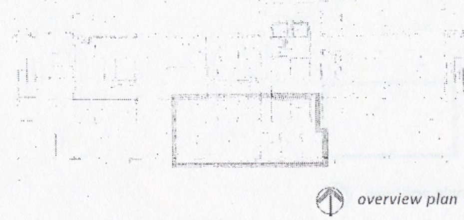


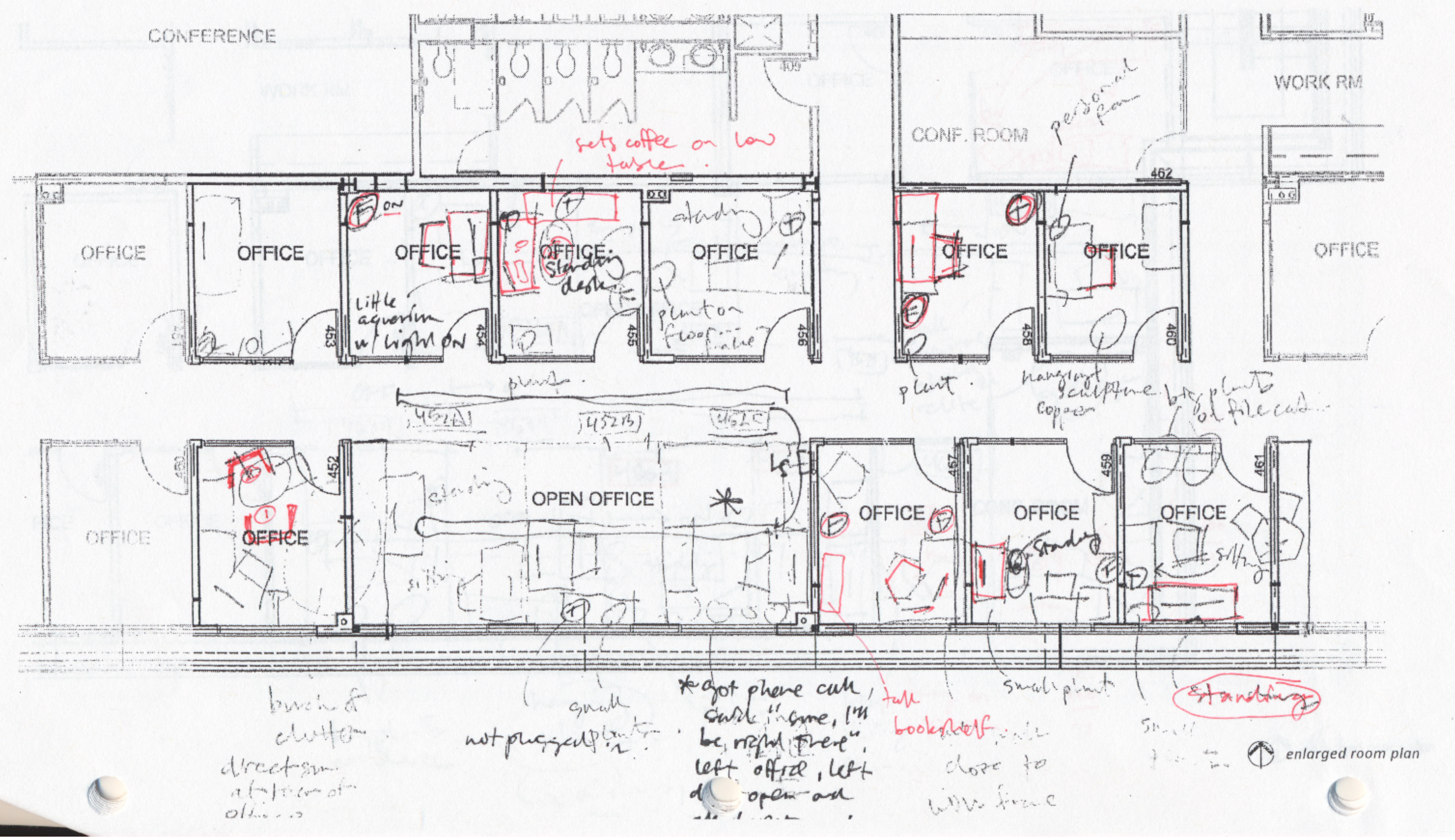

Lighting+Behavior Observations
DATE :
TIME :
overview plan
CONFERENCE
COFFEE
OFFICE
441
OPEN OFFICE
OFFICE
OFFICE
OFFICE
OFFICE
OFFICI
443
446
448
449
451
450
OPEN OFFICE
CONF. ROOM
OFFICE
OFFICI
enlarged room plan

Lighting+Behavior Observations

DATE : 11/3

TIME : 11:10 - 11:25



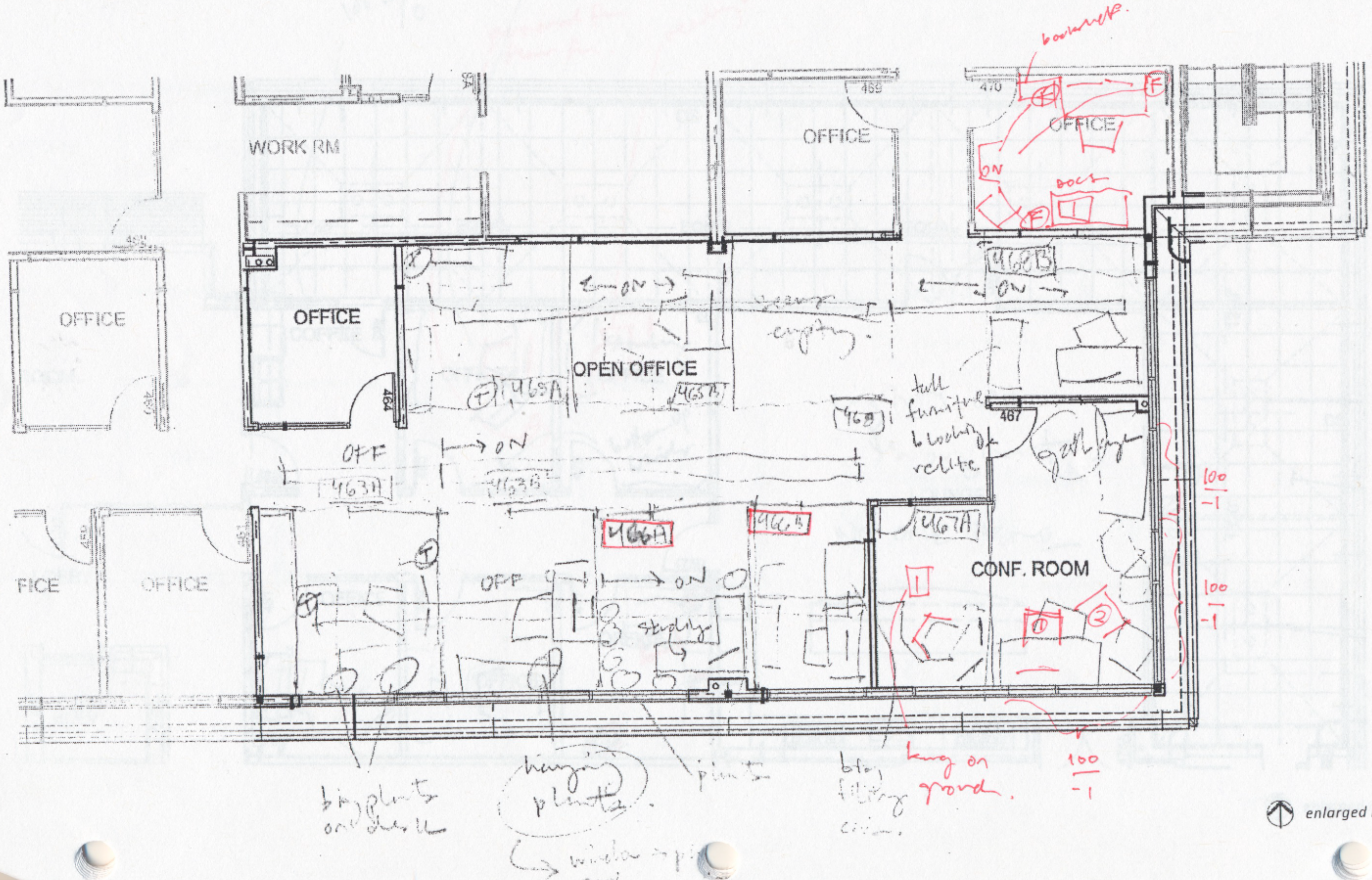


Lighting+Behavior Observations

DATE : ~~10/~~ 11/3

TIME : ~~[illegible]~~ 11:25 - 11:35

overview plan

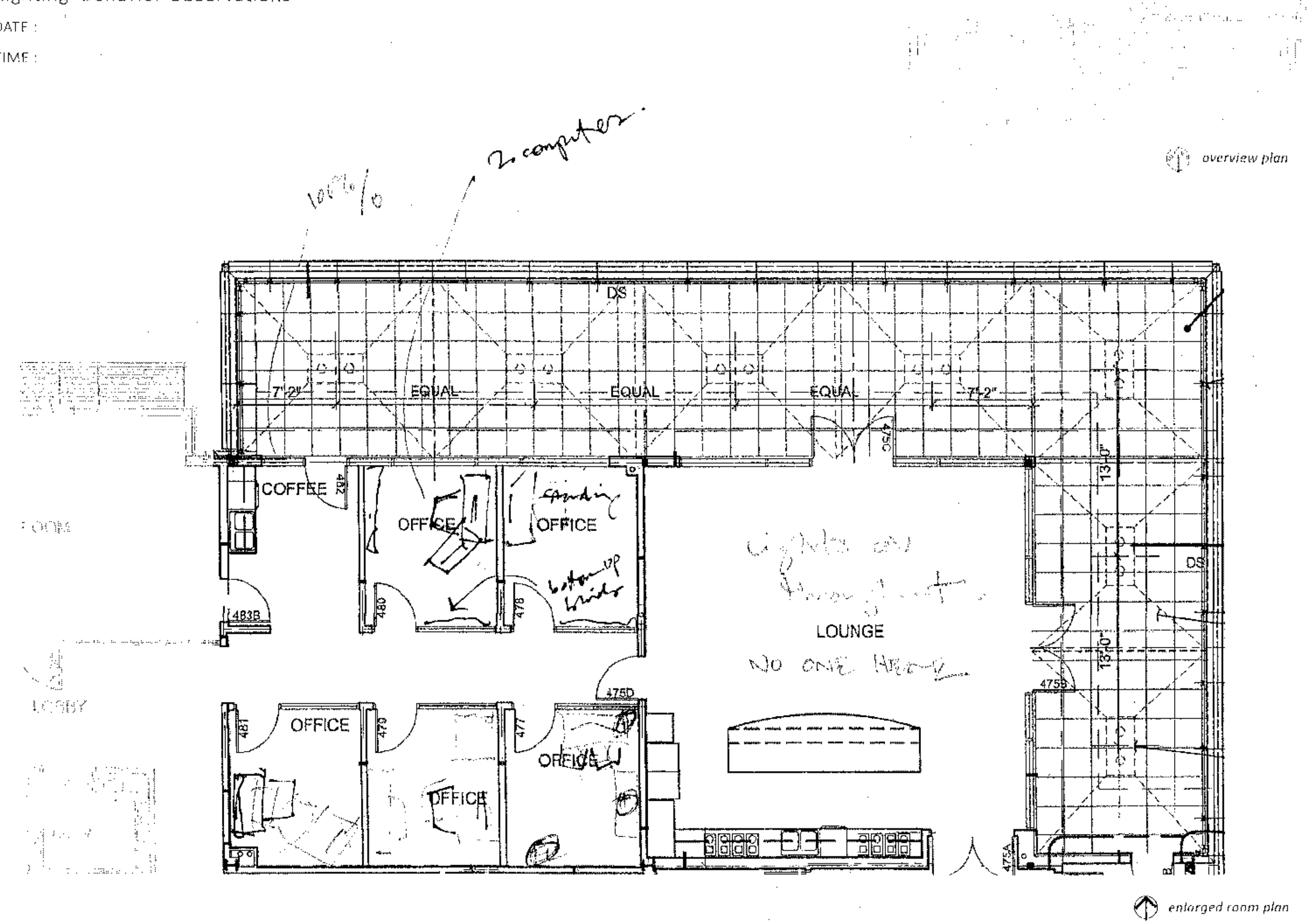


enlarged room plan

Lighting+Behavior Observations

DATE :

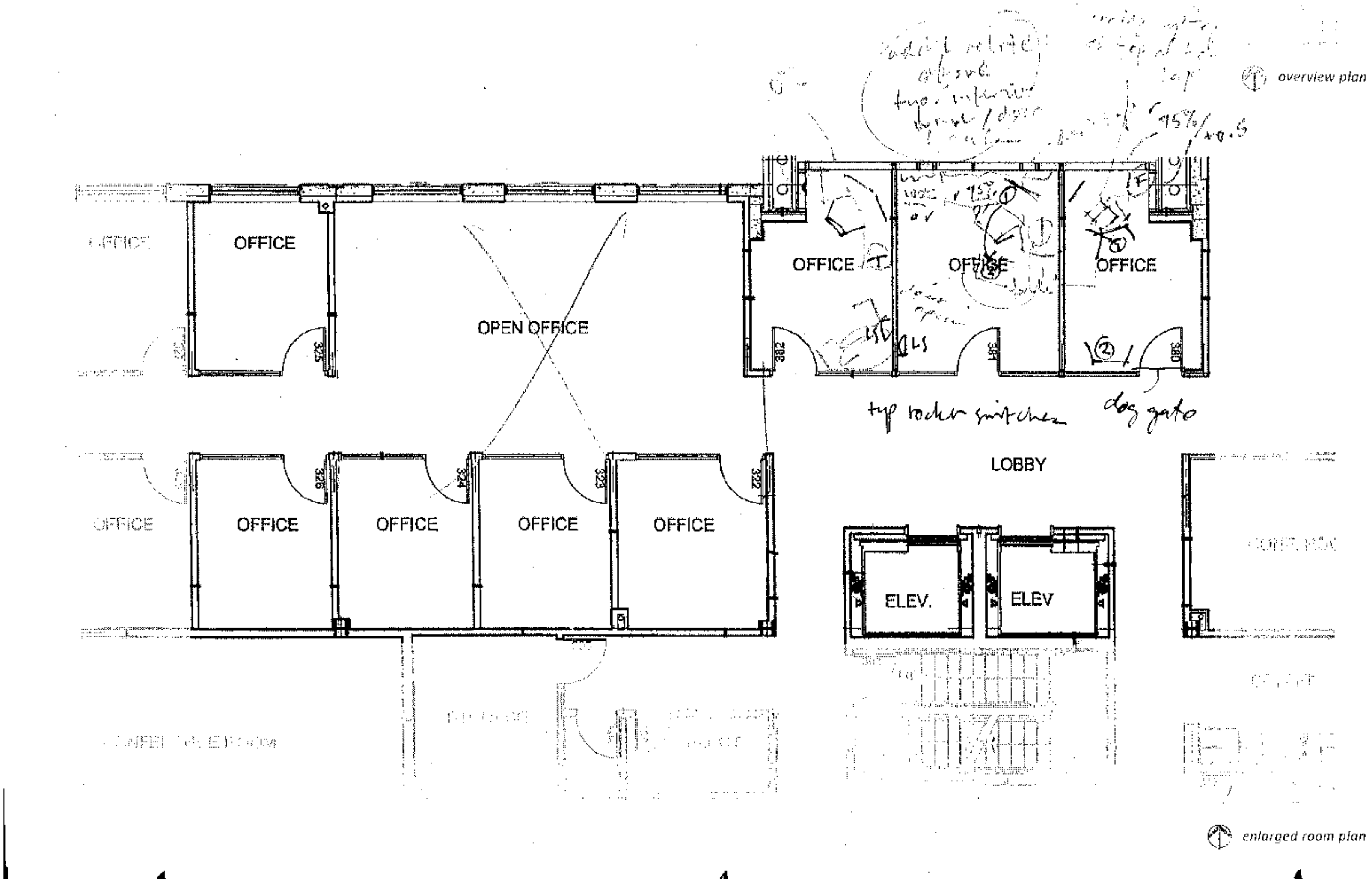
TIME :



Lighting+Behavior Observations

DATE :

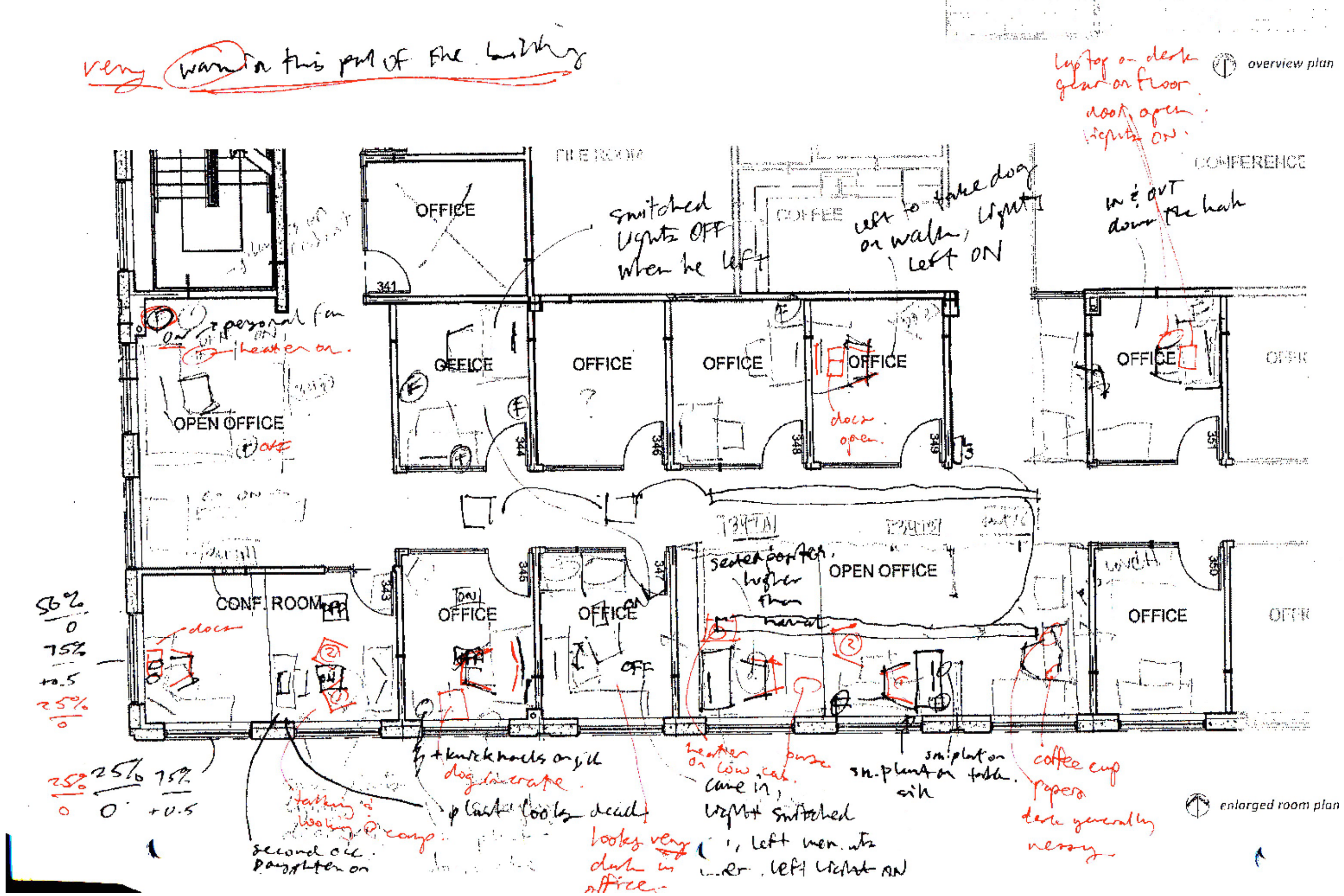
TIME :



Lighting+Behavior Observations

DATE : 11/3

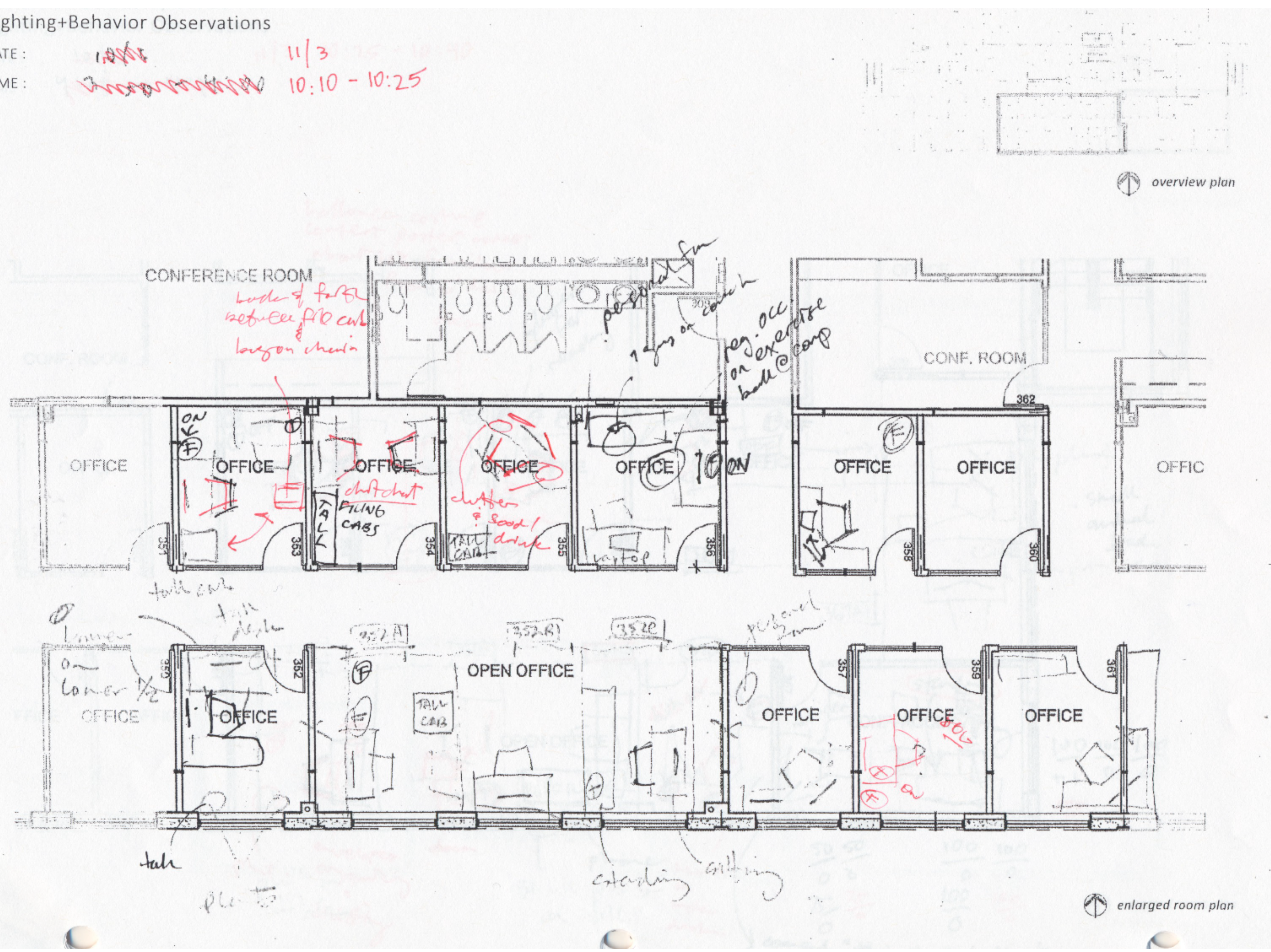
TIME : 10:00 - 10:10



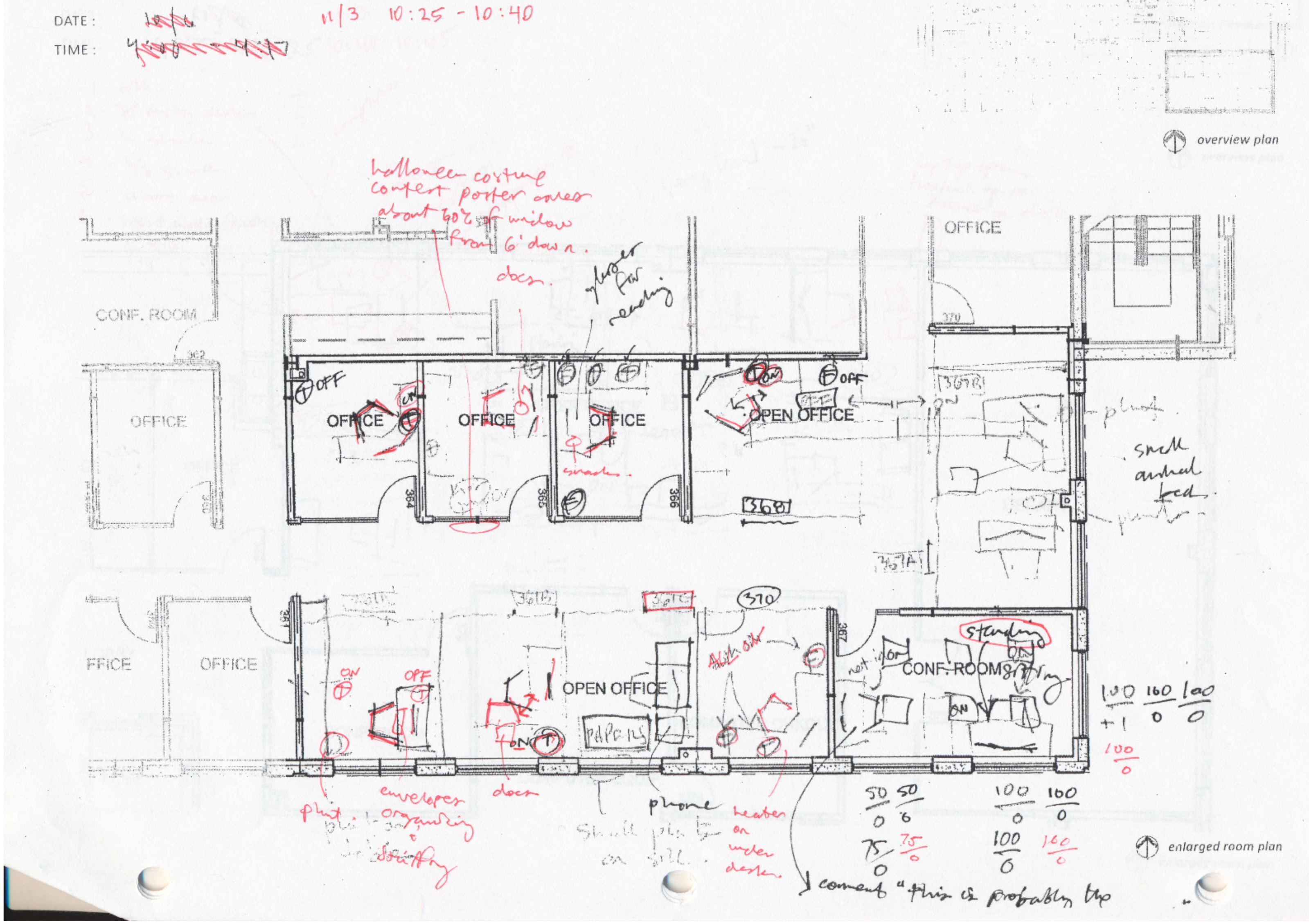
Lighting+Behavior Observations

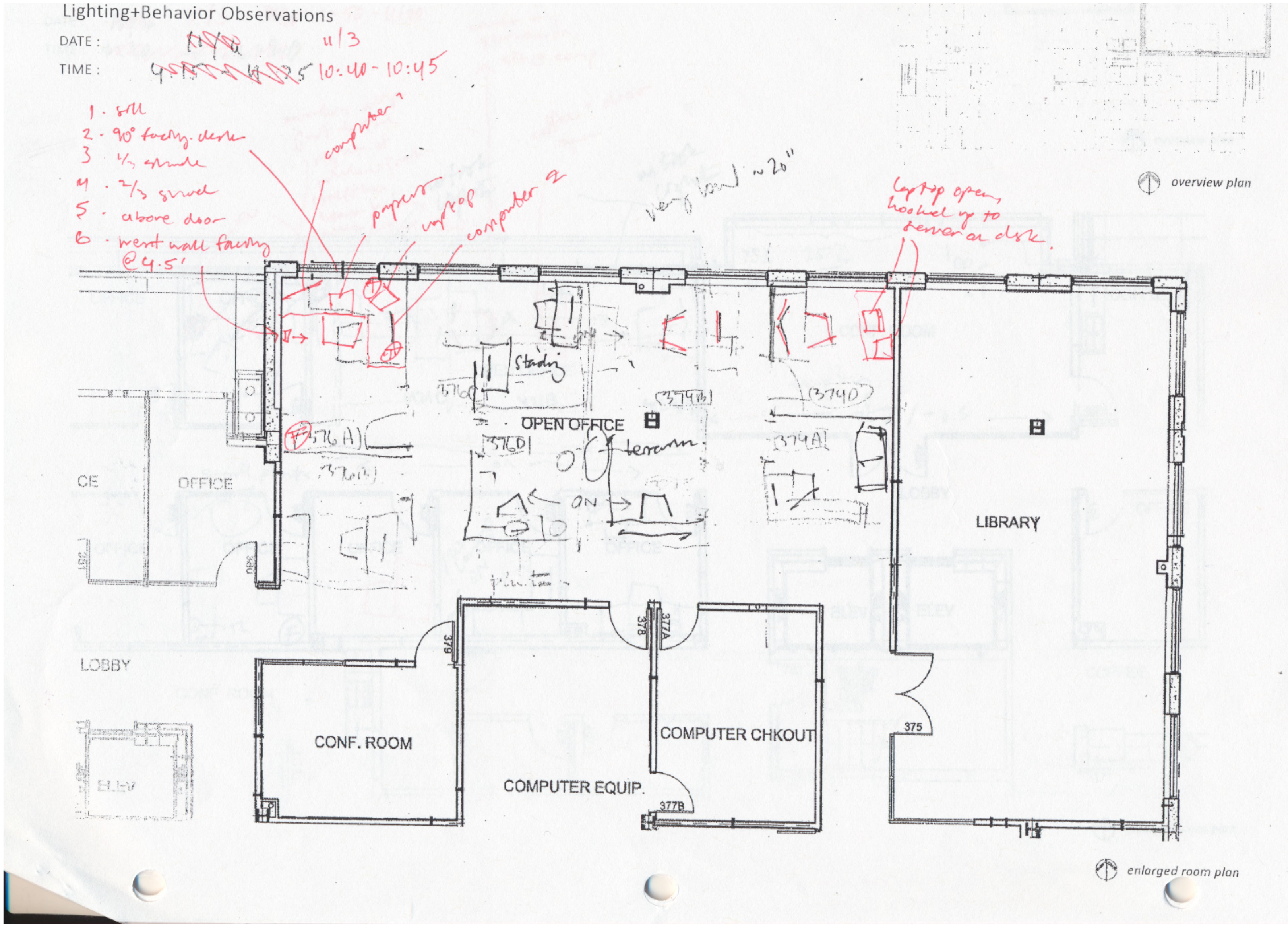
DATE : 11/3

TIME : 10:10 – 10:25



Lighting+Behavior Observations




Lighting+Behavior Observations
DATE :
11/3
TIME :
10:40 - 10:45
1 . sill
2 . 90° facing desk
3 . 1/3 shade
4 . 2/3 swivel
5 . above door
6 . west wall facing @ 4.5'
computer 1
paper
laptop
computer 2
laptop open, hooked up to server on desk.
overview plan
OPEN OFFICE
LIBRARY
OFFICE
LOBBY
CONF. ROOM
COMPUTER EQUIP.
COMPUTER CHKOUT
379
378
377A
377B
375
ELEV
enlarged room plan

Time	Floor	Office #	TASK	WRKSTN clean	OCC #	OCC ORIENT (0-360)	Electric Lighting OVRHD	Electric Lighting TASK	Electric Lighting CORR	Exterior Shade %	Exterior Shade TILT	Interior Shade %	Interior Shade TILT	Direct Sun in OFFICE	Direct Sun on WRKSTN	Direct Sun on COMP	Direct Sun on SILL	Direct Sun in OCC VIEW	Illuminance Work Plane	Illuminance Window Sill	Illuminance Center	Illuminance Interior Wall	Illuminance Corridor
9:56		380	comp	1	1	316	2	0	1	75%	+0.5	75%	+0.5	0	0	0	0	0	—	—	—	—	—
		381	comp	1	1	45	1A	0	1	75%	0	75%	0	0	0	0	0	0	—	—	—	—	—
		382	—	1	0	—	0	0	1	0%	0	0%	0	0	0	0	0	0	640	1348	285	113	85
		342	out	1	0*	270	0.5	1	1	0%	0	open		0	0	0	0	0	—	—	—	—	—
		343A	writing	1	1	270	0	0	1	25%	0	0%	0	0	0	0	0	0	—	—	—	—	—
		343	meet.	1	2/1	90	1B	0	1	25%	+0.5	75%	+0.5	0	0	0	0	0	—	—	—	—	—
		344	—	1	0	—	0	0	1	—	—	75%	0	—	—	—	—	—	—	—	—	—	—
10:06		345	comp	1	1	90	1A	0	1	75%	+0.5	75%	0	0	0	0	0	0	—	—	—	—	—
		346	—	1	0	—	0	0	1	—	—	75%	-1	—	—	—	—	—	—	—	—	—	—
		347	—	1	0	—	0	0	1	100%	0	0%	0	0	0	0	0	0	—	—	—	—	—
		348	—	1	0	—	0	0	1	—	—	50%	-0.5	—	—	—	—	—	—	—	—	—	—
		347A	out	1	0*	270	1	0	1	50%	+1	open		0	0	0	0	0	—	—	—	—	—
		347B	comp	1	1	270	1	0	1	25%	0	closed		0	0	0	0	0	—	—	—	—	—
		347C	out	1	0*	270	1	0	1	75%	0	open		0	0	0	0	0	—	—	—	—	—
		349	comp/out	0.5	0*	270	1A	0	1	—	—	50%	-1	—	—	—	—	—	—	—	—	—	—
		350	—	1	0	—	0	0	1	0%	0	75%	+0.5	0	0	0	0	0	—	—	—	—	—
		351	out	1	0*	90	2	0	1	—	—	50%	+0.5	—	—	—	—	—	—	—	—	—	—
		352	—	1	0	—	0	0	1	25%	+0.5	0%	0	0	0	0	0	0	—	—	—	—	—
		352	—	1	0	—	0	0	1	—	—	75%	0	—	—	—	—	—	—	—	—	—	—
10:16		344	chitchat	1	2	90	1A	0	1	—	—	75%	-1	—	—	—	—	—	—	—	—	—	—
		353	organize	1	1	270	1A	0	1	—	—	75%	0	—	—	—	—	—	just arrived				
		352A	—	1	0	—	1	0	1	0%	0	closed		0	0	0	0	0	—	—	—	—	—
		352B	—	1	0	—	1	0	1	100%	+0.5	closed		0	0	0	0	0	—	—	—	—	—
		352C	—	1	0	—	1	0	1	25%	+0.5	closed		0	0	0	0	0	—	—	—	—	—
		355	comp	1	1	45	1B	0	1	—	—	75%	0	—	—	—	—	—	—	—	—	—	—
		356	—	1	0	—	0	0	1	—	—	0%	0	—	—	—	—	—	2 OVRHDS + 1 TASK light left ON w/o Nor. 1				
		357	out	0.5	0*	45	0	0	1	25%	+1	75%	+1	0	0	0	0	0	logger #2 not yet moved				
		358	—	1	0	—	0	0	1	—	—	95%	+0.5	—	—	—	—	—	—	—	—	—	—
		359	comp	1	1	270	1A	2	1	75%	+1	75%	+1	0	0	0	0	0	—	—	—	—	—
		360	—	1	0	—	0	0	1	—	—	75%	+0.5	—	—	—	—	—	—	—	—	—	—
		361	phone/comp	1	1	45	1A	0	1	0%	0	75%	+1	0	0	0	0	0	—	—	—	—	—
10:27		364	comp	1	1	45	2	1	1	—	—	75%	+0.5	—	—	—	—	—	—	—	—	—	—

check.

Time	Floor	Office #	TASK	WRKSTN clean	OCC #	OCC ORIENT (0-360)	Electric Lighting OVRHD	Electric Lighting TASK	Electric Lighting CORR	Exterior Shade %	Exterior Shade TILT	Interior Shade %	Interior Shade TILT	Direct Sun in OFFICE	Direct Sun on WRKSTN	Direct Sun on COMP	Direct Sun on SILL	Direct Sun in OCC VIEW	Illuminance Work Plane	Illuminance Window Sill	Illuminance Center	Illuminance Interior Wall	Illuminance Corridor
10:27		361A	comp/envelopes	1	1	90	0.5	1	1	0%	0	open		0	0	0	0	0	—	—	—	—	—
		365	comp	0.5	1	70	1B	0	1	—		75%	+0.5	—	—	—	—	—	—	—	—	—	—
		361B	writing	1	1	180	0.5	1	1	25%	-1	open		0	0	0	0	0	—	—	—	—	—
		366	comp	1	1	270	0	4	1	—		75%	0	—	—	—	—	—	—	—	—	—	—
		361C	—	1	0	—	0.5	0	1	0%	0	closed		0	0	0	0	0	—	—	—	—	—
	368	~~366~~	comp	1	1	315	0	1	1	—		open		—	—	—	—	—	—	—	—	—	—
		370	comp	1	1	45	0	3	1	50%	+1	75%	+0.5	0	0	0	0	0	—	—	—	—	—
		367	out	1	0*	180	0	0	1	100%	0	0%	0	0	0	0	0	0	—	—	—	—	—
					0*	270	0	0	1	75%	0	0%	0	0	0	0	0	0	—	—	—	—	—
		367A	out	1	0*	0	1	0	1	0%	0	open		0	0	0	0	0	—	—	—	—	—
		367B	out	1	0*	0	1	0	1	100%	0	open		0	0	0	0	0	—	—	—	—	—
		374A	out	1	0	—	1	0	1	—		closed		—	—	—	—	—					
		374B	comp	1	1	90	1	0	1	0%	0	—		6	0	0	0	0					
		374C	out	0.5	6*	180	1	1	1	—		open		—	—	—	—	—					
		374D	comp	1	1	270	0	0	1	25%	-1	0%	0	0	0	6	0	0					
		376A	out	1	0*	0	1A	0	1	0%	0	0%	0	0	0	0	0	0					
		376B	—	1	0	—	1	0	1	—		closed		—	—	—	—	—					
		376C	out	0.5	0*	270	1	0	1	0%	0	—		6	0	0	0	0					
10:50		376D	—	1	0	—	1	0	1	—		open		—	—	—	—	—					
		481	out	1	0*	315	2	0	1	75%	+0.5	75%	+0.5	0	0	0	0	0					
		477	out/comp	1	1	0	0	3	1	—		50%	-1	—	—	—	—	—					
		478	reading/writing	1	1	0	1A	0	1	0%	0	50%	—	6	0	0	0	0					
		479	—	1	0	—	0	0	1	—		0%	0	—	—	—	—	—					
		480	comp	1	1	90	1A	0	1	75%	+0.5	50%	—	0	0	0	0	0					
		481	—	1	0	—	0	0	1	—		45%	-0.5	—	—	—	—	—					
		421A	—	1	0	—	1	0	1	0%	0	open		0	0	0	0	0					
		421B	comp	1	1	270	1	0	1	50%	-1	open		0	0	0	0	0					
		421C	—	1	0	—	1	0	1	0%	0	open		0	0	0	0	0					
		422	—	1	0	—	0	0	1	—		0%	0	—	—	—	—	—					
		423	—	1	0	—	0	0	1	—		75%	0	—	—	—	—	—					
		424	comp	1	1	90	1A	0	1	—		75%	+1	—	—	—	—	—					
11:00		425	comp	1	1	45	0	2	0	0%	0	0%	0	0	0	0	0	0					

Time	Floor	Office #	TASK	WRKSTN clean	OCC #	ORIENT (0-360)	Electric Lighting OVRHD	Electric Lighting TASK	Electric Lighting CORR	Exterior Shade %	Exterior Shade TILT	Interior Shade %	Interior Shade TILT	Direct Sun in OFFICE	Direct Sun on WRKSTN	Direct Sun on COMP	Direct Sun on SILL	Direct Sun in OCC VIEW	Illuminance Work Plane	Illuminance Window Sill	Illuminance Center	Illuminance Interior Wall	Illuminance Corridor
11:00		426	—	1	0	—	0	0	0	—		75%	0	—					—				
		427	comp	1	1	90	1A	0	0	75%	0	0%	0	0	0	0	0	0	—				
		428	out	1	0*	270	1A	0	0	—		15%	-1	—					—				
		429	—	1	0	—	0	0	0	—		25%	-0.5	—									
		431A	—	1	0	—	0	0	0	0%	0	closed		0	0	0	0	0					
		431B	—	1	0	—	0	0	0	0%	0	open		0	0	0	0	0					
		~~432~~																					
		431D	comp	1	1	270	0	0	0	0%	0	open		0	0	0	0	0					
		430	—	1	0	—	0	0	0	—		75%	+0.5	—									
		431C	comp	1	1	270	0	0	0	0%	0	open		0	0	0	0	0					
		432	comp	1	1	270	1A	0	0	—		75%	-1	—									
		433	—	1	0	—	1	0	1	—		closed		—									
		442A	comp	1	1	270	1	0	1	100%	0	open		0	0	0	0	0					
		442B	—	1	0	—	1	0	1	—		open		—									
		443	—	1	0	—	0	0	1	75%	+0.5	75%	0	0	0	0	0	0					
		444	comp	1	1	90	1A	0	1	25%	+1	75%	-1	0	0	0	0	0					
		445A	—	0.5	0	—	1	0	1	50%	-1	open		0	0	0	0	0					
		445B	comp	1	1	90	1	0	1	25%	+1	prob open		0	0	0	0	0					
		446	—	1	0	—	0	0	1	—		50%	-1	—									
		447A	—	1	0	—	1	0	1	75%	-1	closed		0	0	0	0	0					
		447B	—	1	0	—	1	0	1	75%	+1	closed		0	0	0	0	0					
		448	—	1	0	—	0	0	1	—		75%	+0.5	—									
		449	—	1	0	—	0	0	1	—		0%	0	—									
		447C	comp	1	1	90	1	0	1	75%	0	closed		0	0	0	0	0					
11:18		450	comp	1	1	135	1A	1	1	100%	0	75%	-0.5	0	0	0	0	0					
		451	comp	1	1	135	0	5	1	—		0%	0	—									
		452	meet.	1	2/1	0	1A	0	1	75%	+0.5	75%	+1	0	0	0	0	0					
		453	—	1	0	—	0	0	1	—		75%	+0.5	—									
		454	out	1	0*	90	0	1	1	—		75%	0	—									
		452A	—	1	0	—	1	0	1	100%	0	open		0	0	0	0	0					
		452B	—	1	0	—	1	0	1	50%	+1	closed		0	0	0	0	0					
11:25		452C	—	1	0	—	1	0	1	0%	0	closed		0	0	0	0	0					

Time	Floor	Office #	TASK	WRKSTN clean	STATE: OCC #	ORIENT (0-360)	Electric Lighting: OVRHD	TASK	CORR	Exterior Shade: %	TILT	Interior Shade: %	TILT	Direct Sun: in OFFICE	on WRKSTN	on COMP	on SILL	in OCC VIEW	Illuminance: Work Plane	Window Sill	Center	Interior Wall	Corridor
11:25		455	out	1	0*	270	2	0	1	—	—	0%	0	—	—	—	—	—					
		456	—	1	0	—	0	0	1	—	—	0%	0	—	—	—	—	—					
		457	comp	1	1	135	0	2	1	0%	0	0%	0	0	0	0	0	0					
		458	comp	1	1	270	0	2	1	—	—	0%	0	—	—	—	—	—					
		459	out	1	0*	270	0	0	1	0%	0	0%	0	0	0	0	0	0					
		460	comp	1	1	270	2	0	1	—	—	0%	0	—	—	—	—	—					
		461	out	1	0*	180	0	0	1	50%	-0.5	0%	0	0	0	0	0	0					
		463A	~~out~~	1	0	—	0	0	0	0%	0	open		0	0	0	0	0					
		463B	—	1	0	—	0	0	1	75%	+0.5	open		0	0	0	0	0					
		464	—	1	0	—	0	0	0	—	—	0%	0	—	—	—	—	—					
		465A	—	1	0	—	1	0	1	—	—	closed		—	—	—	—	—					
		465B	—	1	0	—	1	0	1	—	—	open		—	—	—	—	—					
		466A	—	1	0	—	1	0	1	100%	0	closed		0	0	0	0	0					
		466B	—	1	0	—	1	0	1	75%	-1	closed		0	0	0	0	0					
!!! →		467A	out	0.5	0*	135	0	0	1	0%	0	75%	-1	0	0	0	0	0					
		467	comp	0.5	1	180	0.5	0	1	100%	-1	75%	-1	0	0	0	0	0					
		468	—	1	0	—	1	0	1	—	—	open		—	—	—	—	—					
11:37		468B	comp	1	1	180	1	0	1	75%	+1	open		0	0	0	0	0					
		470	comp	1	1	0	0	3	1	—	—	50%	0	—	—	—	—	—					
11:41		479	comp	1	1	90	1A	0	1	—	—	0%	0	—	—	—	—	—					

APPENDIX B

ILLUMINANCE PARAMETER DEFINITION (USEFUL DAYLIGHT EXPECTATION)

Floor Level

Interior illuminance levels vary between the third and fourth floors. This difference is most apparent in the higher magnitude illumination at the work plane and exterior sill of fourth floor offices, as seen in Table 21 and Table 22. Figure 78 shows that illuminance levels tend to converge at the interior wall and corridor measurement locations where illuminance levels show much less variation across the sampled offices in both floors. Mean illuminance of third floor offices are 32.4% lower than the mean illuminance of all offices. The interquartile range (IQR) for the third floor overall is 25% smaller than the IQR for the fourth floor overall, indicating that a smaller range of interior illuminance levels is present in the third floor offices than is seen in the fourth floor offices. Mean work plane illuminance is 56.2% lower when calculated for the third floor offices only, but median work plane illuminance is only 3.7% lower in the third floor offices. Despite the lower work plane illuminance, the measured values still exceed minimum recommended work plane illuminance in more than 75% of the third floor sample.

Table 21: General statistics of interior illuminance measurements for 3rd floor offices only. Percentage differences from ALL OFFICES are shown below each measurement location row.

	Count (n=)	min. (lux)	max (lux)	mean (lux)	median (lux)	std.dev (lux)	25th % (lux)	75th % (lux)	IQR (lux)
3rdFloor	**40**	**20**	**23,220**	**2,442.5**	**688**	**4,596.2**	**294.75**	**1,590**	**1,295.3**
	(% diff)	*(11.1%)*	*-(50.5%)*	*-(32.4%)*	*-(1.0%)*	*-(49.0%)*	*(11.2%)*	*-(16.6%)*	*-(21.1%)*
Ext. Window Sill		245	23,220	8,358.9	7,120	6,608.5	1,974.5	14,228.8	12,254.3
	(% diff)	*(544.7%)*	*-(50.5%)*	*-(28.5%)*	*(39.3%)*	*-(55.2%)*	*(9.9%)*	*-(3.45%)*	*-(5.3%)*
Ctr. of Work Plane		61	19,100	1,889.6	898	3,785.5	448	1,518.8	1,070.8
	(% diff)	*(103.3%)*	*-(56.1%)*	*-(56.2%)*	*-(3.7%)*	*-(61.1%)*	*-(2.7%)*	*-(22.1%)*	*-(28.1%)*
Ctr. of Office		75	4,400	969.1	662.5	911.6	365.5	1,426.5	1,061
	(% diff)	*(226.1%)*	*-(2.3%)*	*-(11.6%)*	*-(12.8%)*	*-(5.9%)*	*-(3.9%)*	*-(16.4%)*	*-(19.9%)*

	Count	min.	max	mean	median	std.dev	25th %	75th %	IQR
Int. Office Wall	25	1,205	418.7	391	285.8	187	601	414	
(% diff)	*(38.9%)*	*-(37.1%)*	*-(17.8%)*	*-(7.0%)*	*-(31.6%)*	*-(3.1%)*	*-(21.7%)*	*-(27.9%)*	
Cnt. of Corridor	20	1,293	370.3	245	328.5	91.5	696.5	605	
(% diff)	*(0.0%)*	*(0.0%)*	*(8.9%)*	*-(1.2%)*	*(13.0%)*	*-(2.1%)*	*(31.3%)*	*(38.4%)*	

Table 22: General statistics of interior illuminance measurements for 4th floor offices only. Percentage differences from ALL OFFICES are shown below each measurement location row.

	Count (n=)	min. (lux)	max (lux)	mean (lux)	median (lux)	std.dev (lux)	25th % (lux)	75th % (lux)	IQR (lux)
4thFloor	**52**	**18**	**46,900**	**4,507.0**	**696**	**11,194.6**	**257**	**1,986**	**1,729**
(% diff)		*(0.0%)*	*(0.0%)*	*(24.7%)*	*(0.1%)*	*(24.3%)*	*-(3.0%)*	*(4.1%)*	*(5.3%)*
Ext. Window Sill		38	46,900	14,294.6	3,350	18,481.3	1,779	41,500	39,721
(% diff)		*(0.0%)*	*(0.0%)*	*(22.3%)*	*-(34.5%)*	*(25.3%)*	*-(1.0%)*	*(181.6%)*	*(206.9%)*
Ctr. of Work Plane		30	43,500	6,182.2	977.5	12249.1	504.5	3,206.5	2,702
(% diff)		*(0.0%)*	*(0.0%)*	*(43.2%)*	*(4.8%)*	*(25.8%)*	*(9.6%)*	*(64.4%)*	*(81.3%)*
Ctr. of Office		23	4,505	1,193.3	858	1,007.7	385	1,965	1,580
(% diff)		*(0.0%)*	*(0.0%)*	*(8.9%)*	*(13.0%)*	*(4.1%)*	*(1.2%)*	*(15.2%)*	*(19.3%)*
Int. Office Wall		18	1,915	578.5	421	486.8	207	864	657
(% diff)		*(0.0%)*	*(0.0%)*	*(13.6%)*	*(0.1%)*	*(16.6%)*	*(7.3%)*	*(12.6%)*	*(14.4%)*
Ctr. of Corridor		25	1,110	318.3	256	260.9	92	508	416
(% diff)		*(25.0%)*	*-(14.2%)*	*-(6.4%)*	*(3.2%)*	*-(10.2%)*	*-(1.6%)*	*-(4.2%)*	*-(4.8%)*

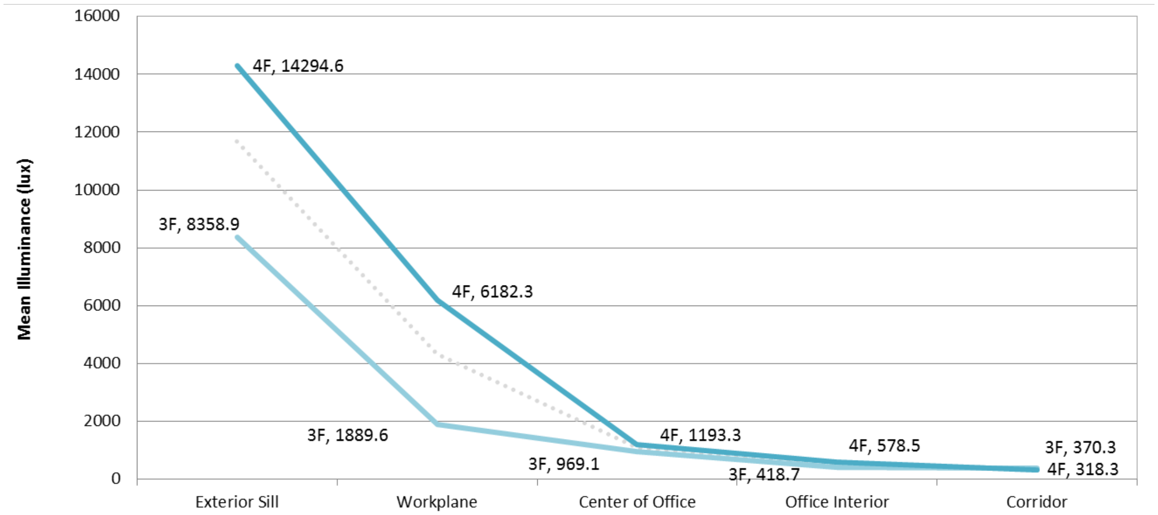


Figure 78: Mean illuminance at five measurement locations in 3rd floor and 4th floor offices. The dotted grey line represents mean values for all offices.

Interior illuminance ratios, representative of the perceived illumination within a space, are seen in the literature to influence people's daylight and electric lighting controls use behavior. Illuminance levels at the exterior window sill and work plane in the 4th floor offices are higher overall than 3rd floor offices but the 3rd floor offices show a larger discrepancy between window sill and work plane illumination, as seen in Figure 79 below. Mean illuminance ratios between window sill and work plane are nearly twice as large for 3rd floor offices. This trend may indicate the exterior shade impacts daylight distribution in the third floor offices, creating a more unbalanced lighting distribution in perimeter offices. Figure 79 also shows a few extreme cases in both the 3rd and 4th floor samples that may affect the mean. These extremes are observed in both samples when direct sun is in the office. Table 23 shows the observed illuminance when direct sun is present in the office. Notably, the IQR for work plane illuminance in 4th floor offices with direct sun is nearly 6 times higher than the full 4th floor sample whereas 3rd floor offices are less than 2 times higher than the full 3rd floor sample. This data may indicate that indoor illuminance levels on the work plane are more likely to increase in 4th floor offices than 3rd floor offices, which could affect negatively affect visual comfort in 4th floor offices.

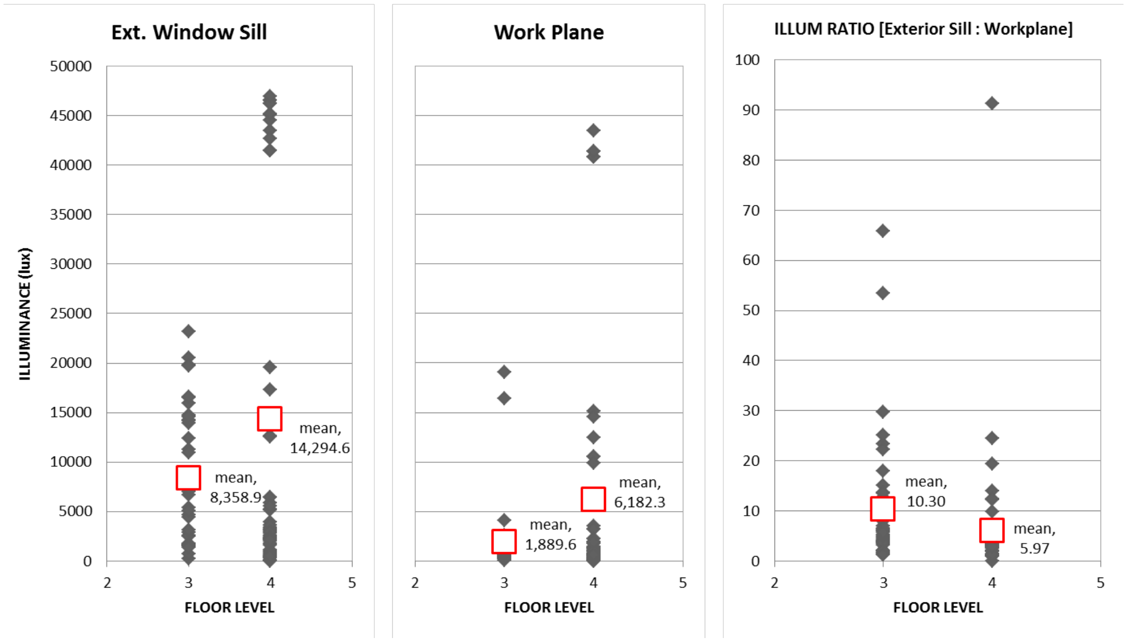


Figure 79: Scatter plots comparing measured illuminance values and mean illuminance at the exterior window sill (left), work plane (center), and the ratios of exterior sill and work plane illuminance (right) between 3rd and 4th floor offices.

Table 23: General statistics for records with direct sun in 3rd floor (top) and 4th floor offices (bottom).

	Count (n=)	min. (lux)	Max (lux)	mean (lux)	median (lux)	std.dev (lux)	25th % (lux)	75th % (lux)	IQR (lux)
3rd Floor	**18**	**20**	**23,220.0**	**3,507.2**	**815.0**	**5,826.6**	**342.8**	**2,685.5**	**2,342.8**
Exterior Window Sill		3,162	23,220.0	12,444.4	13,167.0	6,011.9	7,273.5	16,136.5	8,863.0
Center of Work Plane		231	19,100.0	3,082.6	1,317.0	5,402.1	714.3	1,900.3	1,186.0
4th Floor	**22**	**50**	**46,900.0**	**9,273.1**	**1,902.0**	**15,430.4**	**632.0**	**6,430.0**	**5,798.0**
Exterior Window Sill		5,112	46,900.0	28,825.9	41,500.0	18,320.7	7,962.0	45,925.0	37,963.0
Center of Work Plane		419	43,500.0	13,775.4	6,702.5	16,104.3	2,038.3	15,003.3	12,965.0

Office Orientation

Results are parsed by orientation and floor in order to examine this effect in greater detail and determine whether the differences between floors are distributed equally throughout the building area. Figure 80 shows mean illuminance values at each measurement location for 3rd floor and 4th floor offices facing north and south. East and west facing offices are not included in this break down due to the small sample size (n=6). While there are some differences between 3rd and 4th floor north-facing offices, these are relatively minor compared to the overt differences between 3rd and 4th floor south-facing offices. South-facing offices show the greatest variation in measured illuminance at the exterior window sill and work plane although a significant difference is still observable at the center-of-office and interior wall measurement locations. Table 24 shows general statistics broken down according to floor level and orientation. The same trend identified above, of higher overall illuminance in 4th floor offices but higher ratio between exterior window sill and work plane illuminance in 3rd floor offices, is evident only in south-facing offices. The IQR for exterior window sill illuminance of south-facing 3rd floor offices is nearly 9 times that of the work plane illuminance IQR, whereas the same comparison of IQR values for 4th floor offices shows only a 4 times increase between exterior window sill and work plane values. This data shows average work plane illuminance levels of south-facing 3rd floor offices are not influenced by direct sun to the same extent as south-facing 4th floor offices.

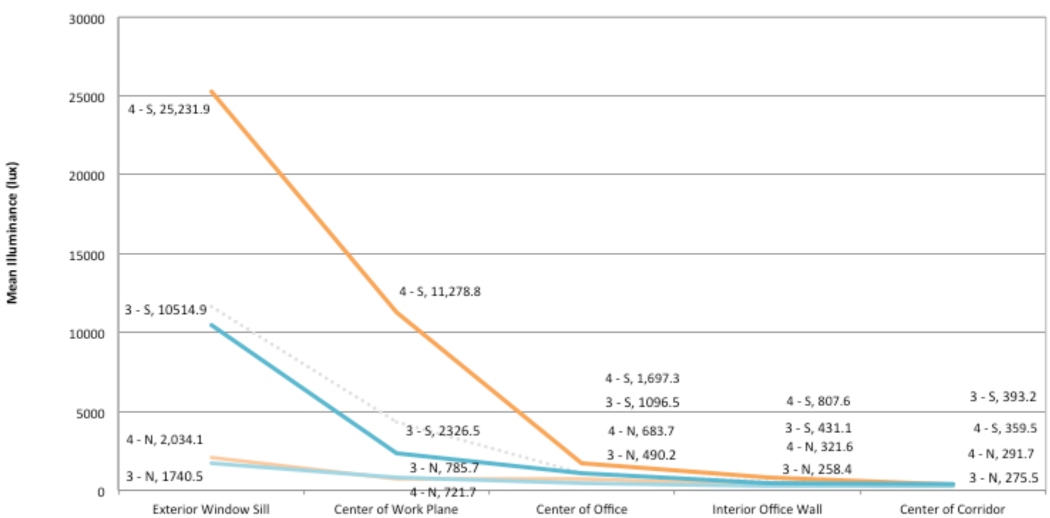


Figure 80: Mean illuminance values at five measurement locations in 3rd and 4th floor offices facing north and south. The dotted grey line shows mean illuminance for all offices.

While this effect may positively impact visual comfort from overly bright surfaces near the work plane in 3rd floor offices, the high illuminance ratio between exterior window sill and work plane may contribute to the perception that the work plane is insufficiently illuminated. In addition, large differences in illuminance between the window sill and work plane may create an asymmetric visual field, which could cause visual discomfort or fatigue. To the other extent, the larger effect of direct sun on work plane illuminance in south-facing 4th floor offices may create sources of visual discomfort because of either overly bright working surfaces or stark contrasts between directly illuminated surfaces on the work plane and nearby shaded surfaces. North-facing offices on both floors experience a drastically different lighting environment, in terms of illumination. While still meeting minimum recommended illumination levels on the work plane, the ratio between the exterior window sill and the work plane is drastically lower than in south-facing offices. Conversely, illuminance in the corridor is about 25% lower in north-facing offices than south-facing offices, which may indicate the effective daylighting depth in south-facing offices is higher due to direct sun and indirect reflections of daylight.

Table 24: General statistics for measured illuminance in 3rd and 4th floor offices facing north and south.

	Count *(n=)*	min. *(lux)*	max *(lux)*	Mean *(lux)*	median *(lux)*	std.dev *(lux)*	25th % *(lux)*	75th % *(lux)*	IQR *(lux)*
3 - N	**6**	**85**	**2,510**	**725.6**	**480**	**610.4**	**257**	**854**	**597**
Ext. Window Sill		1,348	2,510	1,740.5	1,628	406.1	1,542	1,768.8	226.8
Ctr. of Work Plane		454	1,235	785.7	765.5	262.0	659.5	843.8	184.3
Ctr. of Office		285	783	490.2	441.5	200.9	341.3	622	280.8
Int. Office Wall		113	500	258.4	212	144.9	210	257	47
Ctr. of Corridor		85	480	275.5	212.5	165.2	189	414.5	225.5
3 - S	**29**	**20**	**23,220**	**2,988.2**	**741**	**5,211.5**	**285**	**2,384.5**	**2,099.5**
Ext. Window Sill		245	23,220	10,514.9	10,980	6,417.2	5,040	14,737	9,697
Ctr. of Work Plane		61	19,100	2,326.5	1,100	4,381.9	480	1,862	1,382
Ctr. of Office		75	4,400	1,096.5	887	1,025.5	382	1,575	1,193
Int. Office Wall		25	1,205	431.1	427	302.6	187	601	414
Ctr. of Corridor		20	1,293	393.2	245	351.0	88.5	714	625.5
4 - N	**23**	**18**	**3,906**	**810.5**	**561**	**895.4**	**154**	**1,051.5**	**897.5**
Ext. Window Sill		38	3,906	2,034.1	2,163	1,163.7	1,349	2,888.5	1,539.5
Ctr. of Work Plane		30	1,792	721.7	615	510.8	440.5	948.5	508
Ctr. of Office		23	1,974	683.7	611	523.5	215	943	728
Int. Office Wall		18	796	321.6	317	237.9	120.5	423	302.5
Ctr. of Corridor		34	891	291.7	160	294.8	87.5	447.5	360
4 - S	**27**	**25**	**46,900**	**7,931.1**	**1,128.5**	**14,691.0**	**450**	**4,960.3**	**4,510.3**
Ext. Window Sill		345	46,900	25,231.9	19,570	19,790.8	5,690	45,150	39,460
Ctr. of Work Plane		102	43,500	11,278.8	3,181	15,426.0	977.5	13,499.5	12,522
Ctr. of Office		62	4,505	1,697.3	1,938	1,093.8	721	2,396.5	1,675.5
Int. Office Wall		31	1,915	807.6	823	540.4	381	1,024	643
Ctr of Corridor		25	1,110	359.5	331	230.3	201.5	501	299.5

Window Occlusion State

Occupant shade use and lighting use behaviors impact interior illuminance levels. The degree to which specific behaviors impact interior illuminance is an important aspect of characterizing the lighting environment of the study setting and is briefly discussed in this section. The sampled offices featured a range of lighting and shade configurations including full daylight without shades or occupant lighting (n=36), daylight in occupant shade settings (n=26), and occupant lighting and shade states (n=30). For this data in particular, the analysis approach warrants a bit of qualification. The conceptual model for this study assumes that people use their shades and lights for a reason, or at least, that shade and lighting use affects the way people interact with their environment. So while the beginning of this section describes the lighting environment in terms of straight illuminance levels, this section reports on illuminance in terms of how the lighting environment changes as a result of the occupants' behavior. Accordingly, the ratio between the work plane and exterior window sill illumination is calculated in order to normalize comparisons between offices under different sky conditions and characterize a critical component of illuminance distribution. Figure 81 shows a summary of the illuminance levels observed throughout the study period grouped according to the general electric lighting or exterior shade state.

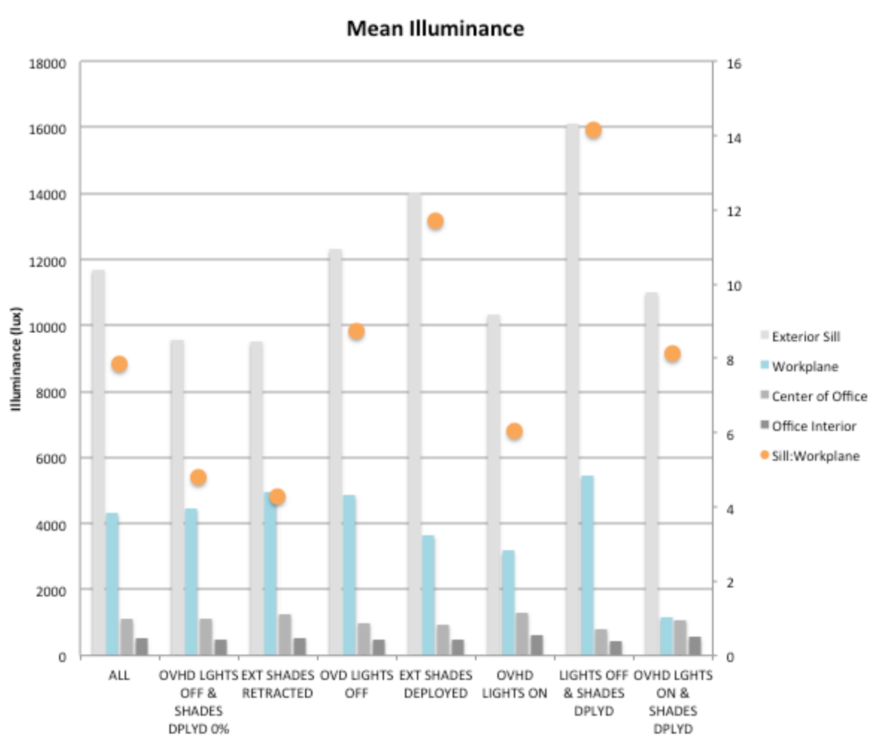


Figure 81: Mean interior illuminance at each measurement location grouped according to general lighting or shade state.

As can be seen, the two groupings with 0% window occlusion ('Ext Shades Retracted' and 'Ovhd Lghts Off & Shades Deplyd 0%') display the lowest ratio between the illuminance at the exterior window sill and the work plane of all the groupings, 39.1% - 45.4% lower than the average of all records. The groups 'Ext Shades Deployed', which represents all records in which the exterior window is at least partially occluded, as well as 'Lights Off & Shades Dplyd' display the highest ratio between illuminance at the exterior window sill and work plane of all the groupings, 48.6% - 79.8% higher than the average of all records. The following section describes a series of test cases exploring the how exterior shade use affects interior illuminance distribution in order to better explain how these groups differ.

In office #012, shown on the keyed plan in Figure 82, a controlled series of measurements were taken under clear sunny skies while progressively increasing window occlusion (Figure 83). The results of these measurements can be seen in Figure 84. In this case, horizontal illuminance measurements taken on the exterior window sill are not included in order to show the results of the other measurement locations. In lieu of exterior window sill data, a simple ratio between exterior window sill and work plane measurements is calculated and plotted alongside the illuminance measurements in Figure 84.

Figure 82: Office #012 shown on third floor plan.

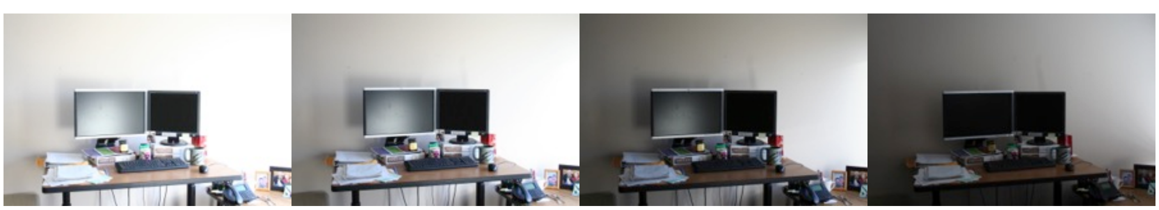


Figure 83: Office #012 during illuminance measurements under window occlusion states from 0% (left) to 100% (right).

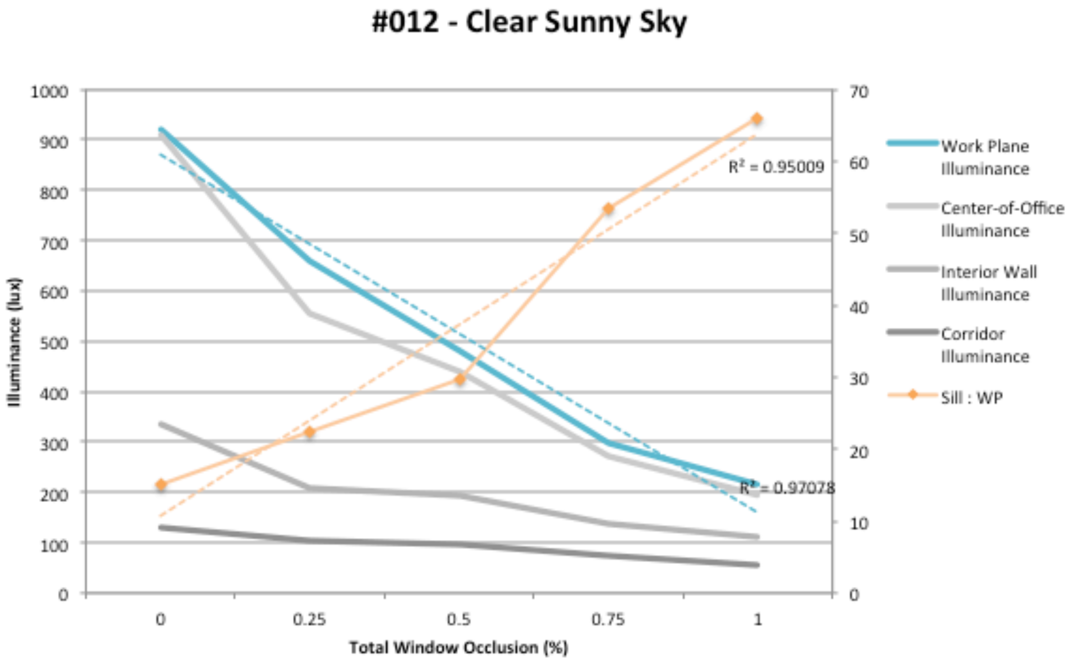


Figure 84: Total window occlusion and interior illuminance measurements in Office #012.

As expected, work plane, center-of-office, interior wall and corridor illuminance levels decrease as total window occlusion increases. Work plane illuminance measurements and total window occlusion show a strong negative correlation in the data shown in Figure 84 (R^2=0.97078). Horizontal illuminance at the exterior window sill is expected to display a similar correlation but shows a weak correlation according to Pearson's (R^2=0.332706). The ratio between exterior window sill illuminance and work plane illuminance however, shows a strong positive correlation to total window occlusion (R^2=0.95009). This result is unexpected but can be explained as a product of solar geometry and workspace layout. The measurements shown in Figure 84 are from mid-morning, meaning that the direct sun is incident on the west side of the workspace and still relatively low in the sky. The work plane in office #012 is located along the east side of the office, within 3-4 feet of the exterior wall, and is not expected to receive direct sun (or excess illumination) at the time the measurements are taken. As a result, the exterior window sill is rather exposed to direct sun despite the shades being deployed while the shades immediately cut off the work plane from receiving illuminance from the sky dome. The effect of the shade deployment is thus only observed on work plane and other interior illuminance levels, which causes the illuminance ratio between window sill and interior to steadily increase as the window is occluded more and more. High illuminance ratios observed in office #012 under the occluded window condition, which increases 336% from the fully daylit condition, are markers of potential visual discomfort or fatigue due to extreme asymmetric illuminance contrasts. In this case, the hypothetical occupant behavior (closing the shades) is likely to exacerbate or cause visual discomfort.

A secondary observation from this data is that at the work plane, center-of-office, and interior wall measurement locations the steepest reduction in illuminance levels occurs as a result of the 25% window occlusion state. After increasing the window occlusion by 25%, from 0%, horizontal illuminance decreases at the work plane by 28.3%, at the center-of-office by 38.8%, and interior wall by 38.0%. Further, illuminance ratio between window sill and work plane increases by 47.5% when the window is occluded that first 25%.

In another series of controlled measurements taken in office #009 immediately preceding those taken in office #012 described above, the impact of window occlusion on interior illuminance levels and interior illuminance ratios presents differently. Office #009, highlighted on the keyed plan in Figure 85, is set up similarly to #012 except it is mirrored about the north-south axis such that the work plane is located along the west wall and thus receives direct sun during the mid-morning measurements, shown in Figure 86. The results of these measurements can be seen in Figure 87. In this case, horizontal illuminance measurements taken on the exterior window sill are included in the plotted results in order to illustrate the role that the orientation of the workspace plays in the observations described in this section.

Figure 85: Office #009 shown on the third floor plan.

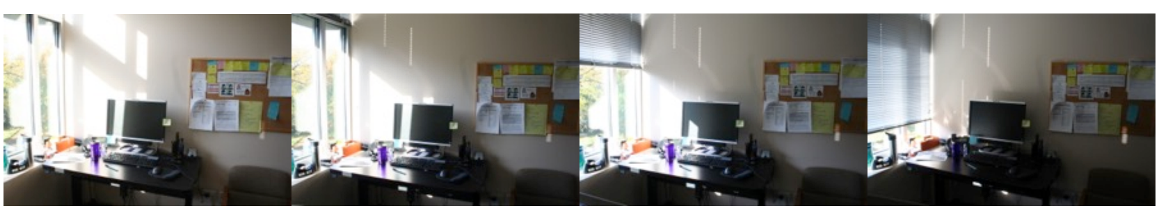


Figure 86: Office #009 during illuminance measurements in window occlusion states from 0% (left) to 100% (right).

In this case, both the exterior window sill and work plane receive direct sun and as a result decrease in illuminance at a similar rate as the window is occluded. As seen in Figure 87 however, illuminance levels at the exterior window sill and work plane decrease more rapidly as the total window occlusion increases from 0% to 25% (10.7% decrease at the window sill, 26.8% decrease at work plane, 42.5% decrease at the center-of-office) than when it increases from 25% to 50% (3.4% decrease at the window sill, 17.9% decrease at work plane, 30.6% decrease at the center-of-office). This pattern is observed in the data collected in office #012 as well. Third floor offices have a horizontal exterior shade located below the top quarter of the window, so when the shade closes to 25% the bottom rail is set to the same height as the exterior shade. In both cases, the total window occlusion values are achieved by deploying a fully tilted shade to the percentage indicated (for example, 25% window occlusion is achieved by deploying the fully tilted shade over the top 25% of the window opening). In line with these observations, it appears that deploying the interior shade below the horizontal exterior shade does not significantly affect interior illuminance distribution until the shade reaches below 50% of the window height. However, the ratio between illuminance on the window sill and on the work plane is seen to increase by more than 300% once the shade is lowered below 50% of the window height. As can be seen in Figure 86 above, the work plane still receives direct sun when the shade is at 50% of the window height and the window sill still receives direct sun when the shade is fully deployed. Based on the data shown here, window occlusion states greater than 50% are still expected to result in high illuminance ratios between the exterior window sill and work plane provided that the work plane isn't directly under/in front of the window sill.

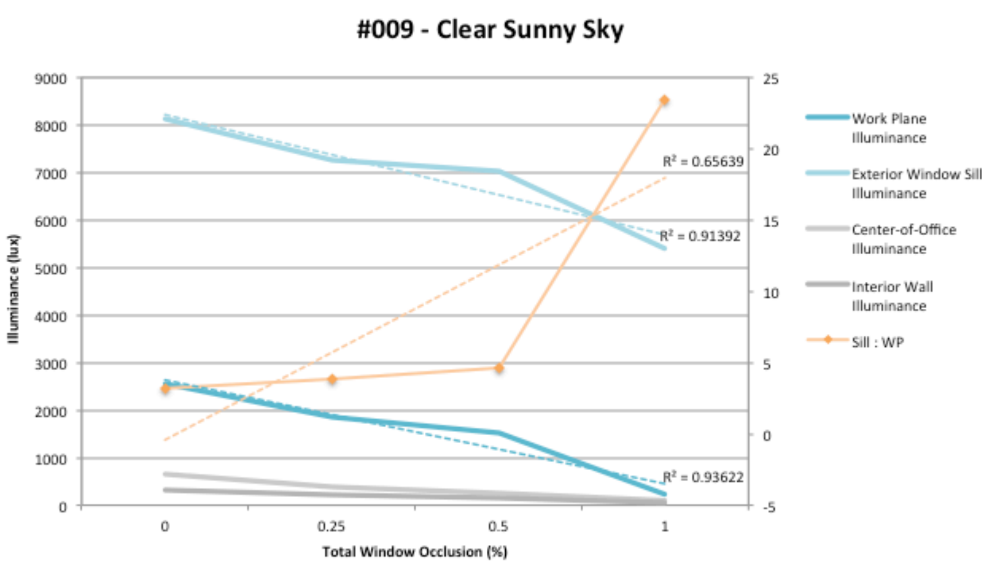


Figure 87: Total window occlusion and interior illuminance measurements in office #009.

The two cases above describe the impacts on interior illuminance distribution of a typical shade use progression – occluding the window in a linear manner from 0% deployed to 100% deployed with the slats tilted fully closed. The next case included in this section describe the impacts on interior illuminance distribution of another typical shade use progression (see Figure 88) – occluding the window gradually, from 0% deployed to 50% then 100% deployed with the slats kept open (flat), then occluding the window rapidly by tilting the slats completely closed at the 100% deployed state. The series of measurements included in this next case are taken in fourth floor office #066, shown on the keyed plan in Figure 89. The results of these measurements can be seen in Figure 90.

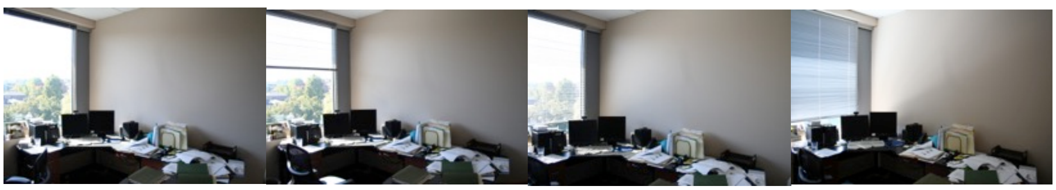


Figure 88: Office #066 during illuminance measurements under window occlusion states ranging from 0% (left), 16.67% (center left), 33.33% (center right), and 100% (right).

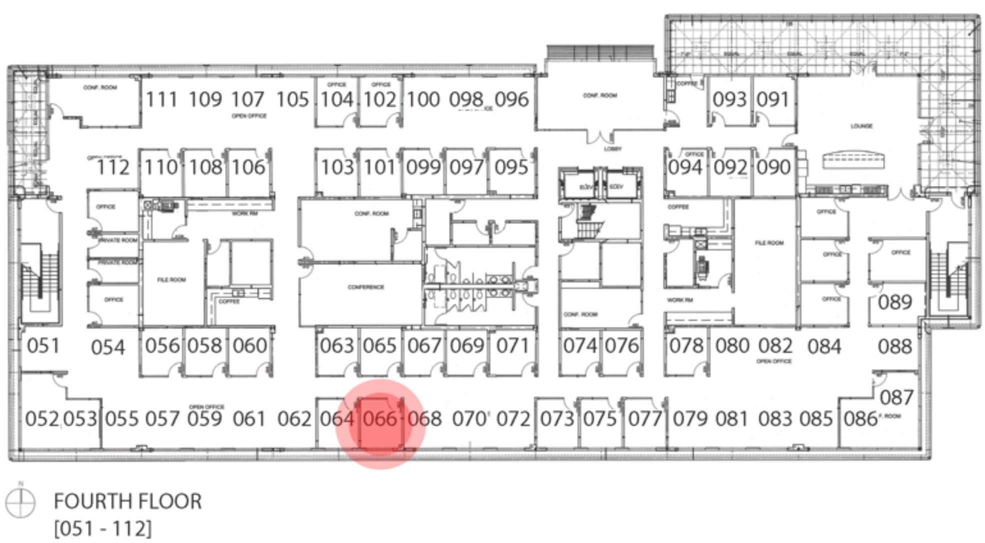


Figure 89: Office #066 shown on the fourth floor plan.

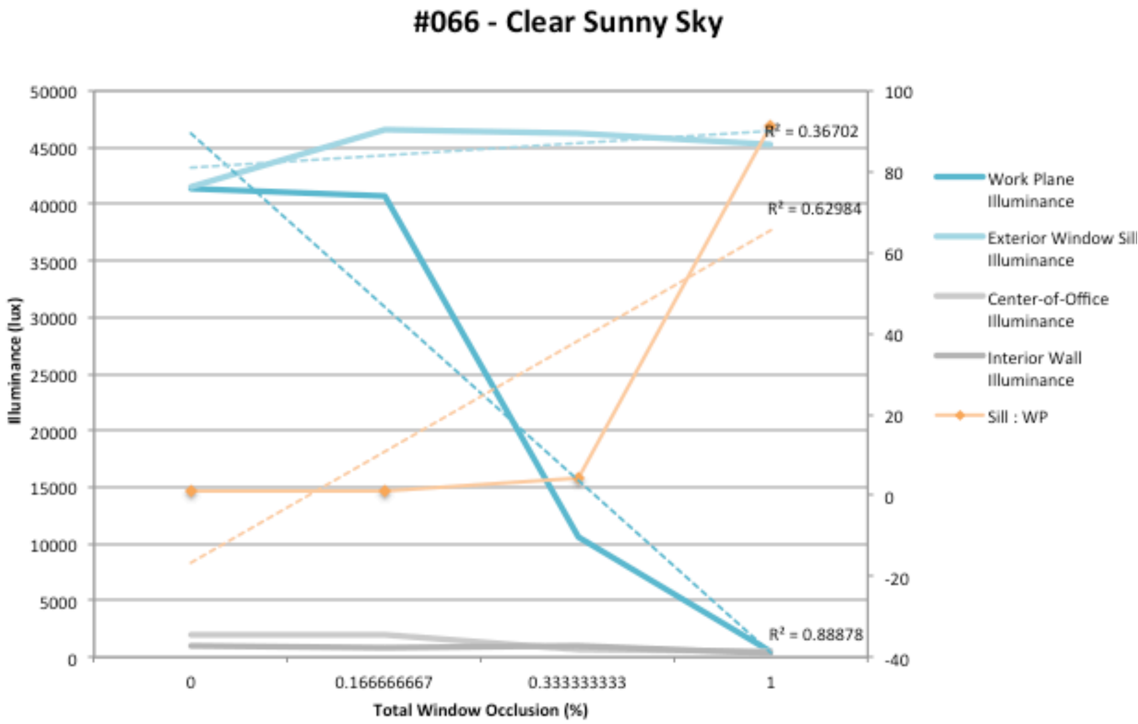


Figure 90: Total window occlusion and interior illuminance levels in office #066.

A couple of key distinctions emerge from the data here compared to the cases described above. First, the 16.67% window occlusion state (shades deployed 50% and slats tilted flat/horizontal) results in little to no appreciable decrease in interior illuminance at the work plane or center-of-office. In the data shown in Figure 90, the illuminance at the exterior window sill increases by 5,000 lux (12.1%) when the window is occluded 16.67%. It is unclear whether this increase was driven by a change in exterior illuminance or a result of the change in exterior shade state. Nevertheless, the change in exterior window sill illuminance is paired with a negligible decrease in work plane illuminance (1.5%) and an increase in center-of-office illuminance (2.5%), which supports the notion that the 16.67% window occlusion state measured here, does not significantly affect interior illuminance. The next window occlusion state tested, 33.3% (shades deployed 100% and slats tilted flat/horizontal), blocks direct sun completely and causes a significant decrease in both work plane illuminance (74.1%) and center-of-office illuminance (64.9%). In contrast to the two cases above, the interior illuminance actually increases by 100 lux (11.1%) when the shade is deployed to 100%, likely caused by increased illumination on the ceiling due to reflections off the top surface of each horizontal slat. Despite the significant drop in work plane illuminance after the shade is deployed completely, the measured illuminance still exceeds 10,000 lux on the work plane. The last window occlusion state tested, 100% (shades deployed 100% and slats tilted up completely), shows further reduction in interior illuminance at all locations but the exterior window sill. Exterior window sill illuminance remains high because the occupant's personal affects prevent the shade from being lowered completely to the sill. Despite this constraint, this shade still is considered fully occluded because the shades are deployed as far as possible in this condition. As can be seen in Figure 90, the 100% window occlusion state is marked by a significant rise in the illuminance ratio between the window sill and the work plane, similar to the observations made in office #012 above. Considering the proximity between the window sill and the work plane, the high illuminance ratio is a clear marker of visual discomfort for the occupant.

While the above cases illustrate how illuminance distribution changes in an individual office as a result of specific changes to the exterior shade, the last case included in this section illustrates differences in interior illuminance distribution within a cluster of open office cubicles on the north side of the 4th floor with different window occlusion states. Measurements in these offices are taken in the mid-morning under partially cloudy and overcast sky conditions. Offices #096, 098, and 100 are shown on the keyed plan in Figure 91. An enlarged plan showing cubicle partition and workspace layout in the three offices can be seen in Figure 92. In each measurement, offices #096 and 100 are in a 0% window occlusion state while office # 098 is in a 50% window occlusion state (shade deployed 50% of the window height and slats tilted closed), as seen in Figure 93. The offices have identical floor space and each cubicle partition is aligned just past the window jamb, which places the window nearby a perpendicular interior wall in all cases. The workspaces are laid out identically in offices #096 and 100, with a rectangular sit-stand desk located on the east side of the cubicle a few feet from the exterior wall. The workspace layout of Office #098 differs only slightly from the other two in that the desk is located on the west side of the cubicle and as a result sits directly in line with the window rather than offset from the window as is the case in offices #096 and 100.

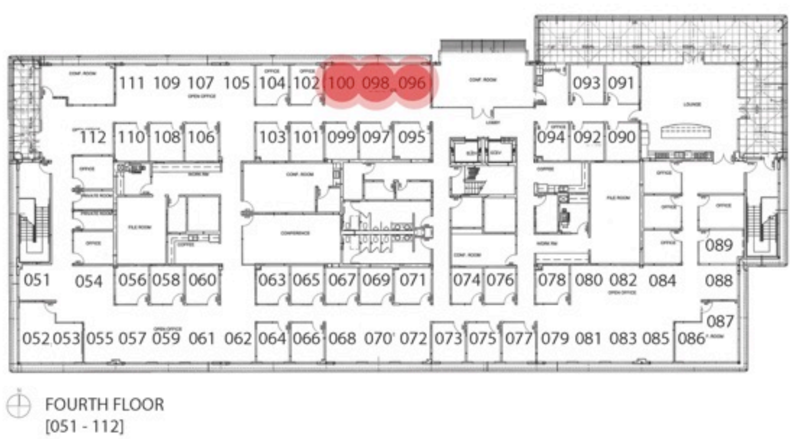


Figure 91: Offices # 096, 098, and 100 shown on the keyed fourth floor plan.

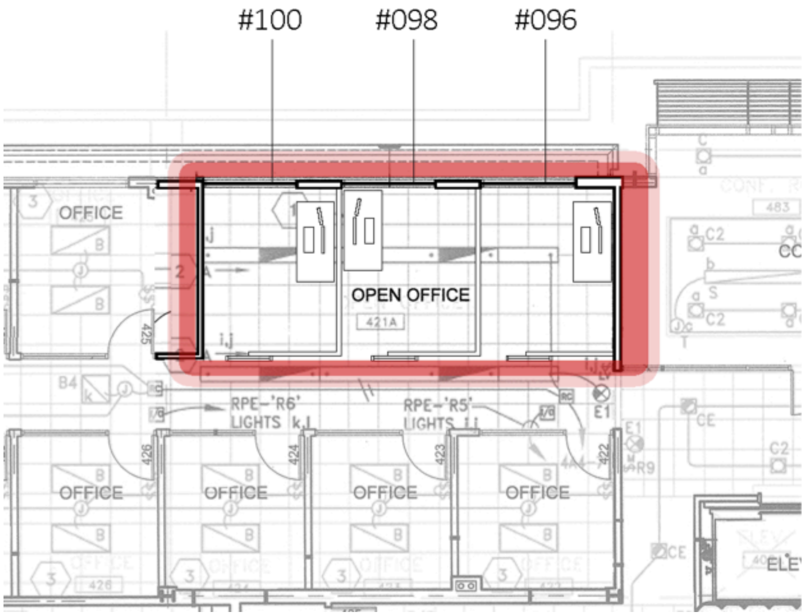


Figure 92: Enlarged plan of open office cluster showing workspace arrangement of offices #096, 098, and 100.

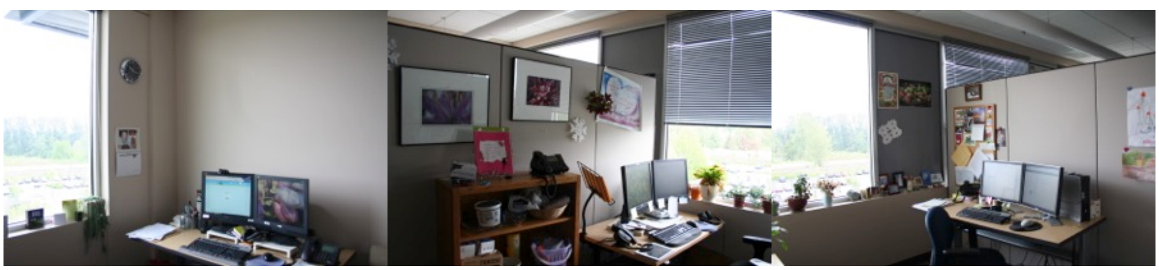


Figure 93: Images showing workspace layout and window occlusion state of offices #096 (left), 098 (center), and 100 (right).

The results of these measurements in partially cloudy skies can be seen in Figure 94 and in overcast skies can be seen in Figure 95. In order to compare results between offices, measurement locations, and sky conditions, the percentage difference between measurements taken in office #098 and offices #096 and 100 is plotted using the orange dotted line in both Figure 94 and Figure 95. As can be seen in both sky conditions, the difference in measured illuminance between these offices increases as the distance from the exterior wall increases. The largest difference between indoor illuminance measurements in both sky conditions is observed at the interior wall. This phenomenon is a direct result of the window occlusion state of office #098, which reduces the head height of the daylighting aperture and thus effectively reduces the depth of daylight penetration from the exterior window. Despite the deleterious effects of the window occlusion on center of office and interior wall illuminance levels, the work plane illuminance in office #098 exceeds that of offices #096 and 100 by 10.5% in the overcast sky condition and 58.6% in the partially cloudy sky condition.

This difference may be influenced primarily by the work plane location in each office. While the distance between the work plane measurement location and exterior window was slightly shorter in office #098 than in offices #096 and 100, the more significant difference is the alignment of work plane in relation to the window aperture. This is evidenced by the fact that while the center-of-office measurement location is nearly twice as far from the window as the work plane measurement location, center-of-office illuminance remains 10.2% higher than the work plane in office #096 and 41.2% higher in office #100 under partially cloudy skies (Table 25). If the higher work plane illuminance seen in office #098 were due to the proximity of measurement location to the exterior window, then one would expect the center-of-office illuminance to be much lower than the work plane. This effect is less noticeable in the overcast sky condition as center-of-office illuminance is 3.0% lower than the work plane in office #096 and only 9.2% higher than the work plane in office #100. Further, while all observed interior illuminance levels are lower under overcast skies, the rate of decrease between the partially cloudy and overcast conditions is much more significant for center-of-office illumination measurements. As seen in Table 26 work plane illuminance decreases the most from the partially cloudy condition in office #098 (52.7%) where the work plane is located directly in line with the window opening. The work plane in office #096 and 100 is offset from the window opening area, meaning that the work plane sees less window area (less of the sky dome) and more interior surfaces. In lieu of direct sun or strongly directional daylight, those interior surfaces that the work plane sees are not sufficiently illuminated in order to redirect daylight and illuminate the work plane. This data shows that work plane location in relation to the exterior window opening significantly affects interior illuminance on the work plane and that this effect is more noticeable under partially cloudy sky conditions.

While the relationship between work plane and window is seen to affect relative work plane illumination, the relationship between reflective interior surfaces and window is seen to affect relative illumination at the center and interior of the office. Figure 94and Figure 95 show that illuminance at the center-of-office and interior wall in office #100 are consistently higher than office #096. Table 26 shows center-of-office illuminance decreases most in office #100 (74.3%) between the partially cloudy and overcast skies while offices #096 and #098 show similar decreases in center-of-office illuminance (40.4% and 39.2%) between the two sky conditions. This is likely a result of window alignment in relation to the full height interior partition in each office, as shown in Figure 92, where the full height partition in office #100 occurs within a few inches of the window jamb, making it a more effective reflector of daylight.

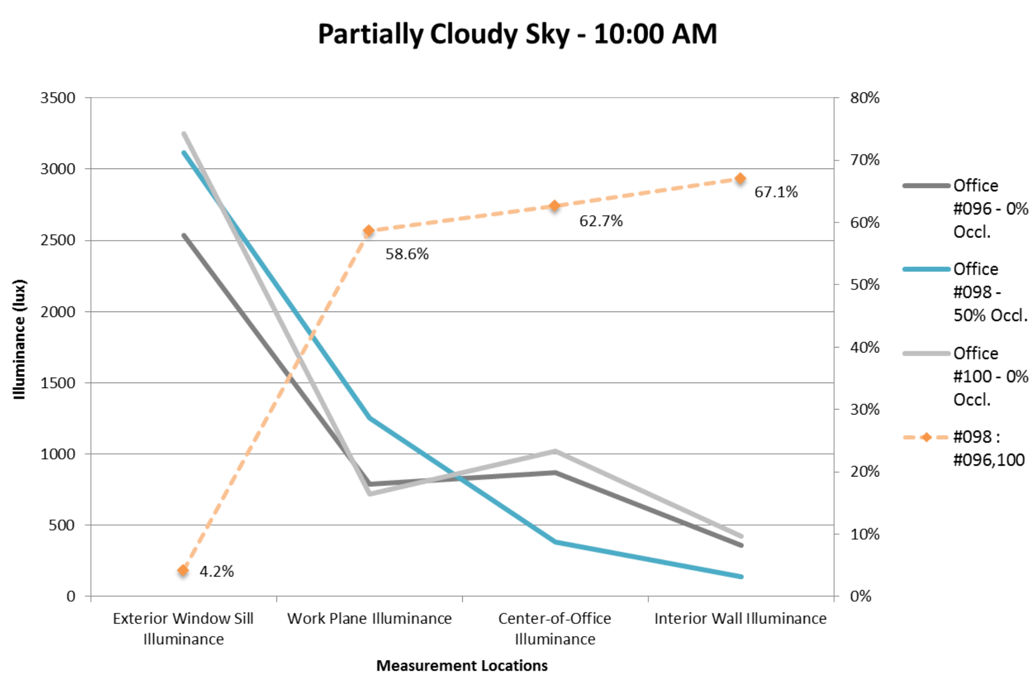


Figure 94: Interior illuminance measurements in offices #096, 098, and 100 under partially cloudy skies. The dotted orange line represents the ratio between illuminance measurements in office #098 and #100.

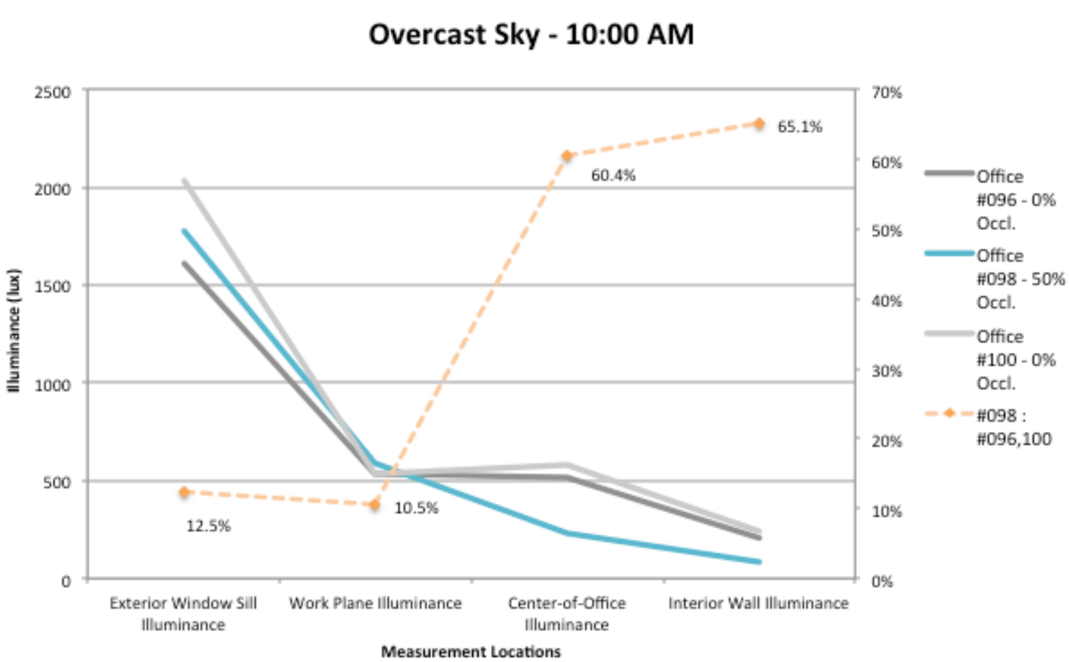


Figure 95: Interior illuminance measurements in offices #096, 098, and 100 under overcast skies. The dotted orange line represents the ratio between illuminance measurements in office #098 and #100.

Table 25: Difference between measurements of interior illuminance at the work plane and center-of-office in offices #096, 098 and 100 under partially cloudy sky and overcast sky conditions.

	% difference between work plane and center-of-office illuminance	
	Partially Cloudy Sky	*Overcast Sky*
Office #096	10.15%	-3.00%
Office #098	-69.60%	-60.91%
Office #100	41.19%	9.16%

Table 26: Percentage difference between interior illuminance levels at the work plane and center-of-office in partially cloudy and overcast sky conditions.

	% difference between partially cloudy and overcast sky	
	Work plane	*Center*
Office #096	-32.36%	-40.44%
Office #098	-52.72%	-39.21%
Office #100	-25.80%	-74.32%

The test cases presented in this section illustrate how interior illuminance distribution is influence by exterior shade use and how illuminance distribution impacts vary according to fenestration design, workstation orientation, workstation location, window location in relation to interior walls, and interior wall finish.

Final Illuminance-Cluster Definitions

This section outlines a method to quantify the primary spatial differences and their impact on interior illuminance levels such that relative Useful Daylight Expectation (uDE) between different offices can be derived. Useful Daylight Expectation is a scaled value representing the range of observed conditions in the study site.

The following procedure to generate baseline uDE values is based on a ranked average illuminance and interior illuminance ratio comparison of perimeter offices on the 3rd and 4th floor facing north and south, the results of which can be seen in Table 27. Lower final values represent higher ranked baseline uDE. Baseline uDE for 3rd floor north facing offices is adjusted to 3.0 from the calculated average rank (4.0) to evenly distribute the four baseline categories.

Table 27: Baseline Useful Daylight Expectation (uDE) values for 3rd and 4th floor south and north facing perimeter offices shown as the sum of ranked average illuminance levels and ratios.

		WP		Sill		Ctr		Int		Sill:WP		WP:Ctr		Σ	RANK	FINAL
	Sky Cond.	*(lux)*		*(lux)*		*(lux)*		*(lux)*		*(lux)*		*(lux)*			*(1-4)*	
4F - S	OVRCST	2,241	*1*	4,705	*2*	906.1	*2*	354.6	*2*	4.43	*3*	1.62	*3*	*13*	*2*	**1.5**
	CLD+SUN	13,826	*1*	41,366	*1*	1,490	*1*	756.9	*1*	17.71	*4*	9.15	*4*	*12*	*1*	
4F - N	OVRCST	579.2	*4*	1,835	*3*	562.5	*3*	273.8	*4*	3.28	*2*	1.23	*1*	*17*	*3*	**2.5**
	CLD+SUN	1,162	*3*	3,103	*3*	1,092	*2*	500.2	*2*	3.00	*2*	1.24	*1*	*13*	*2*	
3F - S	OVRCST	1,304	*2*	7,327	*1*	1,087	*1*	489.1	*1*	6.35	*4*	1.55	*2*	*11*	*1*	**2.0**
	CLD+SUN	1,425	*2*	11,641	*2*	850.0	*3*	337.0	*3*	12.04	*3*	2.54	*3*	*16*	*3*	
3F - N	OVRCST	861.7	*3*	1,796	*4*	546.7	*4*	274.3	*3*	2.09	*1*	1.80	*4*	*19*	*4*	~~4.0~~
	CLD+SUN	633.5	*4*	1,628	*4*	377.0	*4*	234.5	*4*	2.77	*1*	1.65	*2*	*19*	*4*	**3.0**

The next step to generate the final uDE rankings requires each office to be categorized according to specific spatial attributes identified in the prior analysis including workstation location, alignment between interior partitions and window opening, and interior wall finish. Each spatial attribute is quantified as a positive or negative offset value that is applied to the baseline uDE value. Figure 96 shows a diagram of the process by which final uDE values are generated.

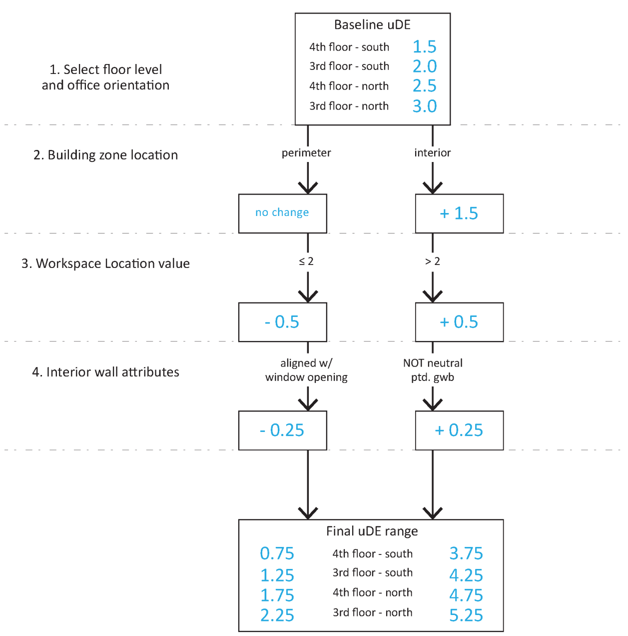


Figure 96: Diagram showing calculation procedure of Useful Daylight Expectation (uDE) based on office floor level, orientation, building zone, workspace location, and interior wall attributes.

APPENDIX C

LUMINANCE PARAMETER DEFINITION (GLARE POTENTIAL)

This section describes the range of interior luminance distribution patterns across different floors, room orientation, view orientation, and office types. HDRscope analysis results report general statistics about the luminance composition of the scene including minimum luminance, maximum luminance, mean luminance, median luminance, and standard deviation. In addition, pixels counts can be tabulated and reported as an overall percentage of the scene that meets a given criteria. While this allows detailed HDRI analysis using luminance ratios, there is little evidence beyond rules-of-thumb to indicate that ratio-based measures of luminance distribution successfully predict discomfort glare perception (Van Den Wymelenberg and Inanici 2014). Accordingly, this study reports on HDRI analysis results in terms of mean luminance within a scene and standard deviation of luminance values within the scene.

Floor Level

Table 28 shows general statistics for mean luminance and standard deviation of all records broken down by floor level. Luminance values appear to be higher in 4th floor offices, which show a 26.9% increase (588.51 cd/m^2) in mean luminance value over 3rd floor offices (463.59 cd/m^2). Despite this, mean luminance values at the 25th percentile for 4th floor offices are 32.1% lower (101.17 cd/m^2) than mean luminance values at the same percentile for 3rd floor offices (148.93 cd/m^2). These two characteristics indicate that 4th floor offices tend to be either brighter (higher mean luminance) or darker (lower mean luminance) than 3rd floor offices. This observation is further supported when mean luminance and standard deviation are plotted for each record (see Figure 97), where it is clear that 4th floor records experience low mean luminance and standard deviation more frequently than 3rd floor records. It could be that the 4th floor displays such marked divide between brighter and darker offices because there are twice as many north-facing offices included in the 4th floor sample (n=22) as there are in the 3rd floor sample (n=11).

Table 28: General statistics of mean luminance and standard deviation values for all HDRI records.

	Count (n=)	Min (cd/m2)	Max (cd/m2)	Mean (cd/m2)	Median (cd/m2)	Std.Dev. (cd/m2)	25th % (cd/m2)	75th % (cd/m2)	IQR (cd/m2)
ALL	**170**	**6.52**	**3,246.6**	**535.60**	**315.18**	**573.41**	**135.23**	**776.15**	**640.93**
	Std.dev.	***8.77***	***4,721.6***	***1,063.7***	***604.60***	***1,069.5***	***236.01***	***1,627.3***	***1,391.3***
3rd floor	72	46.52	2,998.1	463.59	288.63	497.27	148.93	580.86	431.93
	Std.dev.	*41.77*	*4,220.1*	*1,001.4*	*503.50*	*1,090.0*	*264.77*	*1,410.1*	*1,145.3*
4th floor	98	6.52	3,246.6	588.51	390.54	620.63	101.17	838.43	737.26
	Std.dev.	*8.77*	*4,721.6*	*1,109.4*	*799.76*	*1,057.4*	*223.23*	*1,791.5*	*1,568.3*

Office Orientation

In order to determine the role that office orientation has on indoor luminance distribution, HDRI records are parsed by floor level and building orientation (see Table 29). Luminance distribution in north facing offices displays much less variation than south facing offices overall. Luminance data from 3rd floor north-facing offices show an IQR of mean luminance 75.1% smaller than 4th floor north-facing offices and 80.2% smaller than 3rd floor south-facing offices. The same trend is observed for standard deviation of luminance values within 3rd floor north-facing offices.

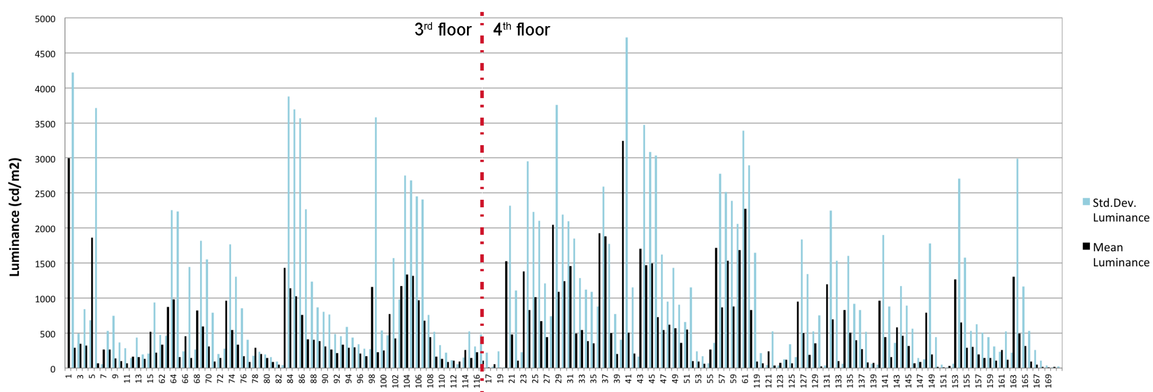


Figure 97: Mean luminance and standard deviation of all HDRI records. 3rd floor records are left of the red line, 4th floor records are right of the red line.

4th floor north-facing offices show mean luminance and standard deviations values more than 50% lower than 4th floor south-facing offices. South-facing 4th floor offices display the highest overall mean luminance values (45.5% higher) and standard deviation (35.9% higher) compared to the full sample of offices. While some of these observations are in line with basic expectations about lighting differences between north and south-facing spaces, there are additional factors outside the building that may affect the results discussed above. First, views from north-facing offices are basically unobstructed and a greater portion of the sky dome is visible to the glazing, which, as shown in Figure 98, increases the mean luminance of the scene without increasing the interior luminance distribution. Second, the exterior sky condition at the time of the observation affects the captured interior luminance data. Observations of 3rd floor north-facing offices were made under overcast skies that could be seen to negate the effect of the unobstructed view on the resulting data. Table 30 shows luminance data parsed by exterior sky condition.

Table 29: General statistics of mean luminance and standard deviation values for all records grouped according to floor level and office orientation.

	Count (n=)	Min (cd/m2)	Max (cd/m2)	Mean (cd/m2)	Median (cd/m2)	Std.Dev. (cd/m2)	25th % (cd/m2)	75th % (cd/m2)	IQR (cd/m2)
ALL	**170**	**6.52**	**3,246.6**	**535.6**	**315.2**	**573.4**	**135.2**	**776.2**	**640.9**
	std.dev.	***8.8***	***4,721.6***	***1,063.7***	***604.6***	***1,069.5***	***236.0***	***1,627.3***	***1,391.3***
3 – N	8	93.1	517.1	211.1	180.0	137.2	126.1	232.3	106.2
	std.dev.	*147.5*	*939.6*	*413.9*	*394.3*	*255.8*	*218.1*	*493.1*	*275.1*
3 - S	60	46.5	1,862.8	462.1	293.1	420.4	159.3	696.5	537.1
	std.dev.	*41.8*	*3,877.2*	*1,042.6*	*522.5*	*1,091.5*	*268.3*	*1,555.4*	*1,287.1*
4 - N	36	6.5	1,523.0	359.9	212.7	374.8	72.5	499.8	427.2
	std.dev.	*10.9*	*2,318.4*	*704.3*	*523.3*	*693.8*	*124.8*	*1,121.7*	*997.0*
4 - S	56	9.7	3,246.6	779.5	541.9	701.0	243.9	1,277.3	1,033.4
	std.dev.	*13.2*	*4,721.6*	*1,446.6*	*1,149.1*	*1,158.5*	*490.6*	*2,271.5*	*1,781.0*

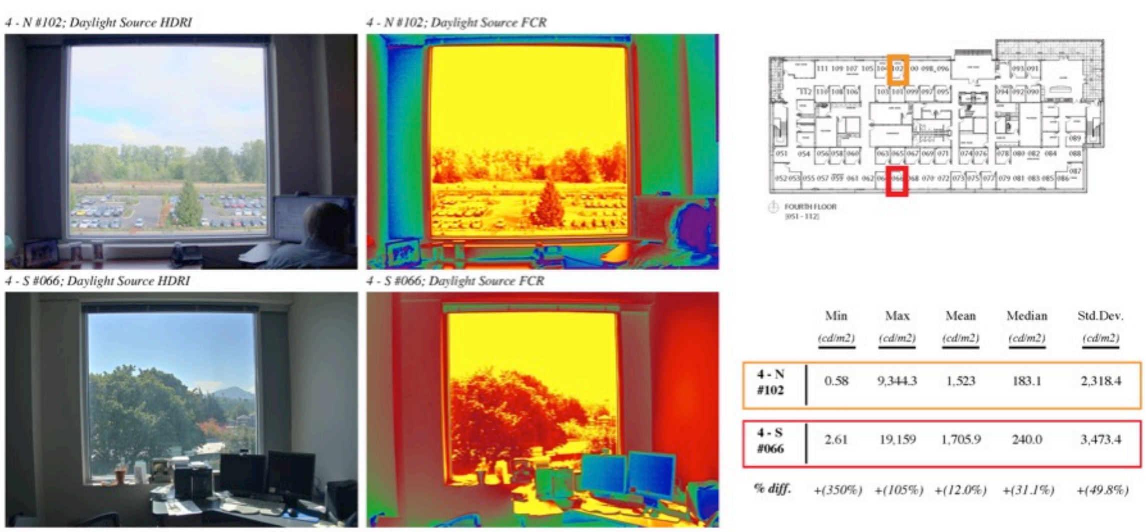


Figure 98: Comparison of view through the exterior window from south and north-facing 4th floor windows showing the impact of unobstructed exterior views on mean scene luminance and luminance distribution.

Exterior Sky Conditions

The partially cloudy sky condition resulted in the highest overall mean luminance as well as the highest variation amongst the observations. The high variation in interior mean luminance under partially cloudy skies may be partially a result of the larger sample size. The views seen in Figure 98 were taken under a partially cloudy sky within a span of 20 minutes. Despite this, the south-facing view displays a higher maximum luminance and a standard deviation 49.6% higher than the north-facing view. The scatter plots seen in Figure 99 show that while there are a few very bright records, the mean value falls in the middle of a widely distributed range of records. Table 31 shows general statistics for south-facing offices under each sky condition, which demonstrates that south-facing offices exhibit higher mean luminance values and larger variation in luminance values than north-facing offices under overcast as well as partially cloudy skies. No north-facing offices are sampled under the clear sunny sky condition but based on this data there are few indications that the clear sunny sky would significantly affect these measurements.

Table 30: Luminance data grouped according to sky condition at the time of measurement.

	Count	Min	Max	Mean	Median	Std.Dev.	25th %	75th %	IQR
	(n=)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)
ALL	**170**	**6.52**	**3,246.6**	**535.6**	**315.2**	**573.4**	**135.2**	**776.2**	**640.9**
Overcast Sky	59	9.71	2,998.1	419.8	224.7	534.5	106.8	433.1	326.3
Partial Clouds	92	6.52	3,246.6	656.9	486.8	617.4	199.8	980.3	780.5
Clear Sunny Sky	19	46.5	962.8	308.1	199.5	256.8	141.9	442.9	300.9

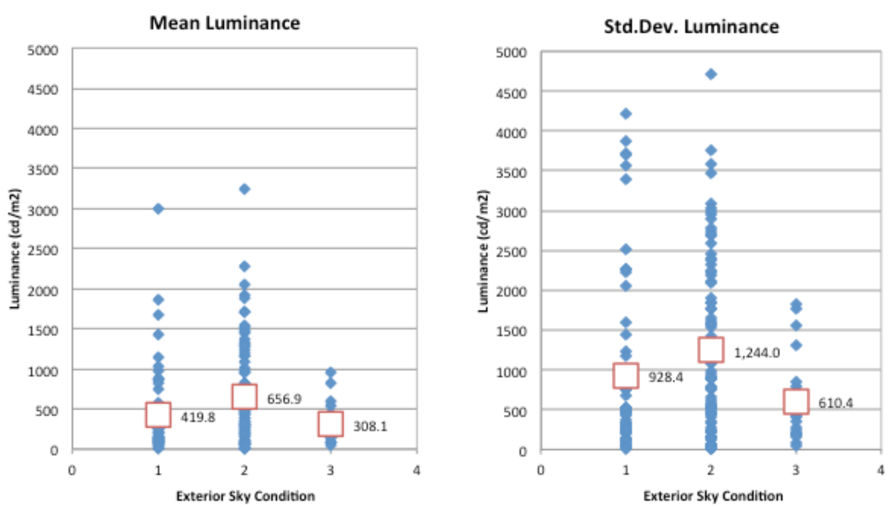


Figure 99: Scatter plots summarizing observed mean luminance value (left) and standard deviation of luminance within a scene (right) according to exterior sky conditions: 1 - overcast sky, 2 - partially cloudy sky, 3 - clear sunny sky.

Table 31: General statistics for south-facing offices grouped by exterior sky condition.

	Count	Min	Max	Mean	Median	Std.Dev.	25th %	75th %	IQR
SOUTH OFFICES	(n=)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)	(cd/m2)
Overcast Sky	35	65.3	1,862.8	472.8	262.1	485.6	139.2	811.4	672.2
Partial Clouds	58	59.69	3,246.6	841.6	591.8	653.9	339.9	1,294.4	954.6
Clear Sunny Sky	19	46.52	962.8	308.1	199.5	256.8	142.5	389.1	246.6

View Type

In order to determine the impact of occupant orientation and workspace arrangement on luminance distribution illuminance data is parsed according to view type and orientation. Daylight source and overview images are taken at consistent locations in relation to the exterior window and thus results from these two views are easily compared across offices. Workstation views are established based on the workstation arrangement in the sampled office and thus comparisons across offices based solely on the view type are difficult to make. In order to allow meaningful comparisons, views are described in terms of the difference between office orientation and view orientation. For example, a view taken from a south-facing office (180 degrees) oriented directly at the exterior window (180 degrees) would produce a relative view orientation of 0 degrees could thus be compared to a view taken from a north-facing office (0 degrees) oriented directly at the exterior window (0 degrees) whether or not that view is a workstation or daylight source view type. Views that do not face directly toward the exterior window are described in either positive or negative degree values based on whether the rotation occurs clockwise or counterclockwise when drawn on a floor plan (Figure 22). This analysis results in a straightforward way to categorize expected luminance distribution in a given office or from a given workstation based on office orientation and occupant orientation in relation to the exterior window. Table 32 shows general statistics for mean luminance and standard deviation of luminance within the scene according to relative view orientation. These results are also summarized in the scatter plots seen in Figure 100 below.

Views oriented directly towards the exterior window (0 degrees relative view orientation) display the highest overall mean luminance as well as the highest luminance variation within each image. This result is expected because in these views the exterior window comprises a large portion of the image itself and exterior surfaces, that often see the sun or sky dome directly, are typically quite bright compared to interior surfaces, that often only see indirect or reflected light. +45 and -45 degree groups display a mean luminance 30.6% and 40.6% lower than 0 degree relative view orientations. Mean standard deviation values of +45 and -45 degree groups display a similar reduction compared to the 0 degree group. No significant differences between the +45 and -45 degree groups are apparent in the data and it is likely that any differences between the two groups results from distribution of images taken in the morning (n= 119) compared to those taken in the afternoon (n=50). +90 and -90 degree groups display the lowest overall mean luminance. It is notable that the -90 degree groups displays a mean luminance 68.4% lower than the +90 degree group. This can perhaps be attributed to a greater percentage of the images being taken in the morning as any effects this had on the +45 and -45 degree groups would be amplified in the +90 and -90 degree groups. This is because images in the +90 and -90 degree groups are more likely to show none of the exterior window in the captured view, so the resulting data renders the closest description of interior luminance distribution in an indirect or reflected lighting condition. Direct sun in the workspace is likely the cause of the few outliers in the standard deviation plot seen in Figure 100 for the +90 degree group.

Table 32: General statistics for mean luminance and standard deviation of luminance within a scene (in italics) grouped according to relative view orientation.

	(n=)	Min (cd/m2)	Max (cd/m2)	Mean (cd/m2)	Median (cd/m2)	Std.Dev. (cd/m2)	25th % (cd/m2)	75th % (cd/m2)	IQR (cd/m2)
0	53	19.87	3,246.6	801.75	649.25	687.84	255.22	1,169.5	914.3
	Std.dev.	*48.77*	*4,721.6*	*1,659.1*	*1,579.6*	*1,241.3*	*506.44*	*2,388.2*	*1,881.8*
-45	43	13.21	2,273.2	476.20	302.33	489.76	163.8	542.22	378.42
	Std.dev.	*26.12*	*3,579.8*	*989.15*	*564.43*	*970.03*	*292.81*	*1,202.8*	*909.96*
+45	29	25.34	2,047.9	556.48	348.96	566.77	145.62	726.8	581.18
	Std.dev.	*37.72*	*3,756.1*	*1,053.7*	*842.62*	*941.98*	*278.35*	*1,621.9*	*1,343.5*
-90	21	6.52	316.14	140.15	100.04	97.09	72.26	205.11	132.85
	Std.dev.	*10.85*	*745.87*	*211.1171*	*143.19*	*207.0576*	*59.36*	*232.68*	*173.32*
+90	20	93.09	1,924.6	443.92	399.67	417.75	139.8	573.80	433.99
	Std.dev.	*147.5*	*2,590.6*	*761.638*	*699.98*	*631.48*	*240.97*	*915.92*	*674.95*

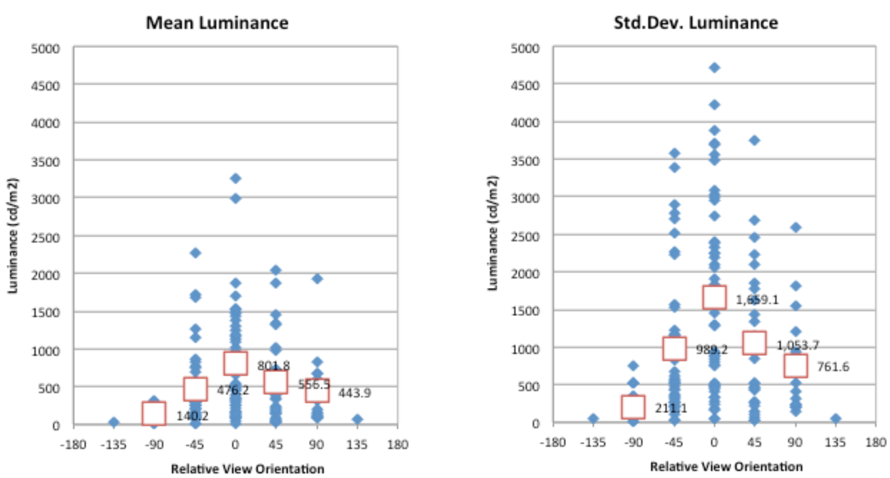


Figure 100: Scatter plots of mean luminance (left) and standard deviation of luminance within the scene (right) organized by relative view orientation.

General trends resulting from the relationship between viewing angle and the exterior window may obscure differences resulting from office orientation and floor level described above in the above sections. Figure 101 below shows mean luminance and standard deviation of luminance within the scene in each of the relative view orientation groups established above and organized by office orientation (left) and floor level (right). The same general relationship between 0 degree, +/- 45 degrees, and +/- 90 degrees groups described above are clearly observable within all of the groupings shown in Figure 101. Mean and standard deviation values of each 4th floor relative view orientation group exceed those of the 3rd floor groups. Similarly, values for each relative view orientation group in offices facing south (180 degrees) generally exceed those of the north-facing groups. These findings support the trends identified above. The disparity between +90 and -90 degree groups is present data from the south-facing offices but not the north-facing offices, which indicates that the incidence of direct sun on interior surfaces significantly affects the resulting mean and standard deviation values, even when the view shows little to no exterior window area. This finding suggests that in south-facing offices any workspaces located within a zone that receives direct sun throughout the year is likely to exhibit high mean luminance values at some point throughout the day. The relatively low standard deviation values of the +90 and -90 degree groups suggests that the influence of direct sun is isolated to mean luminance and does not significantly affect luminance distribution on those surfaces that do not receive direct sun.

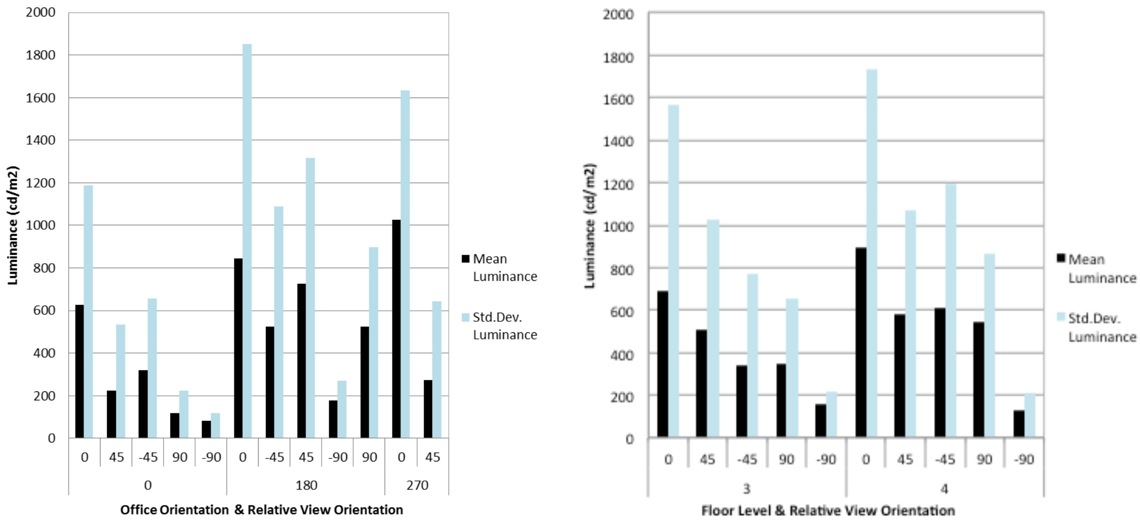


Figure 101: Mean luminance and standard deviation of luminance within the scene organized by relative view orientation and office orientation (left) and floor level (right).

Window Occlusion and Lighting State

Shade and lighting state affect interior luminance distribution, both by modifying the total light incident on visible surfaces and by changing the direction of light hitting visible surfaces. Characterizing the relationship between shade and lighting states and interior luminance distribution metrics is thus an important aspect of describing the luminous environment. For the sake of this study, it is important to determine whether the types of adaptive behaviors that an individual might take to modify their environment and relieve visual discomfort, defined herein as source adaptations, actually improve the visual environment. Further, if individuals habitually set a certain lighting or shade state, the resulting lighting environment is described in the following section. This section provides a general overview of mean luminance values and standard deviation of luminance within the scene for all records grouped according to lighting state and exterior shade state. In addition, a series of test cases are explored that demonstrate specific outcomes of different lighting and shade states in a sample of offices.

Figure 102 shows a general comparison of mean luminance and standard deviation of luminance within the scene for all records grouped according to lighting and shade state. In addition, the average percentage of view area exceeding 7 times the mean luminance, the mean glare threshold (MGT), for that scene is calculated and shown by the orange marker in Figure 102. Calculating the view area outside the MGT describes the luminance distribution in the scene in relation to the mean luminance using a standard ratio-based metric to indicate likely visual discomfort. In the summary data shown in Figure 102, the mean area outside the MGT is strongly correlated to both the mean luminance (r^2=0.997) and mean standard deviation of luminance within the scene (r^2=0.998). Records with electric lighting on as well as those with the exterior shades deployed show the lowest overall mean luminance, standard deviation of luminance, and area outside MGT, while records with the shades retracted completely (deployed 0%) show the highest overall mean luminance, standard deviation of luminance, and area outside MGT. Figure 103 shows mean luminance values of records under different lighting and shade states (in blue) and includes a breakdown of each lighting and shade state by relative view orientation (0, +/-45, +/-90). General statistics for observed mean luminance in the lighting state groups are shown in Table 33 and general statistics for the shade state groups are shown in Table 34. As expected, mean luminance of records with 0 degree relative view orientation consistently exceeds mean luminance of records with 45 degree and 90 degree relative view orientation. The general trend between records with electric lights on and off, shown in Figure 102, is also found in the data shown in Figure 103. However, there does not seem to be a clear relationship between mean luminance and exterior shade deployment state (r^2=0.465) in the data shown in Figure 103. Mean luminance of records with 50% and 100% shade deployment states exceed mean luminance of records with 25% shade deployment state in both 0 degree and +/-45 degree relative view orientations. This result can be explained when window occlusion state is used to group data in lieu of exterior shade deployment state. Figure 104 shows records grouped according to window occlusion state. A strong negative correlation between window occlusion state and mean luminance (r^2=0.9334) is observed in the data. The test cases discussed in this section thus consider shade use behaviors in terms of total window occlusion.

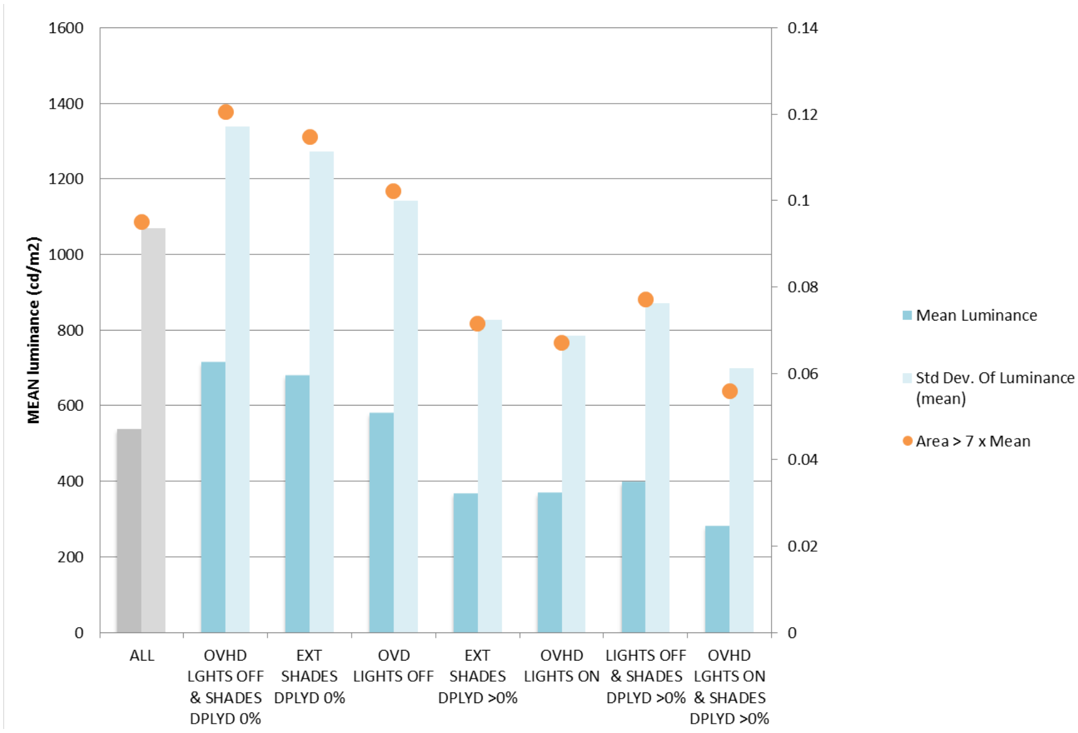


Figure 102: Mean luminance and standard deviation of luminance within the scene for all records grouped according to lighting and shade state.

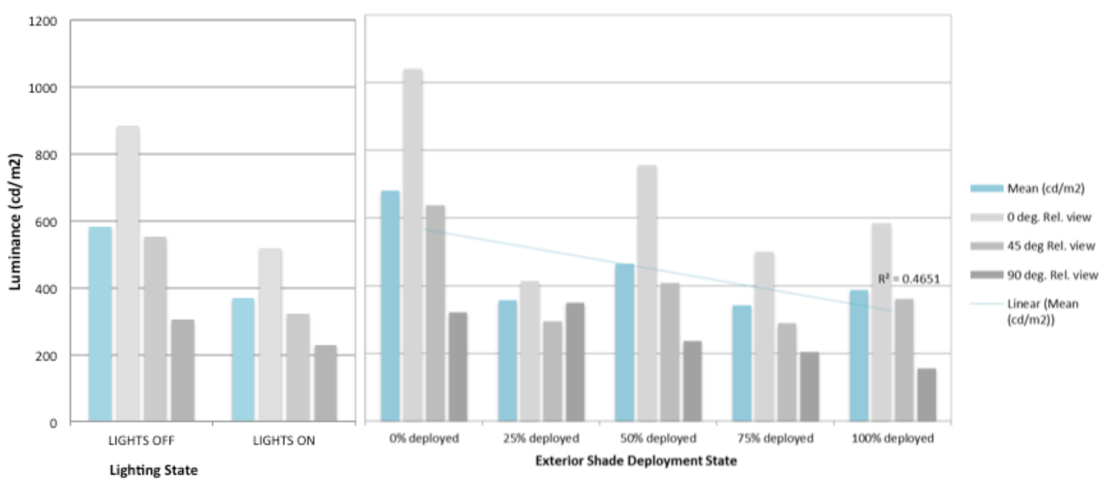


Figure 103: Mean luminance of all records grouped according to lighting state or shade deployment state and relative view angle.

Table 33: General statistics of mean luminance values for all records grouped according to lighting state and relative view orientation.

Lighting State Rel. View Orient.		Min	Max	Mean	Median	Std.Dev.	25th %	75th %	IQR
	(n=)	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*
Off	**135**	**6.52**	**3,246.6**	**581.42**	**353.6**	**606.32**	**142.72**	**828.85**	**686.13**
0	41	19.87	3,246.6	884.43	829.2	720.93	335.3	1240.23	904.93
45	58	13.21	2,273.2	554.05	366.54	546.89	189.43	719.80	530.37
90	33	6.52	1,924.5	302.62	199.48	360.48	87.89	440.19	352.3
On	**34**	**68.28**	**1,523.0**	**369.01**	**221.29**	**381.66**	**133.65**	**438.134**	**304.48**
0	12	100.68	1,523.0	519.29	321.01	483.85	185.38	672.8	487.42
45	14	68.28	1,314.5	319.97	181.77	341.29	130.46	323.47	193.01
90	8	93.09	676.37	229.39	150.79	191.58	126.74	259.14	132.39

Table 34: General statistics of mean luminance values for all records grouped according to exterior shade deployment state and relative view orientation.

Shade Deploy State Rel. View Orient.			Min	Max	Mean	Median	Std.Dev	25th %	75th %	IQR
		(n=)	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*	*(cd/m2)*
0%		**92**	**6.52**	**3,246.6**	**681.30**	**452.02**	**669.43**	**161.63**	**980.29**	**818.65**
	0	28	55.80	3,246.6	1,039.5	962.02	745.25	494.18	1,321.5	827.38
	45	42	13.21	2,273.2	636.76	424.72	609.92	194.03	856.01	661.99
	90	21	6.52	1,924.5	322.04	142.11	434.13	89.30	359.15	269.85
25%		**15**	**105.71**	**594.25**	**356.34**	**384.11**	**168.06**	**200.25**	**497.95**	**297.70**
	0	5	224.67	540.68	413.82	455.25	126.28	353.60	494.89	141.29
	45	4	105.71	542.44	294.47	264.87	206.00	135.64	423.69	288.05
	90	6	159.48	594.25	349.68	321.93	185.60	199.86	486.46	286.60
50%		**19**	**65.30**	**1,862.8**	**463.72**	**293.12**	**518.62**	**109.38**	**578.98**	**469.60**
	0	6	100.68	1,862.8	756.36	492.28	743.30	172.39	1,266.3	1,093.9
	45	7	68.28	1,268.7	407.09	262.10	421.90	165.82	459.46	293.64
	90	6	65.30	541.37	237.15	217.53	182.55	89.68	304.96	215.28
75%		**30**	**59.69**	**1,493.9**	**342.26**	**217.83**	**346.23**	**109.93**	**404.95**	**295.03**
	0	10	95.46	1,493.9	500.56	223.28	516.20	149.62	865.95	716.34

	45	14	59.69	756.73	288.35	247.78	195.09	149.78	392.08	242.30
	90	6	87.89	566.98	204.24	108.83	188.63	97.41	221.68	124.27
100%		**10**	**46.52**	**981.79**	**387.32**	**231.08**	**354.54**	**141.72**	**677.57**	**535.86**
	0	3	87.13	875.20	584.90	792.36	433.06	439.75	833.78	394.04
	45	5	136.01	981.79	361.21	196.20	355.25	158.84	333.21	174.37
	90	2	46.52	265.96	156.24	156.24	155.17	101.38	211.10	109.72

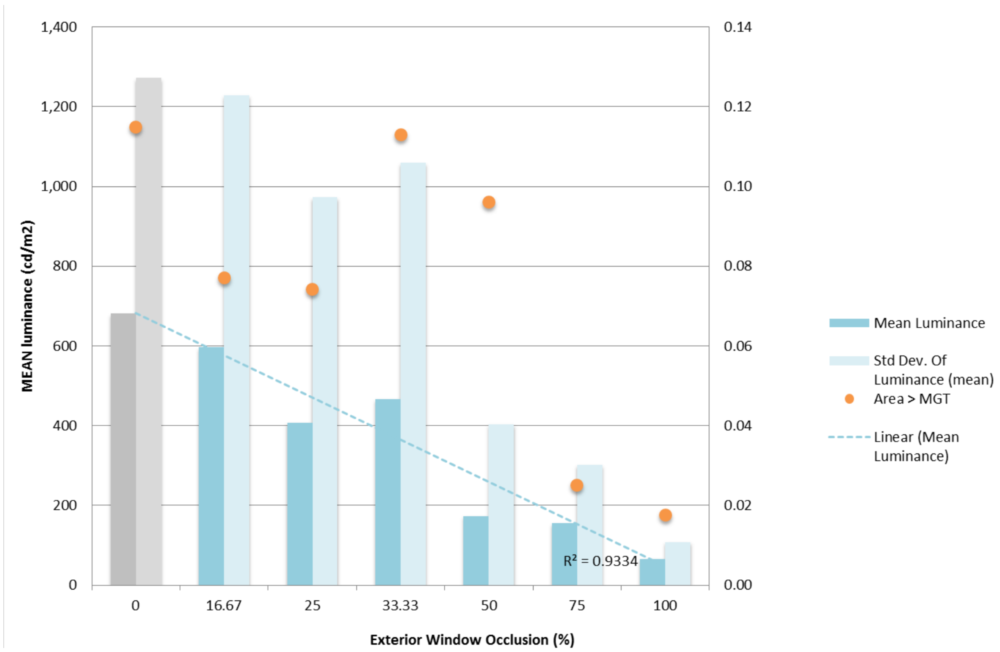


Figure 104: Mean luminance, standard deviation of luminance, and area outside the MGT shown for all records grouped according to exterior window occlusion.

In office #018, shown on the keyed plan in Figure 105, a series of exposure bracketed images were taken in the late morning under partially cloudy skies during different electric lighting states with 0% window occlusion. The resulting HDRI images, false color luminance maps, glare source images and general statistics for each view can be seen in Figure 106. From these images it is clear that the effect of electric lighting state on interior luminance distribution is not very large, especially under the particular sky conditions with direct sun visible in a large portion of the view. Figure 107 shows that mean luminance and standard deviation of luminance are generally higher when the lights are on than when they are off. This trend is evidenced by a 17.2% decrease in mean luminance in the 0 degree relative view orientation and 34.9% decrease in the 90 degree relative view orientation. The +45 degree relative view orientation, however, exhibits a 1.58% increase in mean luminance when the lights are off. This may be a result of the slight variation in viewing angle between the lights on and lights off images taken at +45 degree relative view orientation. As can be seen in Figure 106, the lights off image is tilted slightly upward and angled towards the upper corner of the window, which reduces the incident angle at which light from the window hits the lens and causes luminance values within that portion of the scene to increase. Area outside MGT displays similar trends between the lights on and off data that are observed in the mean luminance and standard deviation of luminance results described above.

Figure 105: Office #018 shown on the third floor plan.

Figure 108 shows another way to visualize and quantify luminance distribution within each scene. The chart seen in Figure 108 describes each scene in terms of the view area that falls within a standardized luminance range. Luminance range boundaries (less than 20 cd/m^2, 20- 200 cd/m^2, and above 200 cd/m^2) are chosen to reflect the range of luminance values observed within difference areas of interior scenes. Luminance values less than 20 cd/ m^2 (low) are typically observed from surfaces that are in shade or dark colors, such as underneath furniture or dark carpets, and are not likely to reflect useful light. Luminance values between 20 cd/ m^2 and 200 cd/ m^2 (mid) are typically observed from surfaces that are reflecting diffused light or light colors, such as painted interior walls or ceilings, and are likely to reflect useful light. Lastly, luminance values above 200 cd/ m^2 (high) are typically observed from exterior surfaces or those that receive direct sun and are usually light colors. As can be seen in Figure 108, each view is primarily composed of surfaces that are in the high luminance range and few surfaces are in the low luminance range. The percentage of high luminance area generally decreases when the lights are turned off and as the relative view orientation increases. The most significant difference in the observed scenes is between the lights on and off state in the 0 degree relative view orientation, which exhibits a 70.3% increase in the amount of view area in the mid luminance range and a 21.2% decrease in the amount of view area in the high luminance range.

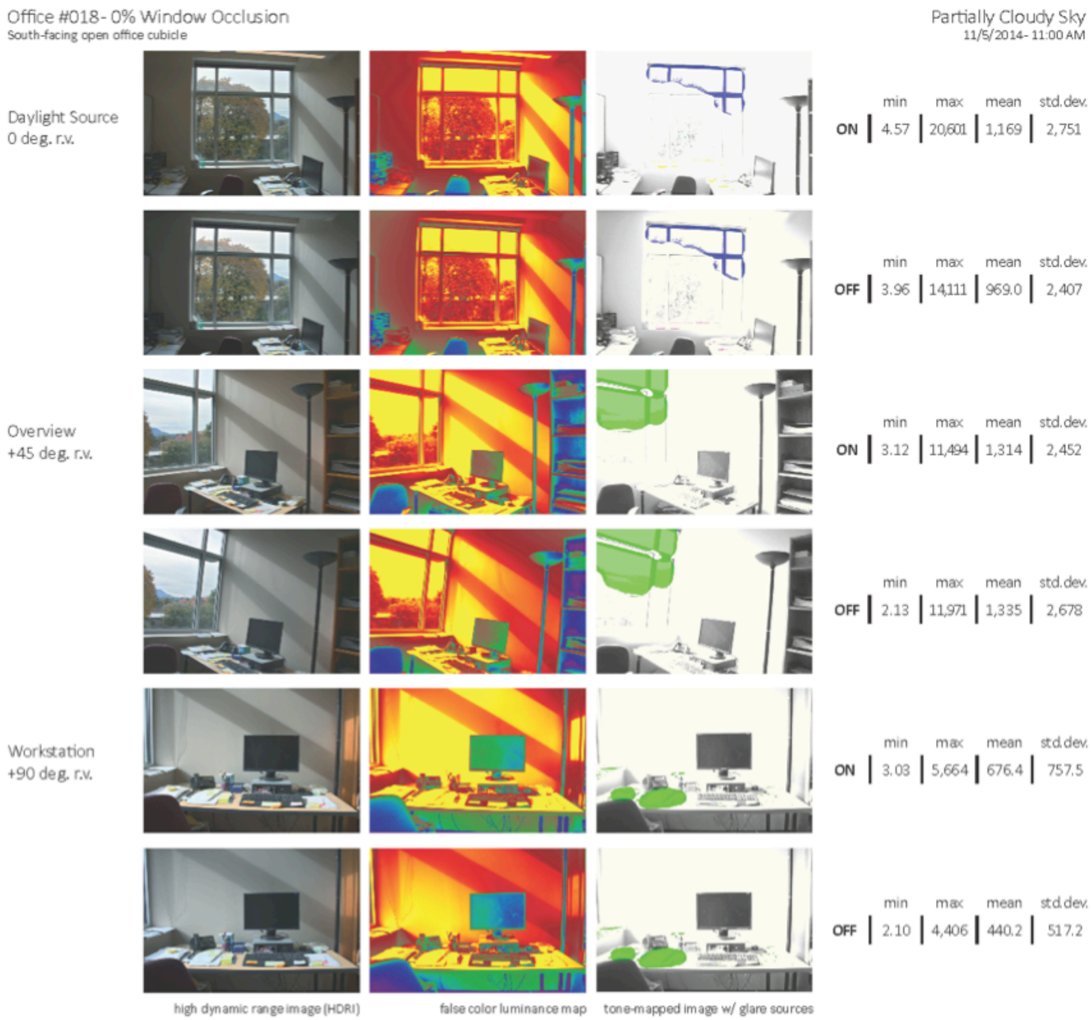


Figure 106: HDRI, false color luminance maps, glare source images and accompanying general statistics for each view and lighting state tested in office #018 with 0% window occlusion in partially cloudy skies.

Data from this test case shows that using the electric lights in an otherwise brightly daylit condition contributes to increases in mean luminance, standard deviation of luminance, area outside MGT, and area within high luminance range. HDRI and false color luminance maps (Figure 106) show the electric lighting acts as an additive function to daylight, rendering all surfaces brighter but not reducing contrast between light and dark areas. With direct sun visible in the office, the electric lights seem to be producing a brighter and potentially glaring indoor environment. The effect of the electric lights is seen in both the 0 degree and +90 degree relative view orientations. Differences in the camera angle between lighting state images in the +45 degree relative view orientation likely obscures the effect of the electric lights on interior luminance metrics.

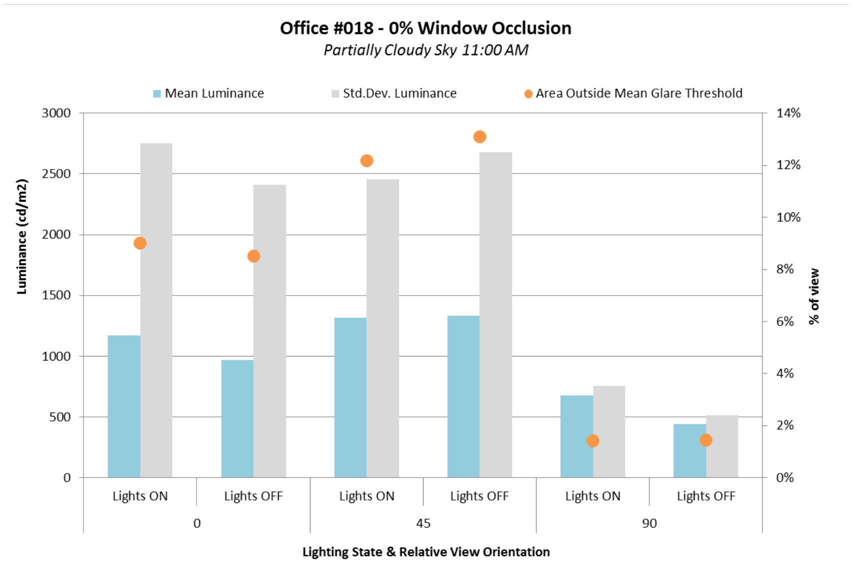


Figure 107: Mean luminance, standard deviation of luminance, and area outside MGT for each relative view orientation and lighting state in office #018.

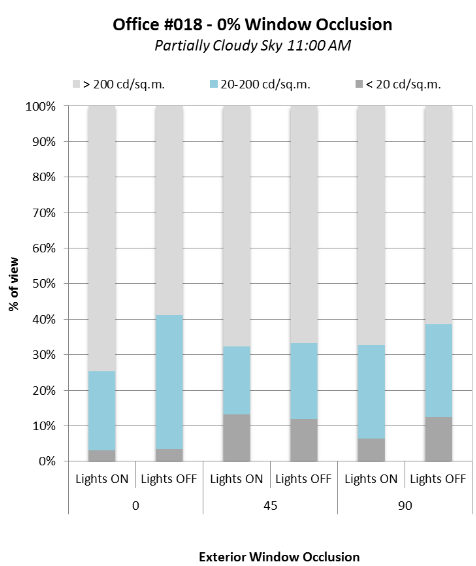


Figure 108: Percentage of view within luminance criteria ranges for each relative view orientation and lighting state in office #018.

The next test case takes place in office #012 (shown on a keyed plan in Figure 82 above) under clear sunny sky conditions in the morning and shows the impacts of changes in window occlusion on interior luminance distribution. Exposure bracketed images are taken at a -90 relative view orientation at 0%, 25%, 50%, 75%, and 100% window occlusion states (Figure 109). Changes in window occlusion state are achieved by deploying the exterior shade to specified distances from the window head (25% down, 50% down, etc.) while the slats are tilted completely closed. General statistics for each window occlusion state are shown at the right hand side of Figure 109.

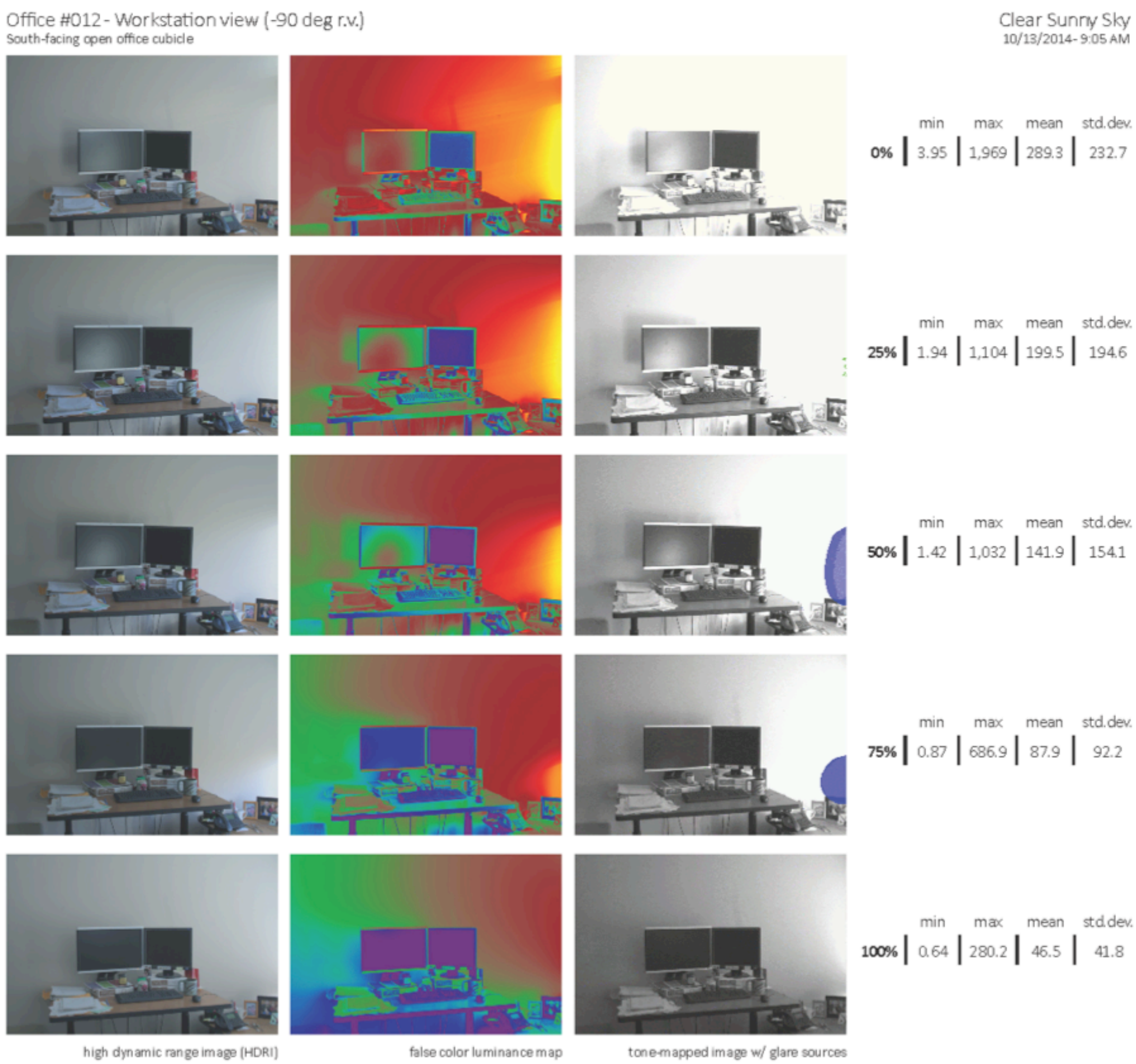


Figure 109: HDRI, false color luminance maps, glare source images and accompanying general statistics for each window occlusion state tested in office #012 with electric lights off in partially cloudy skies at a -90 degree relative view orientation.

While office #012 is under direct sun at the time of observation, 9:00 AM, the workstation is located along the east wall so the portion of the office visible in the images is in shade. The exterior window is located just out of frame to the right. As a result, this data represents luminance distribution for interior elements only and large variations in interior luminance are not expected. Figure 110 shows that mean luminance and standard deviation of luminance in each window occlusion state are closely related (r^2=0.974). Both mean luminance (r^2=0.979) and standard deviation of luminance (r^2=0.991) show a strong negative correlation with window occlusion state. Area outside MGT, however, displays a very weak relationship with window occlusion state (r^2=0.013). Despite this, area outside MGT and the results of the Evalglare protocols seen in the glare source images in Figure 109 indicate that the 50% window occlusion state produces a potentially uncomfortable view at the workstation compared to the other window occlusion states shown. Each progressive window occlusion state can clearly be seen lowering the height of the high luminance areas on the east wall of the office (represented by the yellow and orange pixel areas). At the same time, lower luminance areas expand from the bottom left of the scene and as the window occlusion state increases the lower luminance areas begin to encroach upon the workspace. Figure 111 shows a positive correlation between low luminance range and window occlusion state (r^2=0.936) and a very strong negative correlation between high luminance range and window occlusion state (r^2=-0.995). This data may indicate that while occluding the window may alleviate discomfort in the conditions shown if it results from an overly bright scene in general, the intermediate 50% and 75% window occlusion states may actually exacerbate visual discomfort due to the spatial proximity of low and high luminance areas that results from occluding the top portions of the window.

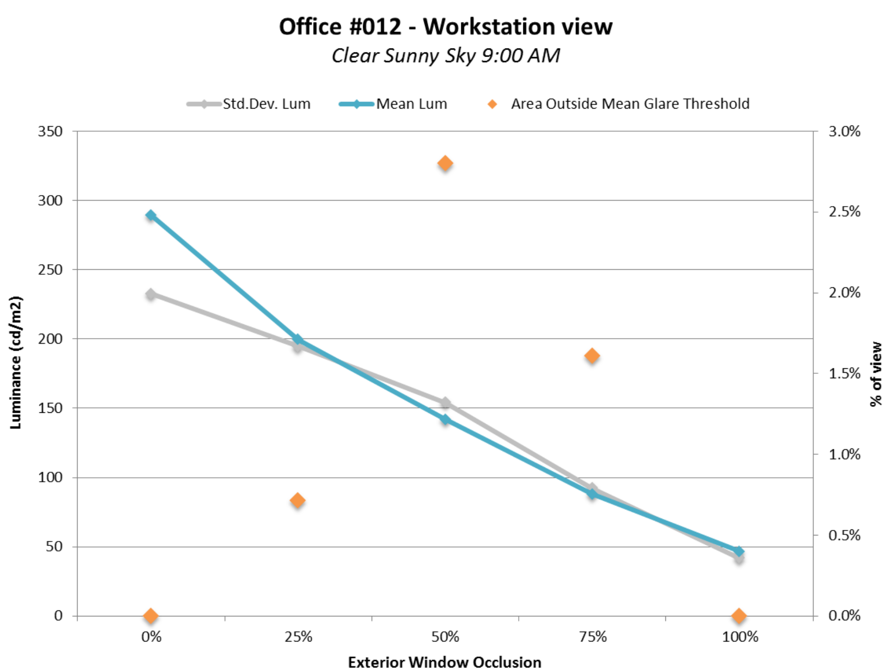


Figure 110: Mean luminance, standard deviation of luminance, and area outside MGT for each window occlusion state in office #018.

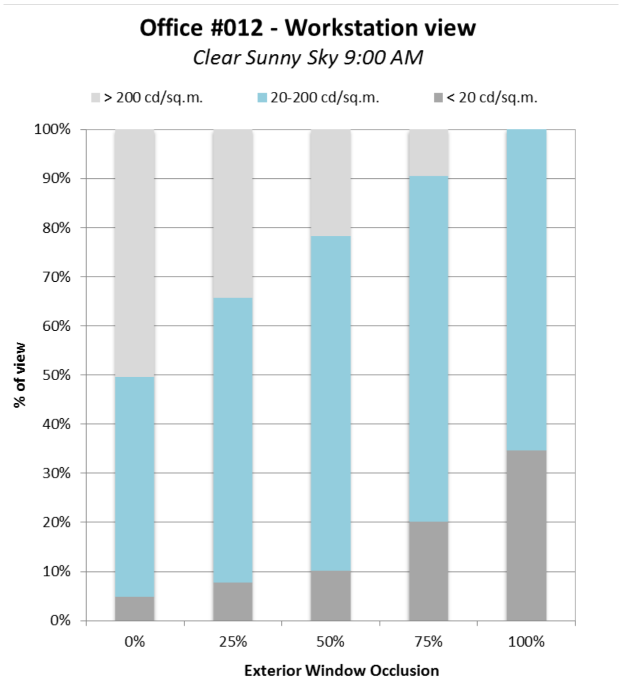


Figure 111: Percentage of view within luminance criteria ranges for each window occlusion state in office #012.

The next case is meant to describe the effect of changes in the window occlusion state on interior luminance distribution with direct sun visible in the scene. In a series of exposure-bracketed images taken in office #009 (seen on keyed plan of the third floor in Figure 85 above) the exterior window is progressively occluded from 0% (shade deployed 0%) to 75% (shade deployed to 75% of the window height with slats tilted completely closed). Figure 112 shows the resulting HDRI, false color luminance maps, glare sources images and accompanying general statistics for each window occlusion state tested. The views show the workstation, at +90 degrees relative view orientation, which is located adjacent to the window along the west wall. There are no other significant spatial variations between office #009 and 012 and thus this case is interpreted as an analog to the previous case whose results could be directly compared in order to assess the differences resulting from direct sun. However, the occupant's personal affects located on the exterior window sill prevent the shade from being deployed completely and the 100% window occlusion state is not achievable in office #009. Nevertheless, any trends resulting from the window occlusion state should be easily observable even without the 100% occlusion state.

Figure 113 shows a strong negative correlation between mean luminance and window occlusion state (r^2=-0.997) and a strong but slightly lower negative correlation between standard deviation of luminance and window occlusion state (r^2=-0.971). Standard deviation of luminance values within each scene is markedly higher than mean luminance for that scene, on average exceeding the mean luminance value by 83.4%. Comparing luminance data between test cases in office #009 and office #012, seen in

Figure 114, shows that when direct sun is present in the view luminance variation (represented by standard deviation of luminance in the scene) increases substantially more than mean luminance. A portion of the exterior window is visible in the scenes shown in Figure 112 because the workstation is located next to the exterior wall, which may partially explain the increased variation in luminance within the scene in office #009. Further, Figure 114 shows the largest differences between mean luminance (197.9%) and standard deviation of luminance (696.8%) in each office when the window is 25% occluded. The effect of direct sun diminishes as the window is occluded further and at the 75% window occlusion state the mean luminance value of the scene observed in office #009 is only 9.3% higher than seen in office #012. Standard deviation of luminance remains 115.8% higher in office #009 than office #012 when the window is 75% occluded however.

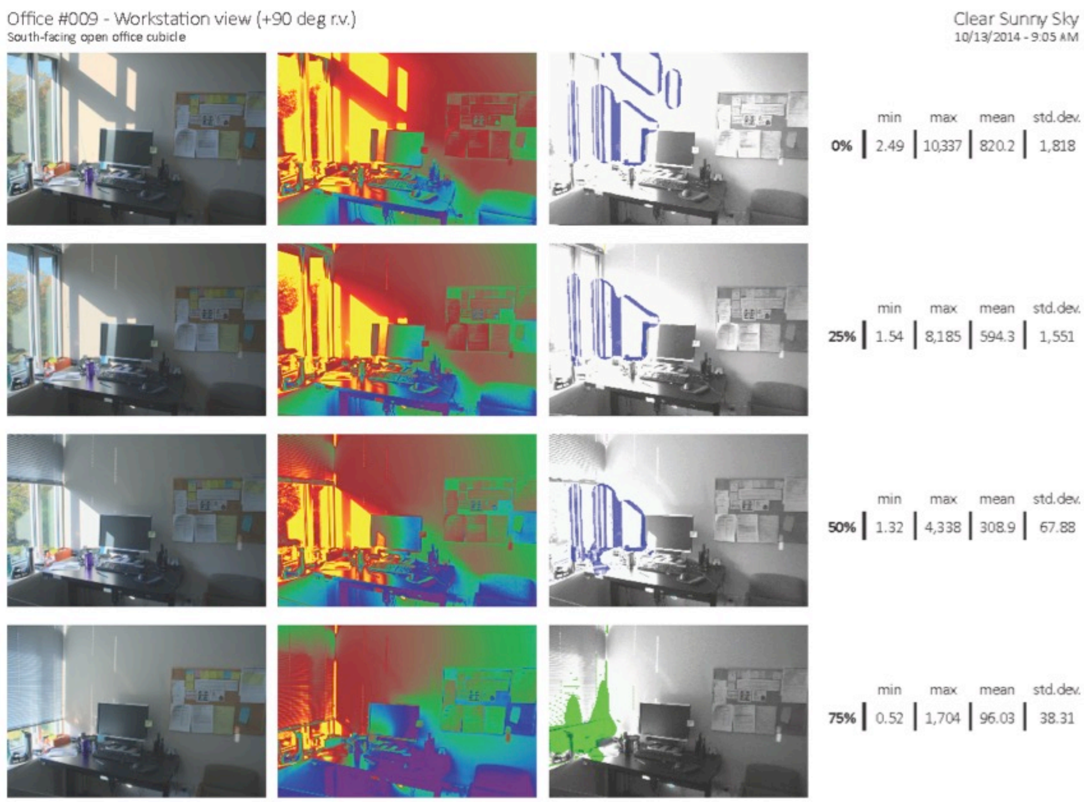


Figure 112: HDRI, false color luminance maps, glare source images and accompanying general statistics for each window occlusion state tested in office #009 with electric lights off in partially cloudy skies at a +90 degree relative view orientation.

Figure 115 shows that even with direct sun visible in the scene, low luminance range areas increase and high luminance range areas decrease as window occlusion increases. This trend is also observed in the data from the previous test case, although the correlation strength decreases slightly for both the low luminance range (r^2=-0.930) and high luminance range (r^2=-0.992). The particular occupant's accouterments, seen in Figure 112 including a pin-up board that takes up a large portion of the interior wall surface area to the right of the workstation, may explain the slightly lower correlation in office #009. Interior walls around the workstation in office #012, seen in Figure 109, are blank and as a result luminance levels decrease smoothly as they get further from the window.

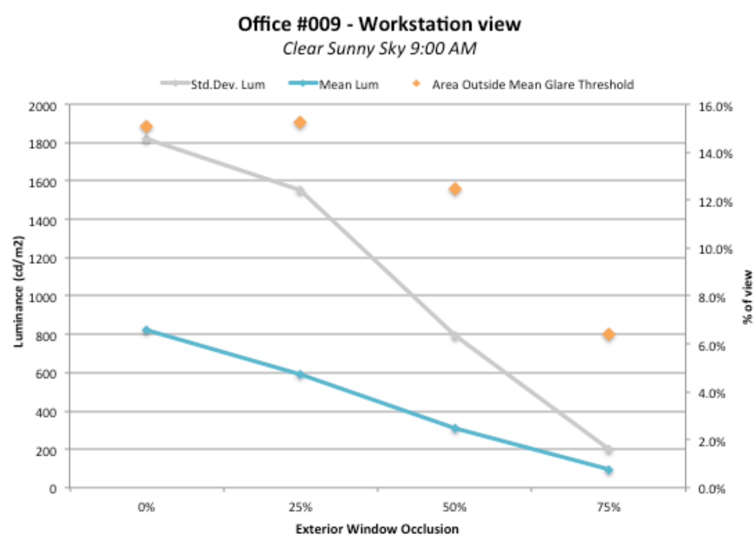


Figure 113: Mean luminance, standard deviation of luminance, and area outside MGT for each window occlusion state in office #009.

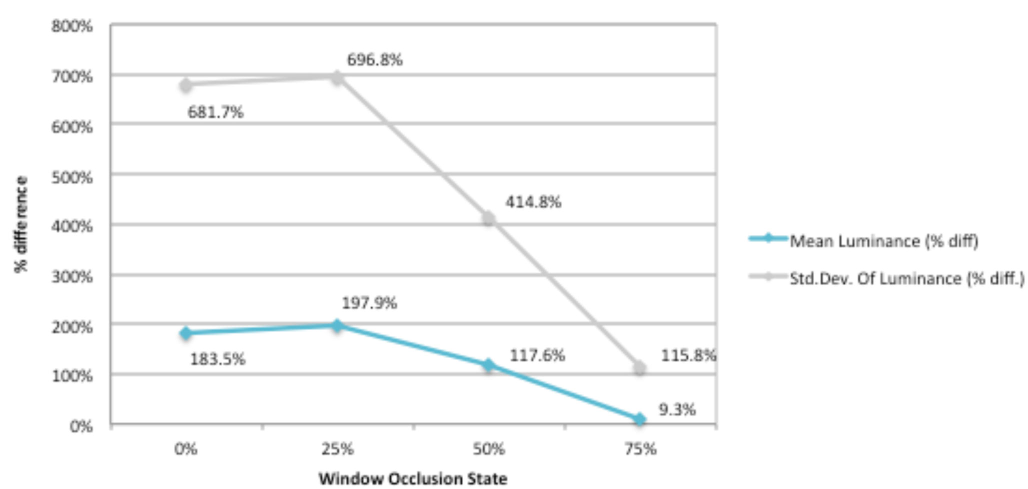


Figure 114: Percentage difference between observed mean luminance and standard deviation of luminance in office #009 and 012 showing the impact of direct sun within the view.

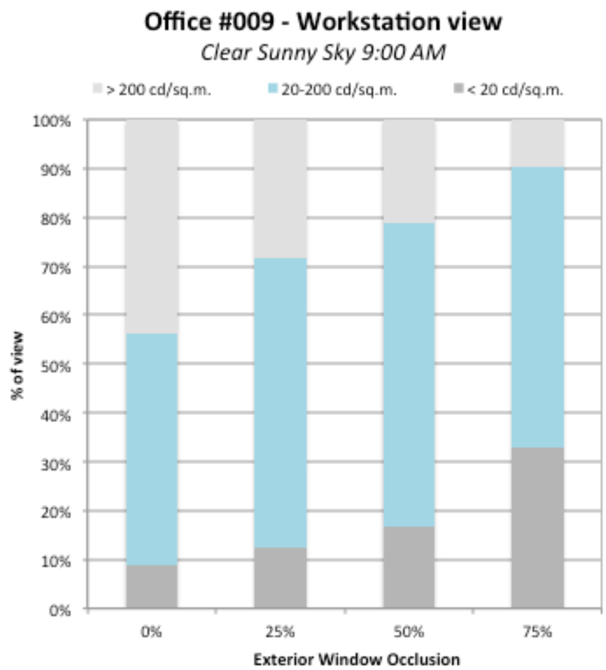


Figure 115: Percentage of view within luminance criteria ranges for each window occlusion state in office #009.

Data from this test case indicates that direct sun generally increases mean luminance, standard deviation of luminance, and area outside MGT but significantly influences luminance variation within the scene more than other measures of luminance distribution. In addition, this effect is seen most strongly when the window is 25% occluded in direct sun. The data also shows that occluding the window when direct sun is visible in the office is a useful strategy to reduce brightness and luminance variation overall but that the most significant effects of occluding the window are not seen until the window is at least 75% occluded.

The next case illustrates what is expected to be a worst-case scenario regarding visual comfort in a daylit office because the workstation is located directly in front of the exterior window and the occupant view is at 0 degree relative view orientation, which are in south-facing offices that exhibit the highest mean luminance and luminance variation of all offices sampled. In a series of exposure-bracketed images taken in office #011 (shown on the keyed plan of the third floor in Figure 116) the exterior window is progressively occluded, in same manner as the test cases in offices #009 and #012, from 0% (shade deployed 0%) to 100% (shade deployed to full height of the window with slats tilted completely closed). Similar to office #009, occupant's personal affects located on the window sill prevent the shade from being lowered completely to the sill. Figure 117 shows the resulting HDRI, false color luminance maps, glare sources images and accompanying general statistics for each window occlusion state tested.

Figure 116: Office #011 shown on the third floor plan.

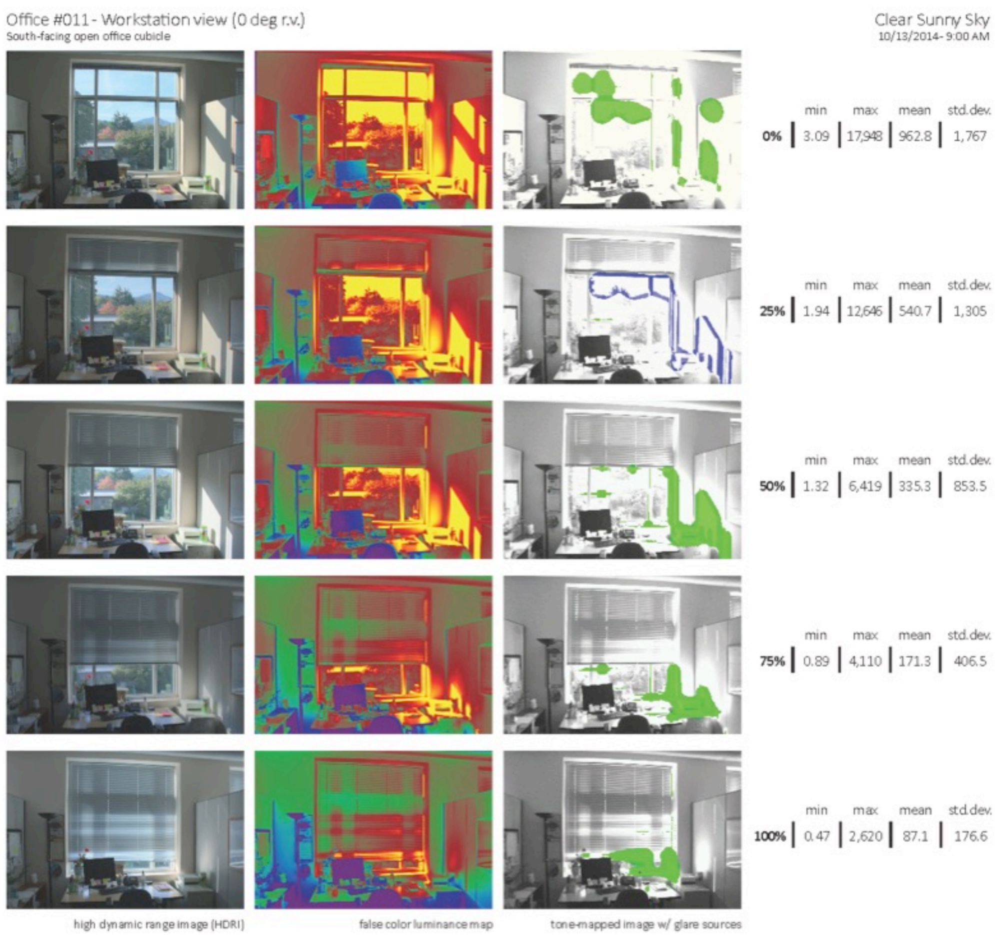


Figure 117: HDRI, false color luminance maps, glare source images and accompanying general statistics for each window occlusion state tested in office #011 with electric lights off in clear sunny skies at a 0 degree relative view orientation.

The conditions captured in these scenes are expected to exhibit clear indicators of visual discomfort. A cursory comparison of the false color luminance maps and glare source images in Figure 117 shows that as the window is occluded further, the highest intensity luminance areas close in on the workstation and computer monitor task area. While there are large glare sources at the top of the window area when the window is occluded 0% and 25%, these seem to be far enough from the workstation to perhaps not significantly impact visual comfort. The overall brightness of the scene when the window is occluded 0% and 25% may cause visual fatigue during prolonged periods of clear or partially cloudy skies however. When the window is occluded further, to 75% and 100%, luminance at the top portion of the window significantly decreases but luminance around the workstation and bottom of the window is not significantly different from the 0% or 25% window occlusion states. Figure 118 shows the downward trend of mean luminance, standard deviation of luminance and area outside MGT as the window is occluded. The decrease in standard deviation is strongly correlated with window occlusion state (r^2=-0.994), particularly as the window is occluded from 0% to 75% (r^2=-1). The loose fit exhibit between 75% and 100% window occlusion is likely a result of the definition used to categorize the final window occlusion state, which is only 85% occluded compared to a completely unobstructed shade deployment path. For the sake of this study, the definition of shade state is necessarily loose. Many offices may have occupant-related factors that affect their ability to exhibit certain behavioral responses. In this case, the final window occlusion state is shy of 100% but clearly different from the 75% window occlusion state, warranting its grouping with the next occlusion state.

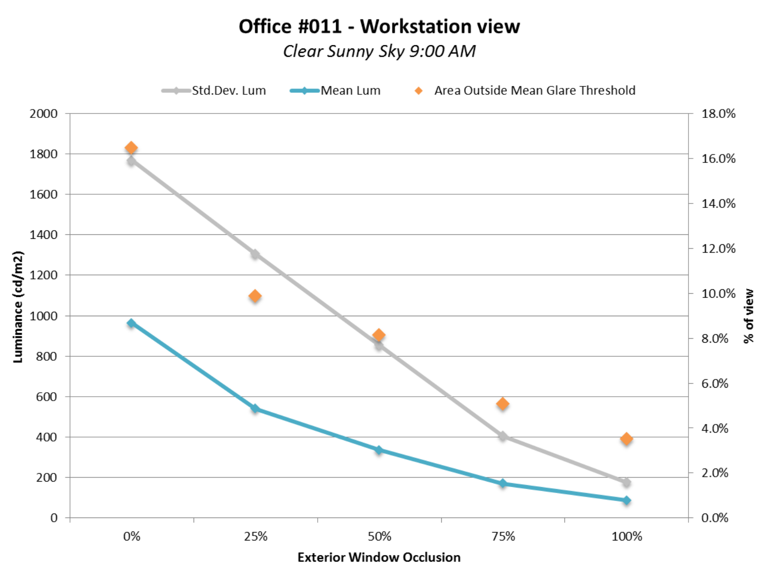


Figure 118: Mean luminance, standard deviation of luminance, and area outside MGT for each window occlusion state tested in office #011.

The scenes examined in this test case show luminance distribution on the occluded portion of the window area resembles luminance distribution on the adjacent exterior wall. In terms of luminance distribution and intensity in the window opening area, the act of occluding the window in the manner shown effectively reduces the aperture size and increases the interior surface (wall) area. This trend is seen in Figure 119 as the high luminance range area steadily decreases as the window occlusion state increases. The low luminance range area however, is only slightly affected by changes in window occlusion state until the window is 100% occluded and the low luminance range area more than doubles. This indicates that low luminance range area is affected by something other than the effective aperture size. It is clear from the false color luminance maps shown in Figure 117 the main difference between the 75% and 100% window occlusion states is that no interior surfaces beyond the immediate proximity of the window opening area receive direct sun when the window is fully occluded. This difference may account for the trend observed in low luminance range area as incident direct sun on interior surfaces acts like another high intensity luminance source that also increases the luminance intensity of nearby surfaces. Removing the direct sun thus removes that second luminance source and causes surfaces not directly illuminated by the window to decrease luminous intensity significantly. While it may be initially interpreted that the inability to deploy the shade completely to the sill prevents the occupant from blocking direct sun intrusion into the office, and thus fully removing sources of discomfort caused by the direct sun, the results of this test case illustrate that the window does not need to be fully occluded in order to prevent direct sun intrusion. Further, the examples of office #011 and office #009 above show that views through the exterior window can at least partially be preserved while still controlling potential sources of discomfort by using the exterior shade.

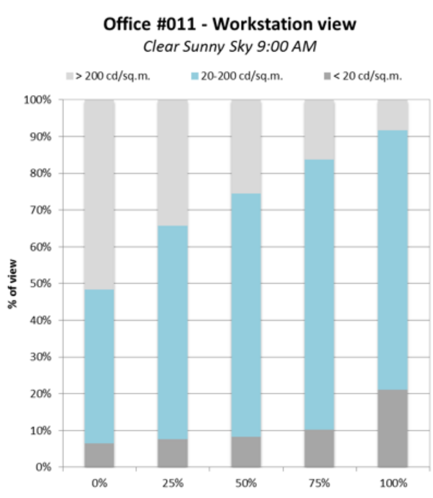


Figure 119: Percentage of view within luminance criteria ranges for each window occlusion state tested in office #011.

Data from this test case illustrates the luminous characteristics of the worst-case scenario workstation orientation (0 degree relative view orientation) and location (directly under the window). In this case, it is difficult to remove glare sources from the exterior window completely using the exterior shades. As the window is occluded, the apparent glare sources shown in Figure 117 get closer to the workstation and near-occupant view area, thus implying that significant window occlusion is required to ameliorate source of glare originating from the exterior window. However, this case illustrates that it is possible to prevent direct sun intrusion and preserve limited views through the exterior window. Both of these observations are a direct result of the style of shade utilized in this building – one shade deployed continuously from the window head to the window sill. The occupant is thus required to occlude the entire upper portion of the window in order to address high luminance zones near the workstation and occupant's view.

The previous cases illustrate a linear window occlusion pattern where the shade is progressively deployed until the window is fully occluded. The results of that window occlusion pattern show gradual changes in luminance distribution and intensity that frequently exhibit a strong linear correlation with window occlusion state. This case includes results of a series of exposure-bracketed images taken in office #066 (shown on the keyed plan of the fourth floor in Figure 89 above) in which the exterior window is occluded 0%, 16.67% (shade deployed 50% with slats horizontal), 25% (shade deployed 75% with slats horizontal), and finally 75% (shades deployed 75% with slats tilted completely closed). In office #066, as is the case in offices #009 and #011, occupant's personal affects located on the window sill prevent the shade from being deployed completely to the window sill. The next case also illustrates a worst-case condition regarding workspace orientation (+45 degree relative view) and location (directly under the window) in the 4th floor office. Figure 120 shows the resulting HDRI, false color luminance maps, glare sources images and accompanying general statistics for each window occlusion state tested.

Luminance distribution patterns in office #066 do not appear to vary much between the first three window occlusion states (0%, 16.67%, 25%). Glare source images in Figure 120 identify large areas at the top of the window as well as smaller areas on the work plane as potential sources of discomfort for the first three window occlusion states. As expected, significant differences emerge in the final window occlusion state. The glare sources identified in the first three window occlusion states do not appear as glare sources when the window is occluded 75%. Only small areas below the bottom rail of the shade continue to be shown as potential glare sources. The test cases above show similar trends where the glare source areas get closer to the workstation and occupant view area as the window occlusion increases. In office #066 however, the glare sources seen in the 75% occlusion state appear quite small and dispersed throughout the remaining window area. This is likely caused by the view composition through the exterior window, which transitions from sky in the upper half to the distance tree canopies in the lower half and display different luminance intensity and variations within their respective regions. To support this observation, the glare sources shown in the 0% and 16.67% occlusion states are contained within the visible sky area only.

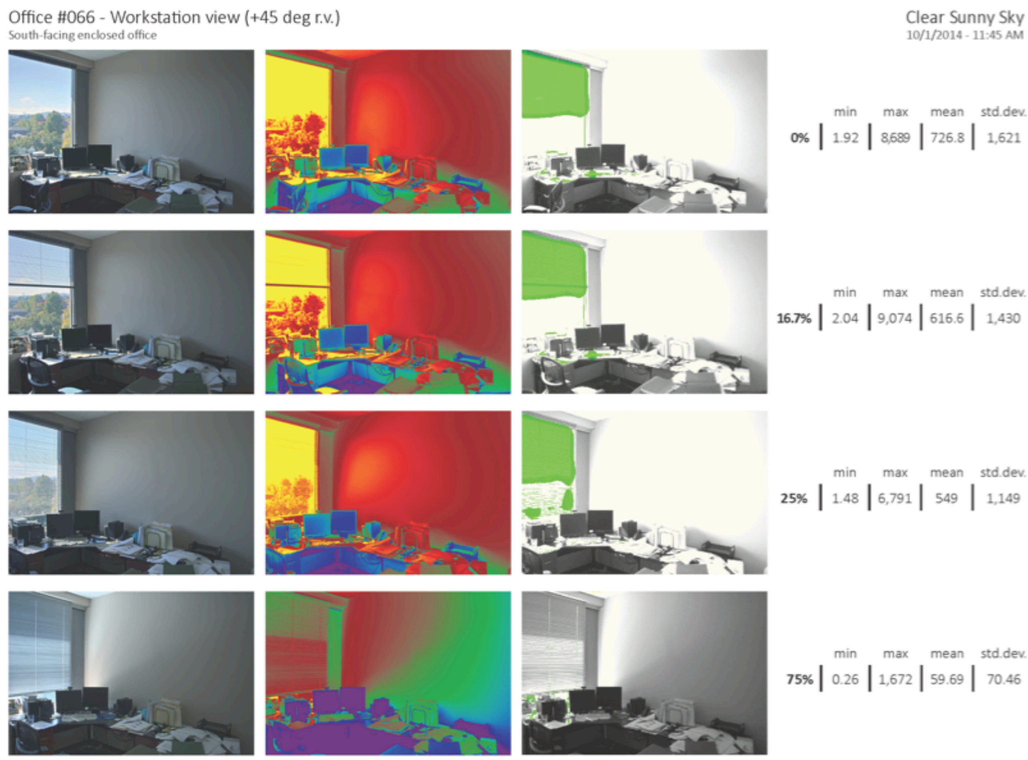


Figure 120: HDRI, false color luminance maps, glare source images and accompanying general statistics for each window occlusion state tested in office #066 with electric lights off in partially cloudy skies at a 45 degree relative view orientation.

While there appear to be few qualitative differences between the scenes in 0% - 25% window occlusion states, Figure 121 shows that mean luminance, standard deviation of luminance, and area outside MGT decrease at similar rates when window occlusion state increases to 25%. Mean luminance shows a strong negative correlation with window occlusion states from 0-25% (r^2= -0.998) but can be seen to decrease at a slower rate as window occlusion increases to 25%. This effect is also visible in the false color luminance map of the 25% occlusion state shown in Figure 120. The bright luminance region on the interior wall near the window opening seems to wash up and to the right, indicating that the top surface of each slat on the exterior shade may be reflecting sufficient quantities of light to affect interior luminance distribution. Simultaneously, the luminous intensity of workstation surface and other near-ground surfaces decrease. Mean luminance of the overall scene thus displays only slight variation while the spatial distribution of luminance within the scene displays more significant changes. Figure 122, which shows the composition of each scene into different luminance ranges, documents this effect at the 25% window occlusion state. High luminance area at 25% window occlusion increases by 23.3% compared to the 16.67% occlusion state while low luminance area increases by 20.3% in between the two window occlusion states. Confirming the observations described above, Figure 122 shows negligible changes in luminance range areas between 0% and 16.67% window occlusion states and significant changes between 25% and 75% window occlusion states. Low luminance range area increases by 91% and high luminance range area decreases by 95% between the 25% and 75% window occlusion states.

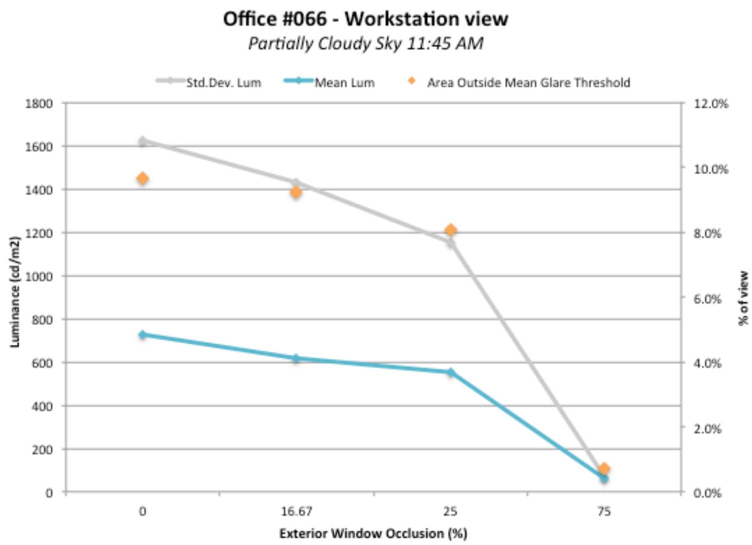


Figure 121: Mean luminance, standard deviation of luminance, and area outside MGT for each window occlusion state tested in office #066.

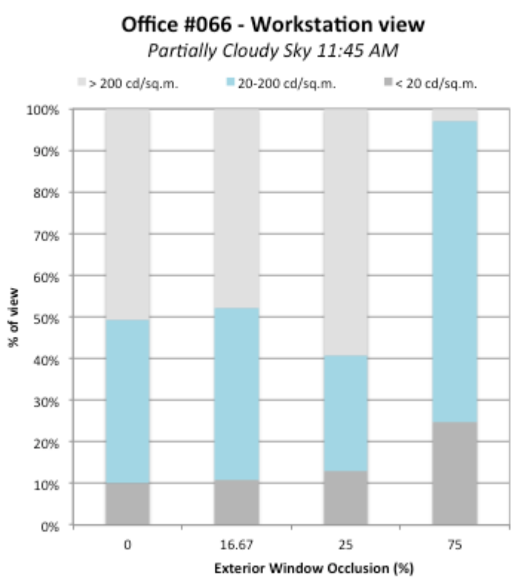


Figure 122: Percentage of view within luminance criteria ranges for each window occlusion state tested in office #066.

The last observation emerging from this test case relates to the differences in fenestration design between 3rd and 4th floor offices. As noted above, the top surface of the slats reflect daylight upwards into the depth of the office. In Figure 123, the bottom portion of the shade is brighter than the upper portion, indicating that only the bottom portion of the shade reflects daylight upward into the space. In order for the shade to reflect daylight at any given height, the shade must see a large enough portion of the sky dome and be sufficiently bright enough on the exterior surface. The upper portion of the shade is demonstrably darker than the lower portion, indicating that different exterior conditions affect the upper and lower portions of the shade. This is a reasonable conclusion considering the large roof overhang above the fourth floor windows. This observation helps to explain why there are only small changes in interior luminance distribution between the 0% and 16.67% occlusion states but large changes between the 16.67% and 25% occlusion states. The height at which the shade begins to appear brighter and reflect more light roughly corresponds to the height of the shade in the 16.67% occlusion state. The shade, when deployed to 50% of the window height and tilted horizontal/open, reflects very little light from the top surface of the slats and in turn only affects the view through the top portion of the window but not interior luminance distribution.

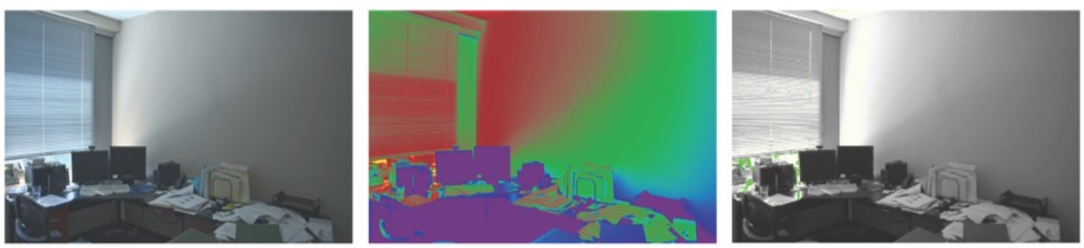


Figure 123: HDRI (left), false color luminance map (center), and glare source image (right) for office #066 with window occluded 75% under partially cloudy skies.

The last test case compares luminance distribution across a cluster of north-facing open office cubicles under two distinct window occlusion states, 0% and 50%. This test case also illustrates differences in interior luminance distribution resulting from the alignment between interior walls, cubicle partitions, and exterior windows. A series of exposure-bracketed images were taken in offices #096, 098, and 100 (seen on the keyed fourth floor plan in Figure 91 above) under partially cloudy skies in the mid-morning. This test case compares an overview image, taken at either +45 or -45 relative view orientations depending on the specific location of the workstation within the office (Figure 124), and daylight source image for each office. Figure 125 shows the resulting HDRI, false color luminance maps, glare sources images and accompanying general statistics for each view and office tested.

Significant differences appear between the offices with 0% window occlusion (#096 and 100) and 50% window occlusion (#098). Continuing the trend identified in previous test cases, glare sources move from the top of the window area when the window is 0% occluded to the bottom portion in the occupants' view area when the window is more than 50% occluded. In addition, the interior surface of the exterior shade nearly resembles the luminous intensity of the adjacent exterior wall surface in the 50% window occlusion state, which indicates that the act of occluding the window in this manner effectively reduces the daylight aperture size and location. The proximity of the workstation as well as the alignment of the cubicle partition with the window opening seem to create glare sources inside of office #098 in the -45 degree relative view orientation, something that is not observed in any relative view orientations of the other two offices. Figure 126 shows that despite these observations, views in office #098 display the lowest overall mean luminance and standard deviation of luminance as well as the lowest area outside MGT in each relative view orientation. These two pieces of data seem to conflict, but together indicate that in office #098 the particular window occlusion state creates an acute source of visual discomfort focused nearby the occupied area rather than a broad source of visual discomfort distributed across more distance parts of the office.

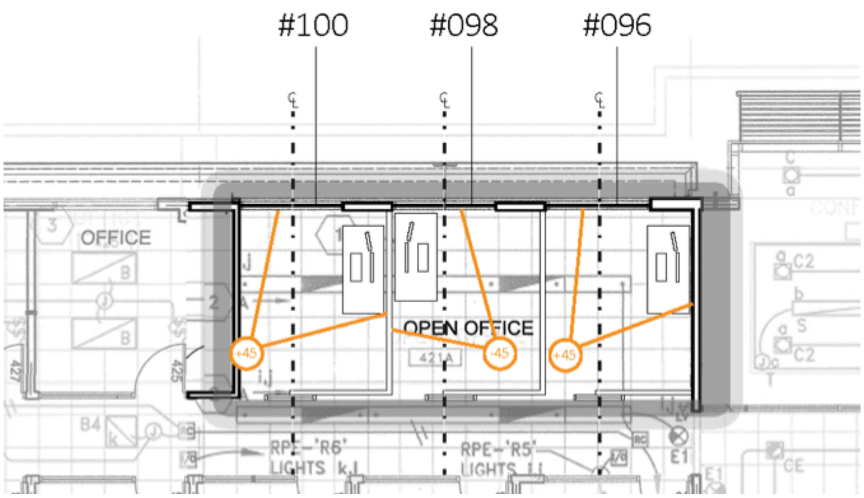


Figure 124: Fourth floor plan showing comparative view shed locations in offices #096, 098, and 100.

This test case also demonstrates the effect of interior wall surface properties on luminance distribution. There are three primary wall surface types present within this open office cluster, which is typical of all open office clusters on the fourth floor. The end walls of each cluster are clad in gypsum wallboard and painted a light, moderately reflective neutral color. The short wall to the right of the window in office #096 matches the end walls. The cubicle partitions are finished with a light gray textile that is less reflective and has a more textured surface than the end walls. Opaque panels between windows, seen to the right of the windows in office #098 and #100, are finished with a medium gray opaque window film that is not very reflective. The opaque film is limited to the fourth floor and found in enclosed offices as well as open office areas. Third floor offices are finished with similarly painted and moderately reflective gypsum wallboard on all walls that are not cubicle partitions. Comparing the 0-degree relative view of office #096 and #100 shows that the gypsum wallboard located to the right of the window in office #096 is much brighter than the opaque window film seen to the right of the window in office #100. In the same views, while the gypsum wallboard on the end wall of office #100 is much brighter near the window opening than the cubicle partition on the west side of office #096, they both exhibit similar overall distributions of light from the window. A similar conclusion can be reached when comparing the luminous intensity of the wall surface beyond the workstation in the 45-degree relative view of office #096 and #100.

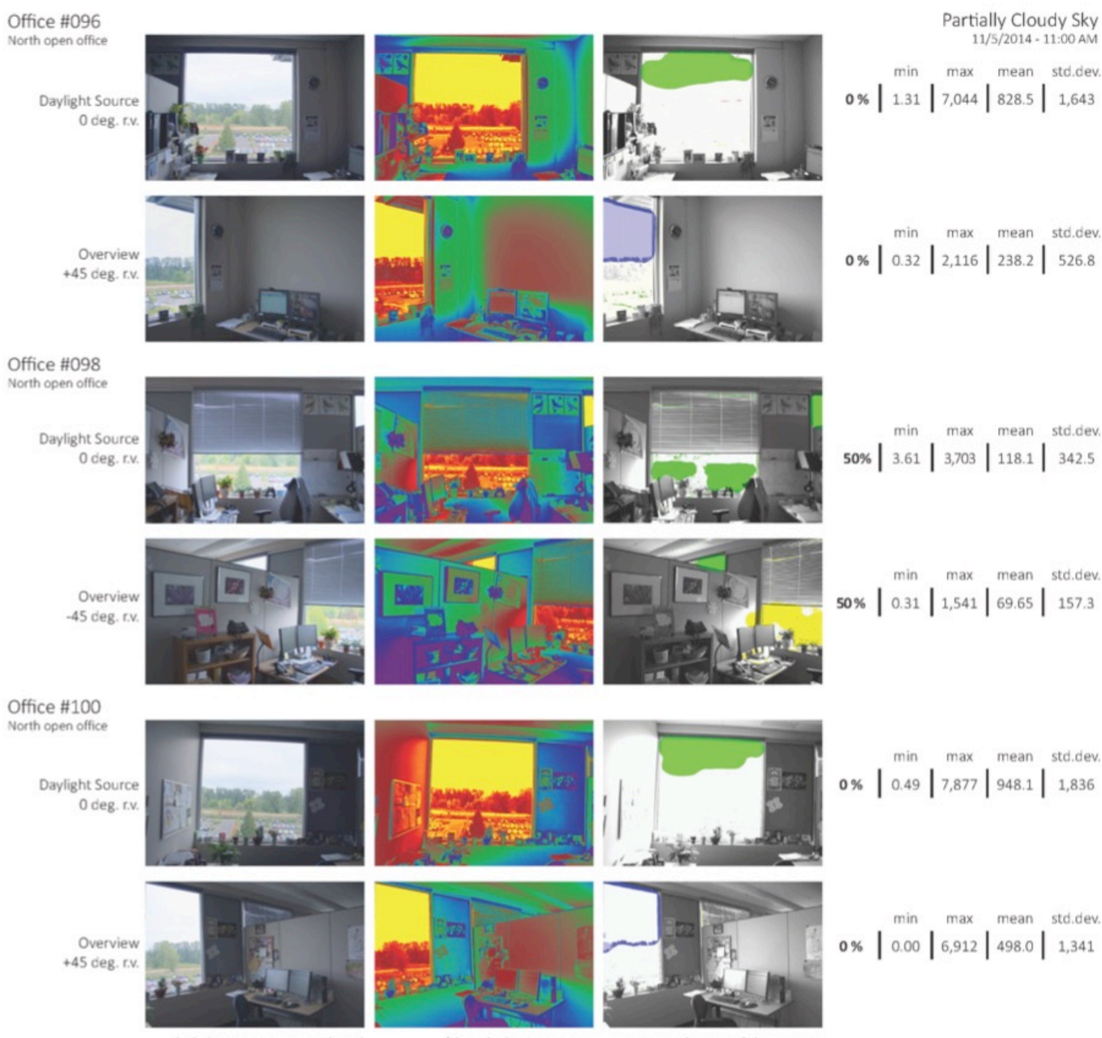


Figure 125: HDRI, false color luminance maps, glare source images and accompanying general statistics for each relative view orientation and window occlusion state tested in offices #096, 098 and 100 with electric lights off in partially cloudy skies.

There are no significant spatial differences between office #096 and #100 in the 0-degree relative view besides the alignment of interior wall surfaces types in relation to the window. As expected due to the alignment of the reflective full height gypsum wall with the window in office #100 compared to the partial height textile cubicle wall in office #096, Office #100 displays higher overall mean luminance and standard deviation of luminance than office #096. Yet, Figure 127 shows that office #096 has a 15.9% smaller high luminance range area and 11.1% smaller low luminance range area than office #100. A similar effect is observed in the 45-degree relative view, where office #096 has a 30.7% smaller low luminance range area and 13.1% smaller high luminance range area than office #100. This could indicate that the gypsum wall located to the right of the window effectively increases luminance distribution in office #096.

In summary, the test cases presented in this section illustrate how luminance distribution is influenced by electric lighting use and exterior shade use and how luminance distribution impacts vary according to fenestration design, workstation orientation, workstation location, window location in relation to interior walls, and interior wall finish.

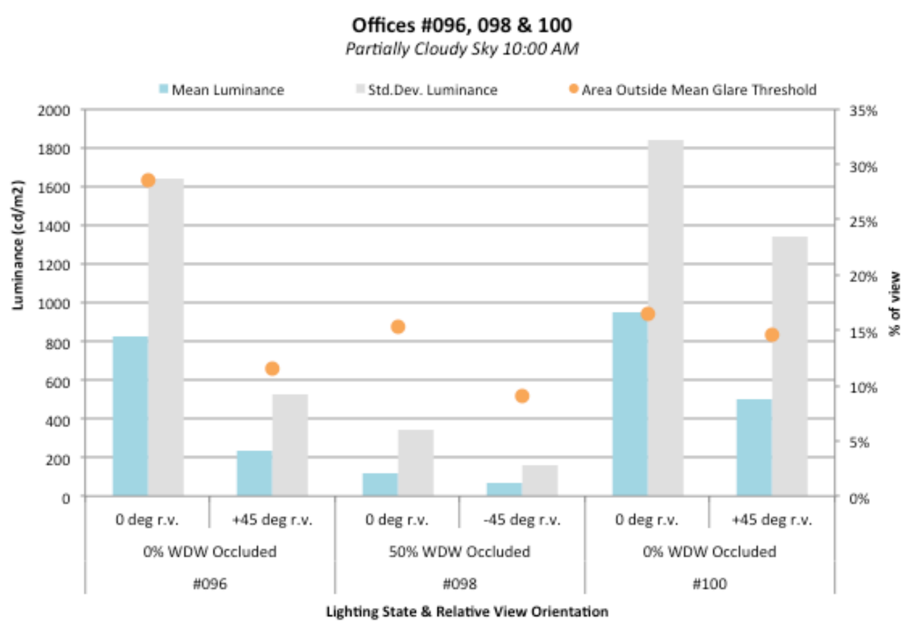


Figure 126: Mean luminance, standard deviation of luminance, and area outside MGT for each relative view orientation and window occlusion state tested in offices #096, 098, and 100.

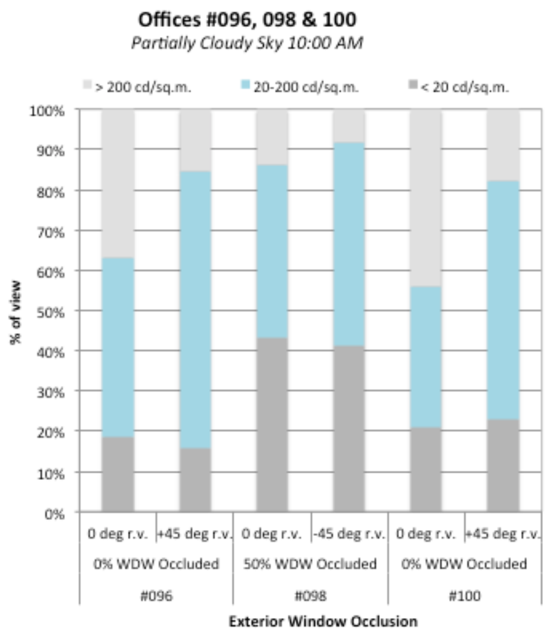


Figure 127: Percentage of view within luminance criteria ranges for each relative view orientation and window occlusion state tested in offices #096, 098, and 100.

Final Luminance-Cluster Definitions

The procedure seen in Table 35 is used to generate baseline GP values is based on a ranked mean luminance and area outside MGT comparison of perimeter offices on the 3rd and 4th floor facing north and south. Lower final values represent lower ranked baseline GP, that is, lower values signify lower potential glare. Baseline GP for 3rd floor south and 4th floor north facing offices is adjusted to 2.50 from the calculated average rank (2.33) in order to evenly distribute the four baseline categories. The next step to generate the final GP rankings requires each office to be categorized according to specific spatial attributes identified in the prior analysis including workstation/occupant relative view orientation, workstation distance from exterior window, and workstation alignment with window opening area. Each spatial attribute is quantified as a positive or negative offset value that is applied to the baseline GP value. Figure 128 shows a diagram of the process by which final GP values are generated.

Table 35: Baseline Glare Potential (GP) values for 3rd and 4th floor south and north facing perimeter offices shown as the sum of ranked mean luminance and area outside mean glare threshold values.

	R.V. Orient	Mean Lum.		Area ≥ MGT		Σ	RANK	FINAL
	(º)	(cd/m2)		(%)			(1-4)	(#)
	0º	1,079.6	*4*	12.74%	*3*	7	4	
4F - S	+/- 45º	795.10	*4*	9.27%	*3*	7	4	**4.00**
	+/- 90º	433.60	*4*	8.77%	*4*	8	4	
	0º	707.27	*2*	24.91%	*4*	6	3	~~2.33~~
4F - N	+/- 45º	309.70	*2*	11.97%	*4*	6	3	**2.50**
	+/- 90º	93.94	*1*	4.14%	*2*	3	1	
	0º	735.27	*3*	10.05%	*1*	4	2	~~2.33~~
3F - S	+/- 45º	450.90	*3*	5.87%	*1*	4	2	**2.50**
	+/- 90º	299.42	*3*	4.97%	*3*	6	3	
	0º	332.30	*1*	11.48%	*2*	3	1	
3F - N	+/- 45º	161.80	*1*	7.16%	*2*	3	1	**1.00**
	+/- 90º	122.69	*2*	3.61%	*1*	3	1	

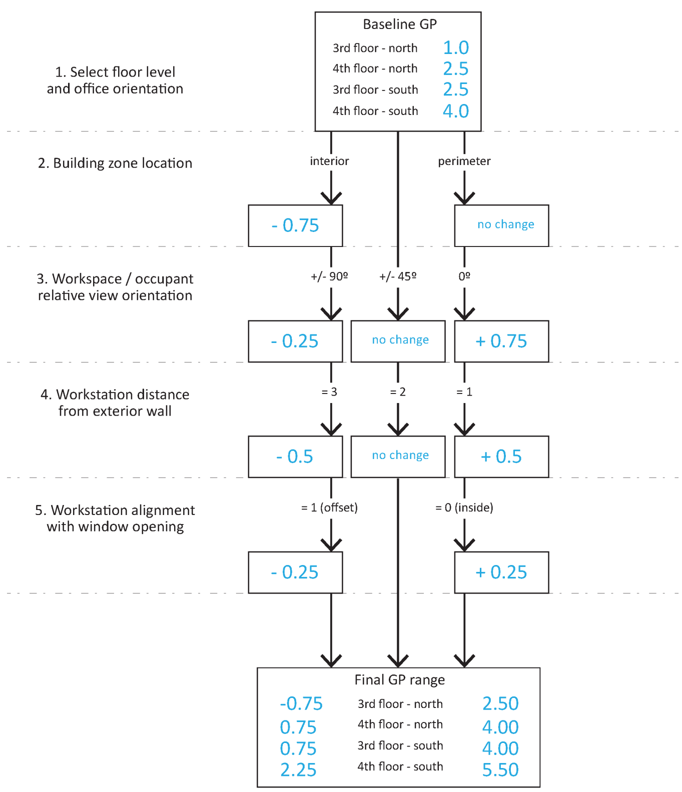


Figure 128: Diagram showing calculation procedure of Glare Potential (GP) based on office floor level, orientation, building zone, workspace/occupant relative view orientation, workstation distance from exterior wall, and workstation alignment with window opening.

APPENDIX D

SOLAR EXPOSURE PARAMETER DEFINITION (ANNUAL SOLAR EXPOSURE)

At the beginning of the study period, fisheye images are taken in a sample of 20 offices in order to calculate annual solar exposure. Annual solar exposure is defined herein as the percentage of daylight hours throughout the year that direct sun is visible from a given point in the office. Results for annual solar exposure (calculated for the full calendar year) and current seasonal solar exposure during the study period (calculated only for the months of September, October, and November) are reported in this section. Sampled offices are oriented south (n=16), east (n=2), and west (n=2), shown on floor plans in Figure 129. North facing offices were not included in this portion of the study because they do not receive any direct solar exposure during working hours. The sample of offices includes enclosed private offices (n=9) and open office cubicles (n=11).

Figure 129: Floor plans showing offices in which solar exposure measurements are taken on the third floor (left) and fourth floor (right).

Figure 130 shows a summary of the observed annual solar exposure and current seasonal solar exposure of the sampled offices. Offices #1-37 are located on the third floor and offices #51-85 are located on the fourth floor. For all offices in the sample but office #1 and #37 solar exposure during the fall season exceeds annual solar exposure. Office #1 and #37 face west and east, respectively, and as a result experience diminished solar exposure in the fall and winter. Office #51, which faces west and is located on the 4th floor, does not display this trend. However, solar exposure in offices #1, 37, and 51 varies only slightly between seasons. The remaining offices sampled all face south and as a result display increasing solar exposure in the fall and winter seasons due to the lower sun angle. Table 36 shows general statistics for annual solar exposure and Table 37 shows general statistics for fall solar exposure of all offices including statistics for south facing offices on the third and fourth floor. A larger range of solar exposure values are observed in the fall compared to the full year, as evidenced by the nearly 100% increase in standard deviation of fall solar exposure for all groups shown. The sampled offices are rank ordered according to the measured annual and fall solar exposure, the results of which are seen in Figure 131 where the office icon saturation increases along with the solar exposure value ranking (offices with lower solar exposure values are shown with less saturated icons). Figure 132 shows combined ranking outcomes whereby results of the fall solar exposure rankings are overlaid on top of the annual results in order to visualize the hierarchy of the current season solar exposure in a composite ranked value.

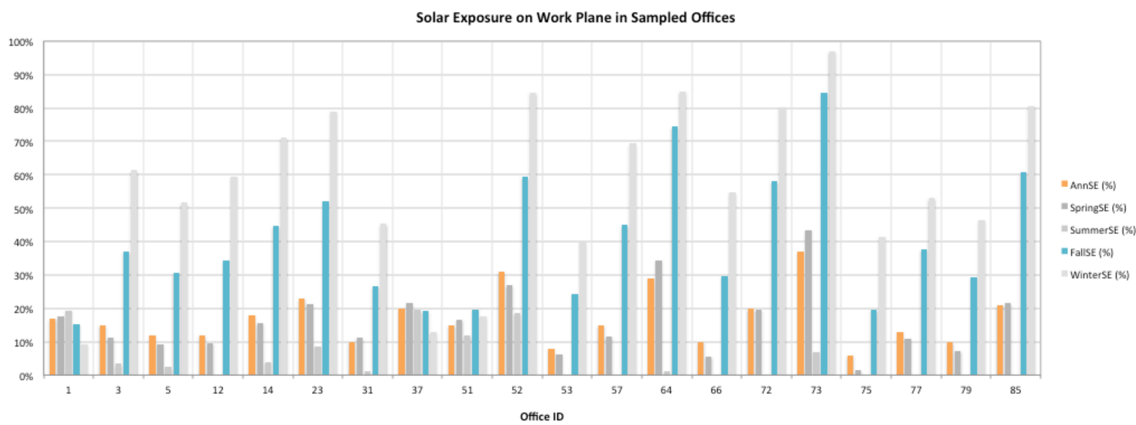


Figure 130: Annual and seasonal solar exposure on work plane in sampled offices.

Table 36: General statistics for annual solar exposure of all office sampled and grouped according to floor level.

ASE	count	min	max	mean	std.dev.	25%	75%	IQR
ALL	**20**	**6.00%**	**37.00%**	**17.10%**	**8.07%**	**11.50%**	**20.25%**	**8.75%**
South Offices	17	6.00%	37.00%	17.06%	8.75%	10.00%	21.00%	11.00%
3F South	6	10.00%	23.00%	15.00%	4.82%	12.00%	17.25%	5.25%
4F South	11	6.00%	37.00%	18.18%	10.34%	10.00%	25.00%	15.00%

Table 37: General statistics for fall solar exposure of all offices sampled and grouped according to floor level.

FALL	count	min	max	mean	std.dev.	25%	75%	IQR
ALL	**20**	**15.33%**	**84.67%**	**40.12%**	**19.37%**	**26.08%**	**53.50%**	**27.42%**
South Offices	17	19.67%	84.67%	44.00%	18.39%	29.67%	58.00%	28.33%
3F South	6	26.67%	52.00%	37.56%	9.34%	31.58%	42.75%	11.17%
4F South	11	19.67%	84.67%	47.52%	21.42%	29.50%	60.00%	30.50%

Figure 131: Floor plans showing sampled offices and solar exposure value rankings for annual solar exposure (left) and fall solar exposure (right).

Figure 132: Combined solar exposure value rankings for sampled offices showing fall ranking results (blue) overlaid on top of annual ranking results (orange).

The results of the solar exposure ranking indicates that solar exposure varies significantly in nearby or adjacent offices. The cluster of 4th floor offices, #072 - #079, contain the office with the highest overall solar exposure (#073) and the lowest overall solar exposure (#075). There are no exterior obstructions or other external factors expected to influence solar exposure measurements between these two offices, which indicates that solar exposure measurements of south-facing offices in the study sample are largely driven by factors inside the office. The aforementioned observation that fourth floor offices exhibit higher solar exposure values is also seen in Figure 131 and Figure 132. This is likely a result of differences in the fenestration design and exterior shading strategy between floors. Fourth floor offices are completely unshaded by the roof overhang during the study period while third floor offices remain approximately 15% shaded by the exterior horizontal shade, as shown in Figure 18 above. While some significant variations in ASE ratings were observed within the study population, the relative ratings and parameter definition methods appear to be redundant with the Glare Potential parameter. ASE results are reported in the initial statistical analysis of GRS index results but are not included in further analysis.

APPENDIX E

BEHAVIORAL OBSERVATIONS

Over the course of the six-week study period, behavioral observations were made during 14 site visits resulting in 1,436 unique records. Each record includes data on occupancy, work activity (task), workspace arrangement, occupant orientation, occupant position (seated or standing), workspace cleanliness, overhead lighting state, task lighting state, corridor light state, exterior shade deployment and tilt state, interior shade deployment and tilt state, and incidence of direct sun throughout the workspace. Appendix A includes behavioral maps and field data intake sheets for a sample of observation periods. In addition, exterior photographs of the building were taken during 29 site visits resulting in 5,915 unique records documenting exterior shade state. This section reports on the major outcomes of this data including occupancy characteristics, exterior shade use, interior shade use, electric lighting use, and spatial use patterns. The results of the analysis contained in this appendix are used to define behavioral clusters including Occupancy Rate, Exterior Window Occlusion Index, Interior Window Occlusion Index, Electric Lighting Use Index, and Spatial Use Variation Index.

Occupancy

This section describes occupancy trends observed during the study period. Electric lighting use, shade use, and spatial behaviors take place solely during times when people occupy the offices included in this study, yet the impacts of behaviors that take place during occupancy can carry over into unoccupied periods, affect other occupants, as well as impact energy consumption. Summary behavioral data described in subsequent sections will thus show results during both occupied and unoccupied periods. Figure 133 shows the total occupancy rate for each office throughout the study period. 10 offices (9% of the study population) were not occupied at all during the study period including 4 offices on the third floor (of which 2 are interior offices) and 6 on the fourth (of which 4 are interior offices). 5 offices (4.5% of study population) were occupied during 100% of all records. 3rd floor offices (#0 – 50) are occupied throughout the study period more frequently than 4th floor offices (#51 – 112) although there are large variations in occupancy rates between offices on both the 3rd and 4th floors.

Figure 134 compares average occupancy rates and standard deviation of occupant rates between floors and within perimeter and interior offices for each floor. There is little variation in standard deviation between the groupings shown in Figure 134, but average occupancy rates vary significantly between the groupings. There is a 21-point difference between the occupancy rates of the third and fourth floor (51% increase in third floor compared to fourth floor). Interior offices are occupied less frequently than perimeter offices and 4th floor interior offices are occupied least frequently of all offices. Interior offices on the third floor are occupied 10% less frequently than perimeter offices while interior offices on the fourth floor are occupied 33% less often than perimeter offices.

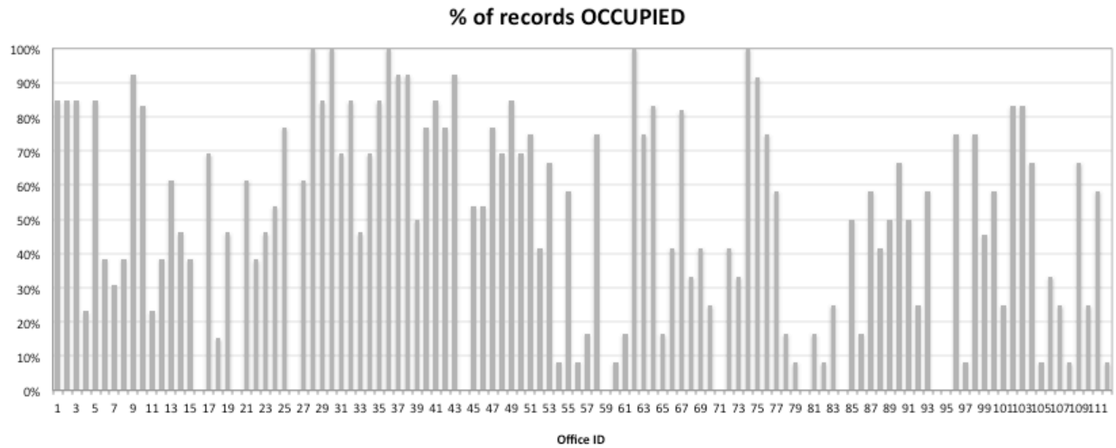


Figure 133: Chart showing total occupancy rates for all offices as a percentage of total observation records.

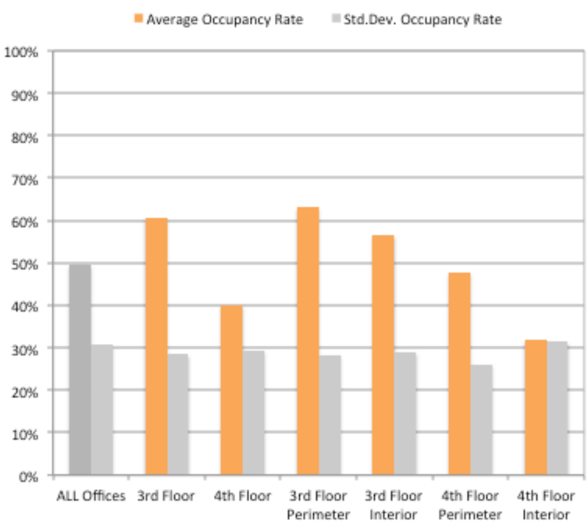


Figure 134: Average occupancy rate and standard deviation of occupancy rate compared between 3rd and 4th floor as well as perimeter and interior zoned offices on each floor.

Data collected from observation walkthroughs do not show any behaviors outside of what would be the typical working hours (8AM – 5PM) or hours during which there is no daylight but the data is likely to still be influenced by individual occupants' personal work schedules. The earliest observation was recorded at 8:30AM and the latest at 4:25 PM. Many in the study population work on different schedules or are able to set their own schedules, so there is no clearly defined or required 'start' time at which the majority of occupants arrive or ‘end’ time at which the majority of occupants leave. During this range of time, occupants were on multiple occasions observed arriving at work or leaving for the day. The occupancy rate ranged from 36% to 59% during morning assessments and 46% to 57% during afternoon assessments but there was no clear relationship between time of day and observed occupancy rate.

Due to organizational and work requirements, during many observations occupants were at work but temporarily outside their office. This “occupied – out” occupancy state is indicated by behavioral traces like an open office door, lights on in the office, computer on, or a bag/purse on their chair or desk. These instances are recorded differently in the data but still counted as occupied records. Figure 135 shows the average occupancy rate for all offices, grouped by floor level and zone, with the portion of occupied records where the occupant was temporarily out of their office shown in white. The average rate of “occupied - out” for all offices is 14% and varies from 8% in 4th floor interior offices to 16% in 4th floor perimeter offices. Figure 136 shows occupancy rates for every office including records where the occupant was temporarily out of their office shown in white. This condition was observed in 77 offices (70% of the study population). The highest recorded rate of “occupied – out” in all offices is 50%, for a south-facing open office cubicle in the perimeter zone (#062), although this office is occupied during 100% of all records.

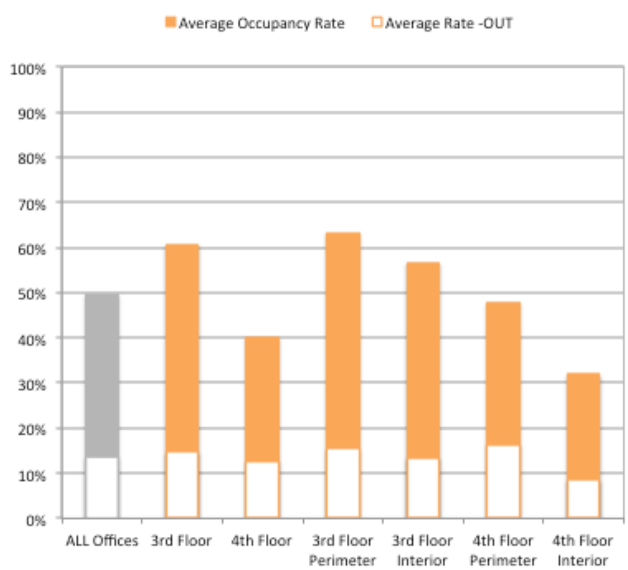


Figure 135: Occupancy rate for all offices showing records during which the occupant was temporarily out of the office, grouped by floor level and perimeter/interior zone.

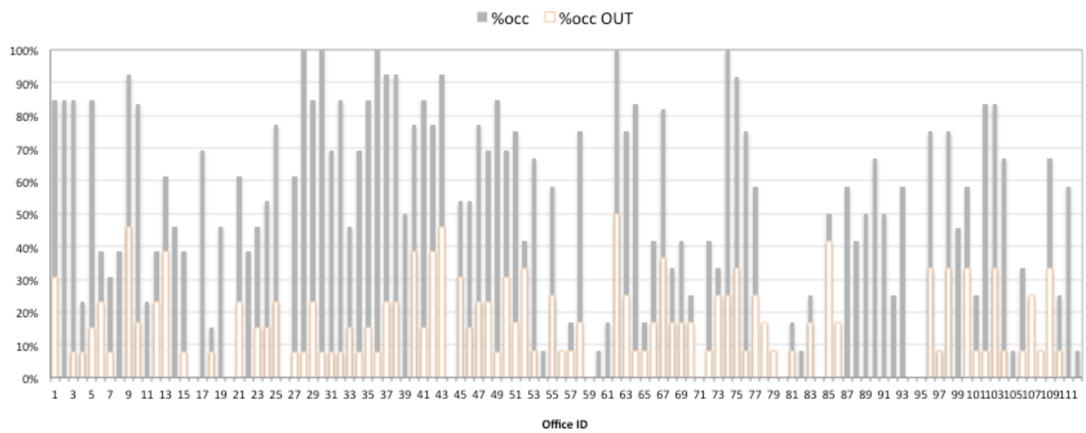


Figure 136: Occupancy rate for all offices highlighting records where the occupant was temporarily out of their office at the time of observation.

<u>Exterior Shade Use</u>

Exterior shade use is documented throughout the study period during walkthrough observations as well as exterior photograph records resulting in 3,891 unique records for areas within the study population, including 2,688 unique records for offices in the study population, in addition to 3,460 unique records for the remaining building areas. This section provides a general overview of trends identified in exterior shade use behaviors in the study population. Data from areas outside the study population are included in general comparisons of shade use behaviors between floors and orientations. Criteria for shade use cluster definitions, based on percentile rankings of each office's window occlusion activity index, are described at the end of this section.

Figure 137 shows the variation in observed shade use between each observation period for offices in the study population. As can be seen, the most commonly observed behavior is the window 0% occluded (34.2% of all records). The second most frequent behavior is the window 25% occluded (14.9% of all records) followed closely by the window 50% occluded (11.7%) and 33.33% occluded (11.6%). The window was more than 50% occluded during17.9% of all observations. The largest variations between observation periods were found in the number of window 0% occluded (standard deviation of 4.3%) and 50% occluded (standard deviation of 4.7%). Figure 139 shows that while the 16.67%, 25%, 33.33%, and 50% window occlusion states each represent two unique shade deployment and tilt configurations and comprise 61.5% of the possible shade configurations, they only account for 45.5% of all observations. The 75% window occlusion state, representing one possible shade configuration, accounts for 8.0% of observations of the study population.

Figure 138 and Figure 140 shows the variation in observed shade use between each observation period for all exterior windows in the building. The records shown include reception, conference, utility, and circulation areas in addition to offices for all 4 floors. Some similarities emerge from this comparison. First, the most commonly observed behavior is the window 0% occluded (33.0% of all records). Second, the window 8.33% occluded is the least commonly observed behavior (2.67% of all records). However, additional differences are noted including the increased frequency of the window 100% occluded which comprises 8.54% of all records for the whole building and only 4.7% of records for the study population. Differences in tenants, interior layout, and spatial use types between floors likely affects the trends observed at the building level.

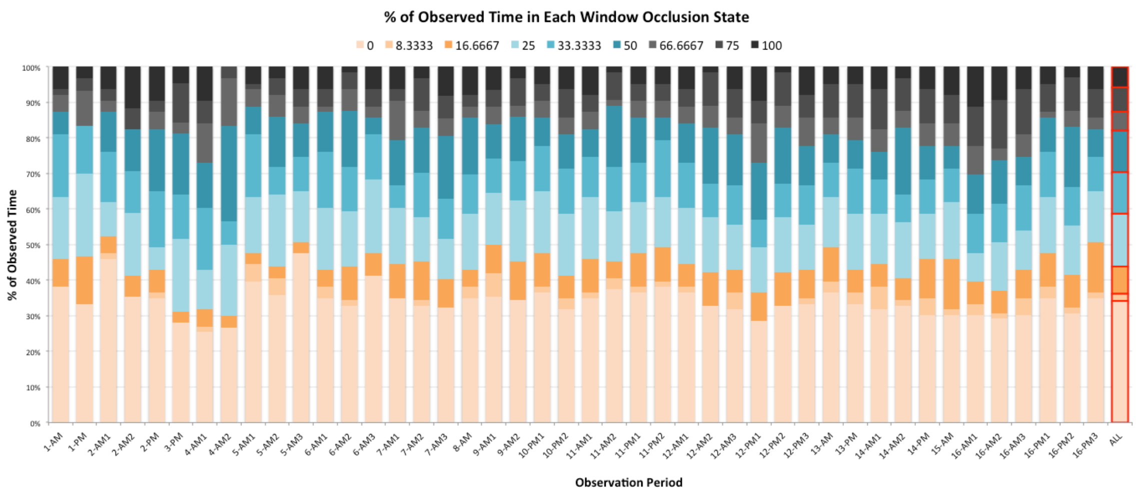


Figure 137: Summary of observed shade use/window occlusion states in each observation period for offices in study population only, shown as a percentage of total observations during that period.

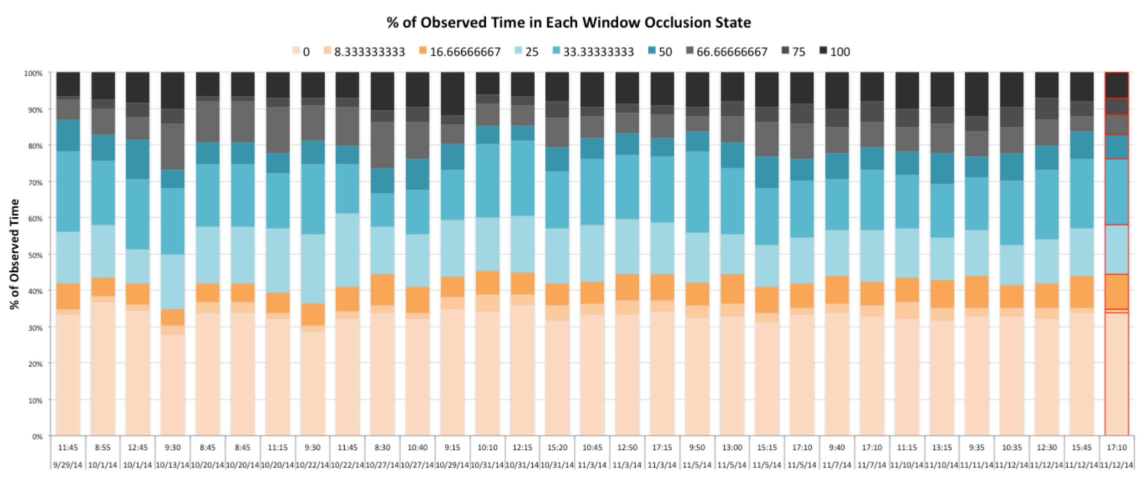


Figure 138: Summary of observed shade use/window occlusion states in each observation period for all exterior windows shown as a percentage of total observations during that period.

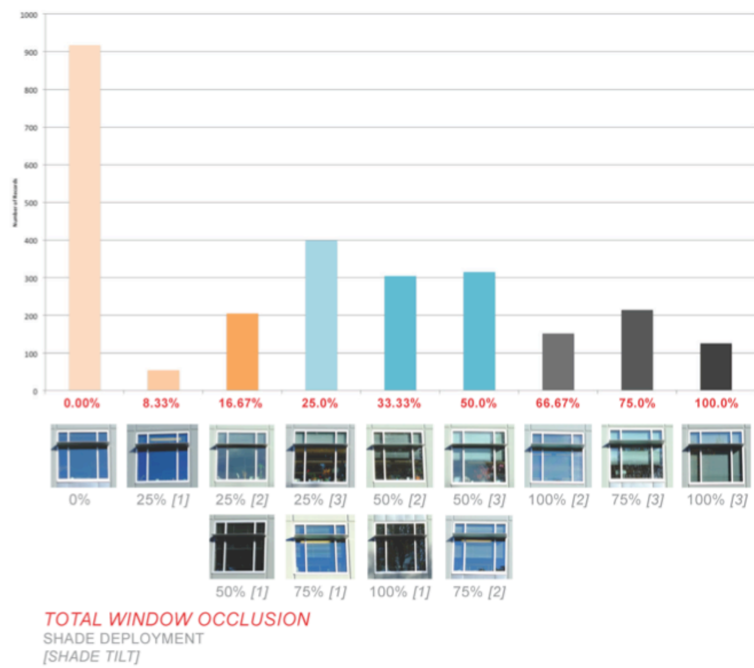


Figure 139: Number of records observed in each window occlusion state for offices in study population.

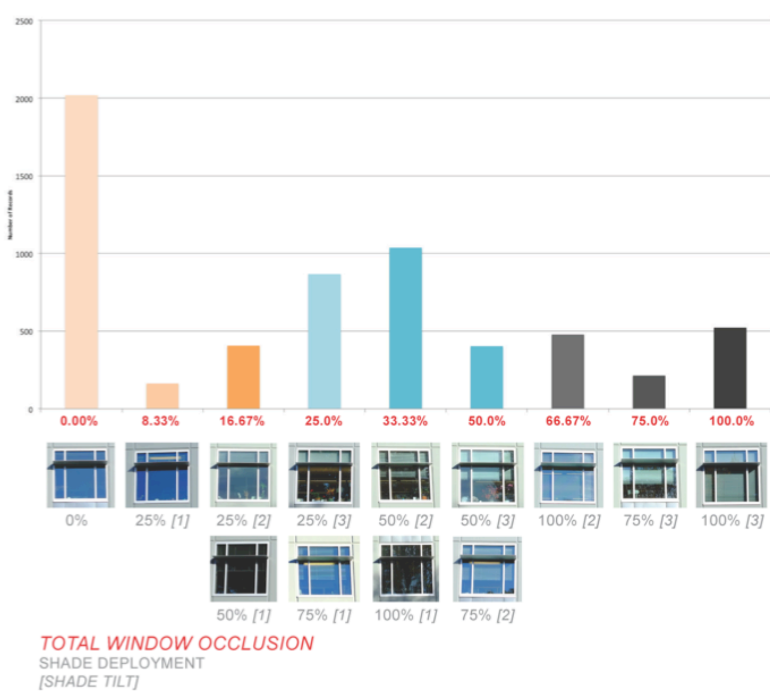


Figure 140: Number of records observed in each window occlusion state for all windows in the building.

Floor Level

Figure 141 shows frequency of observation for each window occlusion state between floor levels. The first floor displays both the highest frequency of 0% window occlusion (47.3%) as well as the highest frequency of 100% window occlusion (17.3%). The second floor displays the lowest frequency of 0% window occlusion (18.4%) and one of the lowest rates of 100% window occlusion (3.2%). While the differences between the first and second floor are significant, the similarity between third and fourth floor window occlusion data in comparison is critical for the purposes of this study. The third and fourth floors display 0% window occlusion at a very similar frequency (less than 1% difference) and differences of less than 3.5% were observed for 8.33%, 25%, 33.33%, 50%, and 66.67% window occlusion states (Figure 142). The largest differences were seen in the frequency of 16.67%, 75%, and 100% window occlusion states. Generally, observations of the exterior shade states on the third floor are more likely to be occluded less than 75% than those of the fourth floor. Conversely, observations of the exterior shade states on the fourth floor are more likely to be occluded 75% or more than those of the third floor.

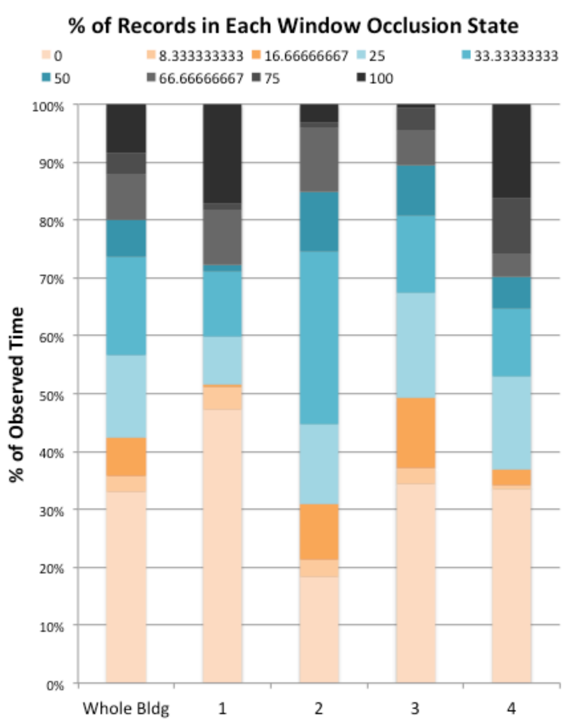


Figure 141: Percent of total records for whole building and each floor level in each window occlusion state.

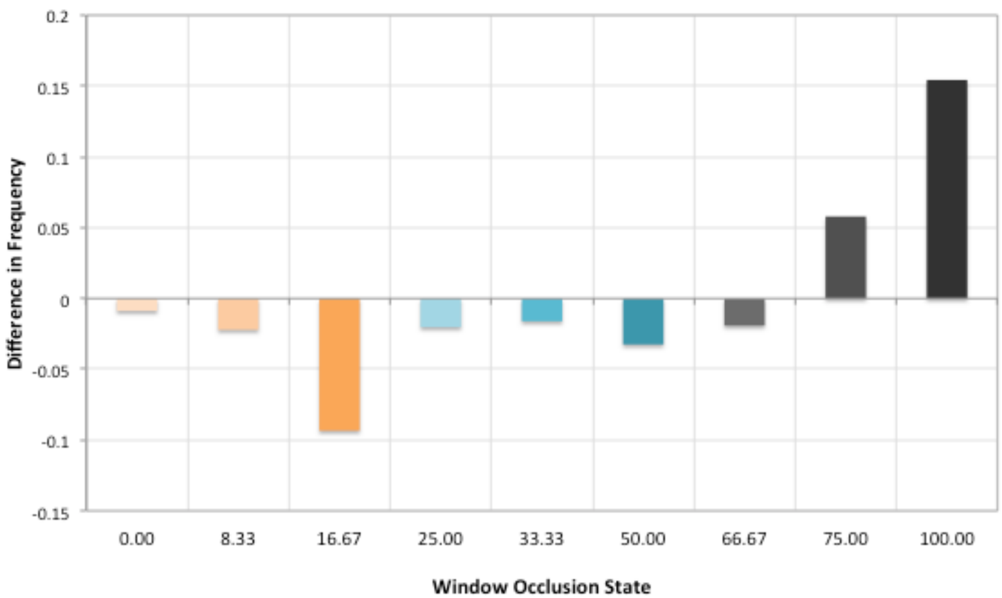


Figure 142: Difference in observed frequency of window occlusion between third and fourth floors (negative values are more frequently observed on the third floor, positive values are more frequently observed on the fourth floor).

Orientation

As expected, numerous differences between orientations are observed. Figure 143 shows window occlusion records for north and south facing windows on all floors. Records for east and west facing windows are not included because there was a comparatively small sample of windows and many windows were observed in only one state of window occlusion throughout the entire study. The data in Figure 143 shows that south-facing offices on all floors are less likely to be observed in a 0% window occlusion state than north-facing offices. The most significant differences were noted between north and south facing offices on the 1st and 4th floors. North-facing windows on the 1st floor and 4th floor were observed in the 0% window occlusion state in more than 60% of all observations and displayed the smallest range of different occlusion states whereas south-facing windows on the 1st and 4th floor were observed in the 0% window occlusion state in less than 30% of all observations and observed in higher window occlusion states (66.67% and higher) in approximately 30% of all observations. While south-facing windows on the 2nd and 3rd floors were also less frequently observed in the 0% window occlusion state than north-facing windows, the frequency of occlusion states higher than 66.67% does not exceed 15% of observations. Further underscoring the differences between these pairs of floors, south-facing windows on the 1st floor are fully occluded (100%) in more than 25% of observations while south-facing windows on the 4th floor are fully occluded in more than 18% of observations. South-facing windows on the 2nd and 3rd floors however, are fully occluded in less than 2% of observations. Privacy or security concerns in 1st floor offices could increase the likelihood that windows are fully occluded, particularly if unoccupied at the time of observation. 4th floor offices should have the lowest privacy and security concerns of all floors though, so this doesn't explain the high incidence of 100% window occlusion on 4th floor windows.

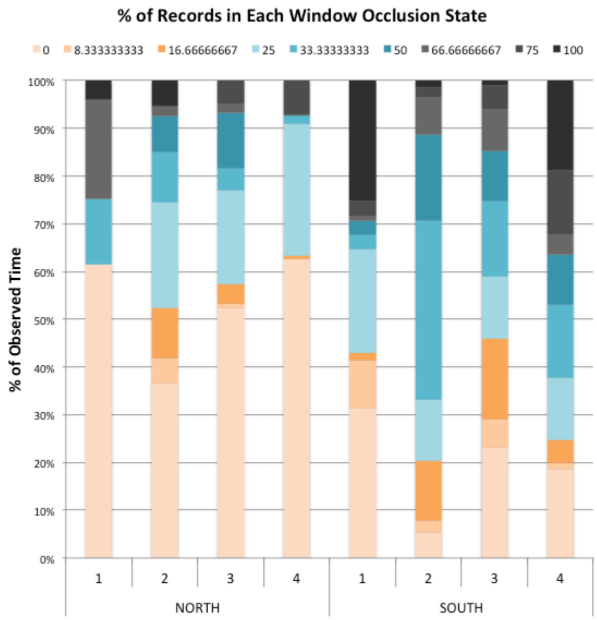


Figure 143: Window occlusion state frequency for north and south-facing windows on all floors.

Additional differences are observed between 2nd and 3rd floor windows facing south. South-facing windows on the 2nd floor are least frequently observed in the 0% occlusion state, accounting for only 5.4% of observations. South-facing windows on the 3rd floor are observed in the 0% window occlusion state for 23.1% of observations, a 17.7% difference from the observed frequency in 2nd floor windows. The 33.33% window occlusion state is observed in a full 37.5% of records for 2nd floor windows but accounts for only 15.8% of records for 3rd floor windows, a 21.6% difference between the two floors. Differences between the observed frequency of 0% and 33.33% window occlusion states account for the majority of the difference between 2nd and 3rd floor windows. The 3rd and 4th floors show very similar frequency of 33.33% window occlusion, suggesting that the incidence of 33.33% window occlusion on the 2nd floor is influenced by different factors than the other two floors. Figure 144 shows a comparison of occlusion state frequencies for south and north-facing offices on the 3rd and 4th floors. While the 3rd and 4th floors differ significantly in the observed frequency of 16.67% window occlusion and occlusion states greater than 75%, as discussed above, the remaining window occlusion states all exhibit less than 5% difference in observed frequency. However, this changes significantly when the 3rd and 4th floors offices are compared by orientation (Figure 145). The largest differences between 3rd and 4th floor offices are observed between 16.67% and 75% occlusion states in south facing offices as well as 0% and 25% occlusion states in north facing offices. Notably, windows 0% occluded are observed in north-facing 4th floor offices 16.6% more often than north-facing 3rd floor offices. Of the south-facing offices, occlusion states of 25% or less are observed 24.7% more frequently on the 3rd floor than on the 4th floor. Conversely, occlusion states of 75% or greater are observed 21.7% more frequently on south-facing 4th floor offices than 3rd floor offices.

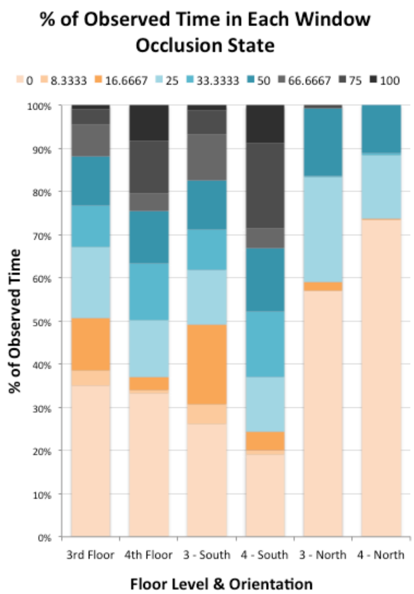


Figure 144: Window occlusion state frequency for 3rd and 4th floor south and north-facing office records.

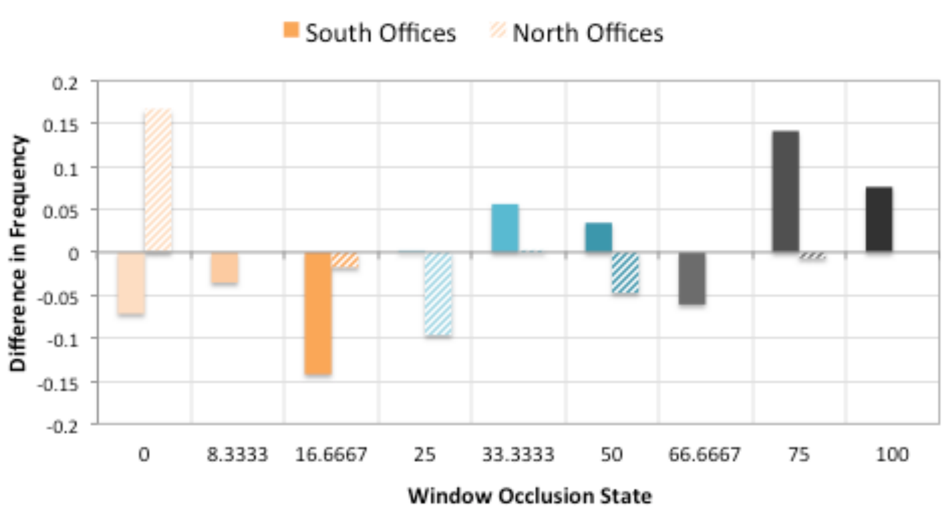


Figure 145: Difference in observed frequency of window occlusion between third and fourth floor north and south facing offices (negative values are more frequently observed on the third floor, positive values are more frequently observed on the fourth floor).

Exterior Sky Conditions

The previous sections show general differences observed in the shade use behaviors of occupants between different floors and office orientations. This section summarizes exterior shade use behavior data under different exterior sky conditions in order to examine how external factors such as exterior illuminance or the incidence of direct sun influence occupants shade use behaviors between floors and office orientations. Figure 146 shows observed frequencies for each window occlusion state under the three sky conditions 'overcast sky', 'partially cloudy sky', and 'clear sunny sky'. For the purposes of understanding how these sky condition definitions might affect shade use, the primary distinction between each sky condition is the expected duration during which direct sun is present. Overcast skies are marked by the sustained absence of direct sun and clear sunny skies are marked by the sustained presence of direct sun. Partially cloudy skies are likely to exhibit intermittent periods of direct sun and clouds. Offices in different orientations are expected to use their shades differently in response to each sky condition. Shade use behaviors in south-facing offices may be influenced by the motivation to occlude direct sun under the partially cloudy and sunny sky conditions while they may be influenced by the motivation to allow more light under overcast sky conditions. Shade use behaviors in north-facing offices may present similarly to the south-facing offices in response to different exterior sky conditions but their motivations might be different. Partially cloudy or sunny sky conditions might elicit the motivation in occupants of north-facing offices to occlude views of bright reflections from exterior surfaces including clouds.

As expected, south-facing offices tend to occlude their windows more under clear sunny skies than overcast skies. Window occlusion states lower than 16.67% are observed in south-facing third floor offices 3.1% less frequently in clear sunny skies than overcast skies while in south-facing fourth floor offices window occlusion states lower than 16.67% are observed 9.5% less frequently in clear sunny skies than overcast skies. Window occlusion states higher than 66.67% are observed 9.6% more frequently in south-facing third floor offices and 5.5% more frequently in south-facing fourth floor offices under clear sunny skies than overcast skies. However, observed rates of window occlusion states between 25-50% in south-facing offices do not follow a clear trend in response to sky condition, decreasing in overall frequency by 3.5% in third floor offices and increasing in overall frequency by 3.9% in fourth floor offices. This trend can be understood if the partially cloudy sky condition is considered an intermediate step between the overcast sky and clear sunny sky conditions, shown in Table 38. In the south-facing third floor offices, the partially cloudy sky condition results in a 2.25% increase in frequency of 25-50% occlusion states and a 1.97% increase in frequency of 66.67-100% occlusion states. The transition to sunny skies then results in a 5.78% decrease in frequency of 25-50% occlusion states and 7.65% increase in frequency of 66.67-100% occlusion states. In this regard, the increase in frequency of 25-50% occlusion states in the partially cloudy sky condition seems to occur in lieu of higher occlusion states for third floor offices. The opposite trend is seen in south-facing fourth floor offices, which show a 3.57% decrease in frequency of 25-50% occlusion states in partially cloudy conditions alongside a 3.85% increase in frequency of 66.67-100% occlusion states. This data seems to indicate that the required intensity of environmental factors, be it direct sun or brightness, to occlude the window further is lower for fourth floor offices. This could be a result of differences in the fenestration design and exterior shading strategy between the floors. In addition, the difference in rate of further occlusion between floors seems to indicate that as exterior conditions change, some occupants may be more likely to delay further window occlusion rather than occluding the window immediately.

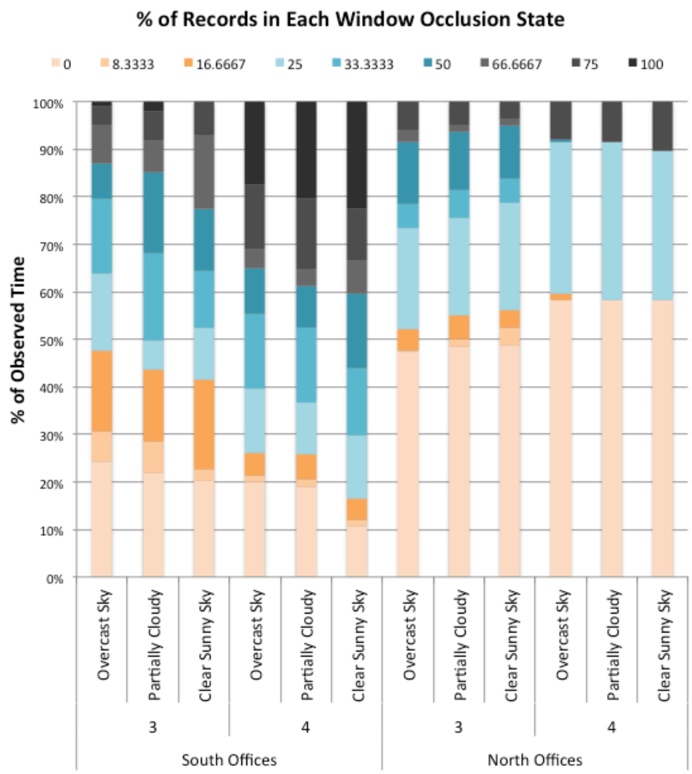


Figure 146: Window occlusion state frequency for south and north-facing offices on the 3rd and 4th floors under different exterior sky conditions.

Table 38: Change in frequency of observed window occlusion states between sky conditions in 3rd and 4th floor south-facing offices.

	3rd fl. SOUTH			**4th fl. SOUTH**		
	Overcast	Partial Clouds	Sunny	Overcast	Partial Clouds	Sunny
0% - 16.67%	47.75%	-4.21%	-1.87%	26.13%	-0.28%	-9.18%
25% - 50%	39.25%	2.25%	-5.78%	38.94%	-3.57%	7.48%
66.67% - 100%	13.00%	1.97%	7.65%	34.92%	3.85%	1.70%

Electric Lighting Use

The section describes results of observations of electric lighting use during the study period, an overview of which can be seen in Figure 147. Results are reported on in aggregate at the floor level, by orientation, zone (perimeter or interior), and office type, as well as at the individual office level to identify trends in spatial and behavioral adjacencies. Studies have shown that most electric lighting switching events happen when arriving at or leaving the offices. Enclosed offices at the research site have occupancy sensors installed on the switch that turn the overhead lights on to 50% lighting power when it detects motion. In turn, occupant electric lighting behaviors may emerge as responses to the automated lighting control, rather than a direct response to environmental lighting conditions upon arrival. The occupancy sensors also have a reset function that switch all overhead lights off if no motion is detected for 15 minutes. As a result, electric lighting use is reported for occupied records only in order to identify direct occupant behaviors. Numerous individuals made adjustments of one kind or another to override the occupancy sensor. Some requested to replace the occupancy sensor switch with manual rocker switches while numerous others utilized more informal means to prevent automated switching such as covering up the occupancy sensor. At least 2 individuals requested to remove the lamps from the linear direct/indirect luminaires above their workspace in an open office cluster. Despite the negative reactions to the automated switching or controls schemes, occupants remain fully empowered to use as much or as little electric lighting as they desire regardless of office type or spatial location and display a wide range of electric lighting use patterns (Figure 148).

Many occupants exhibited very consistent electric lighting use throughout the study period. 55 occupants (53.9%) displayed one unique lighting configuration throughout the duration of the study period. Of these, 4 occupants (3.9%) were observed using only daylight throughout the study period. For each office, the combined electric lighting use state is calculated as the sum of corridor, overhead, and task lighting states (for calculation definition see section III.D.i.c. above). More weighting is applied to overhead and task lighting use than corridor lighting use. Figure 149 shows the number of records for each office where different electric lighting sources are in use. Figure 150 shows the frequency of electric lighting use by source as a percentage of all observation records for each office.

Corridor lights are rarely switched on or off by occupants during the course of a day. The light switches that control corridor lights are disbursed throughout the length of corridor, typically zoned where each cluster of open offices or enclosed offices can control the corridor lights separately. Despite the distributed controls location and sensible zoning of corridor lighting, corridor lights are on during most observations for all but two clusters of adjacent north-facing open and enclosed offices on the fourth floor (seen at the right side of Figure 150, offices # 101 – 111). Corridor lighting use trends may be influenced by the location of corridor lighting controls, which are outside of the offices. In some cases the corridor lighting controls are not easily accessible off the corridor and located inside of another workspace (Figure 151) or inaccessible due to occupant obstructions (Figure 152). Further, lighting impacts are unlikely to be perceived by occupants whose workstations aren't located along or doesn't face the corridor, which may further reduce awareness of corridor lighting state.

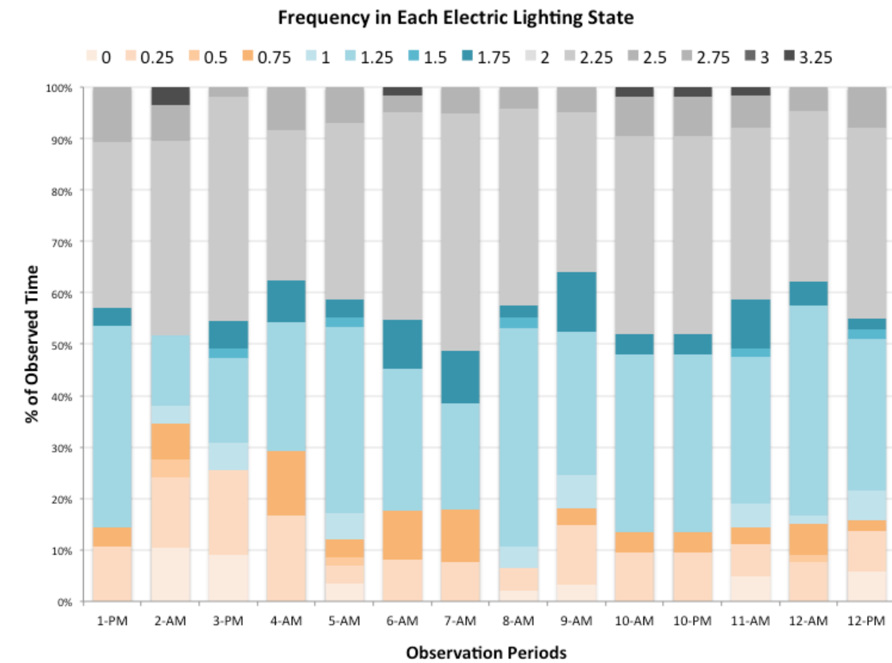


Figure 147: Frequency of electric lighting state observations during each observation period.

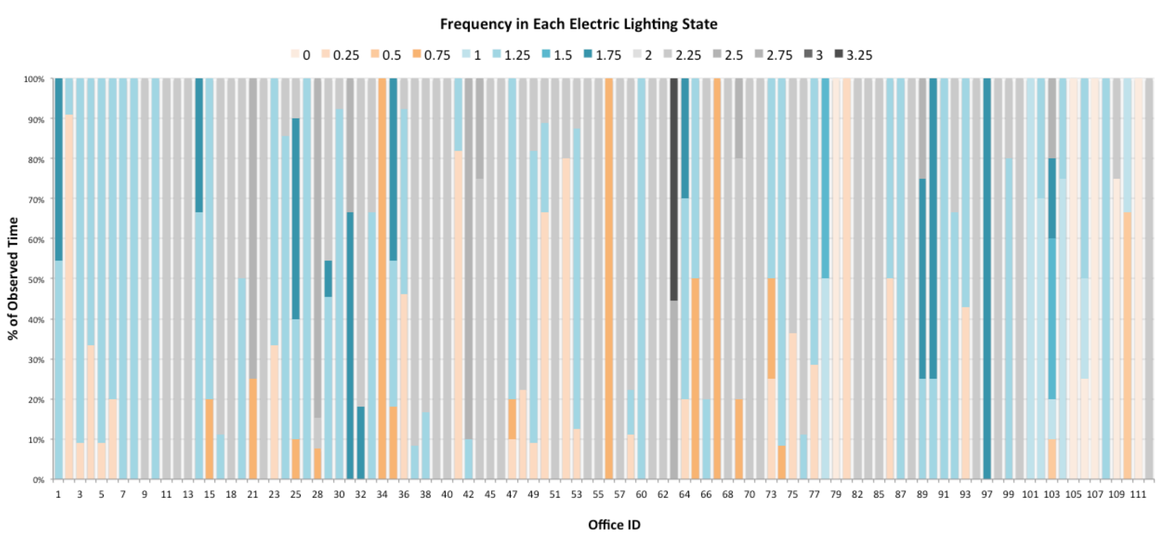


Figure 148: Frequency of electric lighting state observations for each office during the study period.

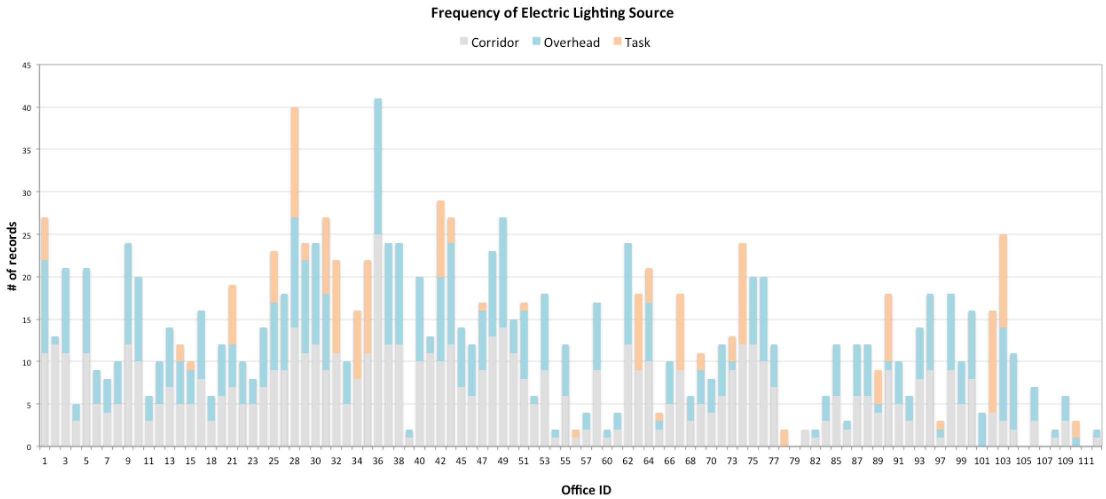


Figure 149: Observed use of electric lighting by source (corridor, overhead, or task) for each office.

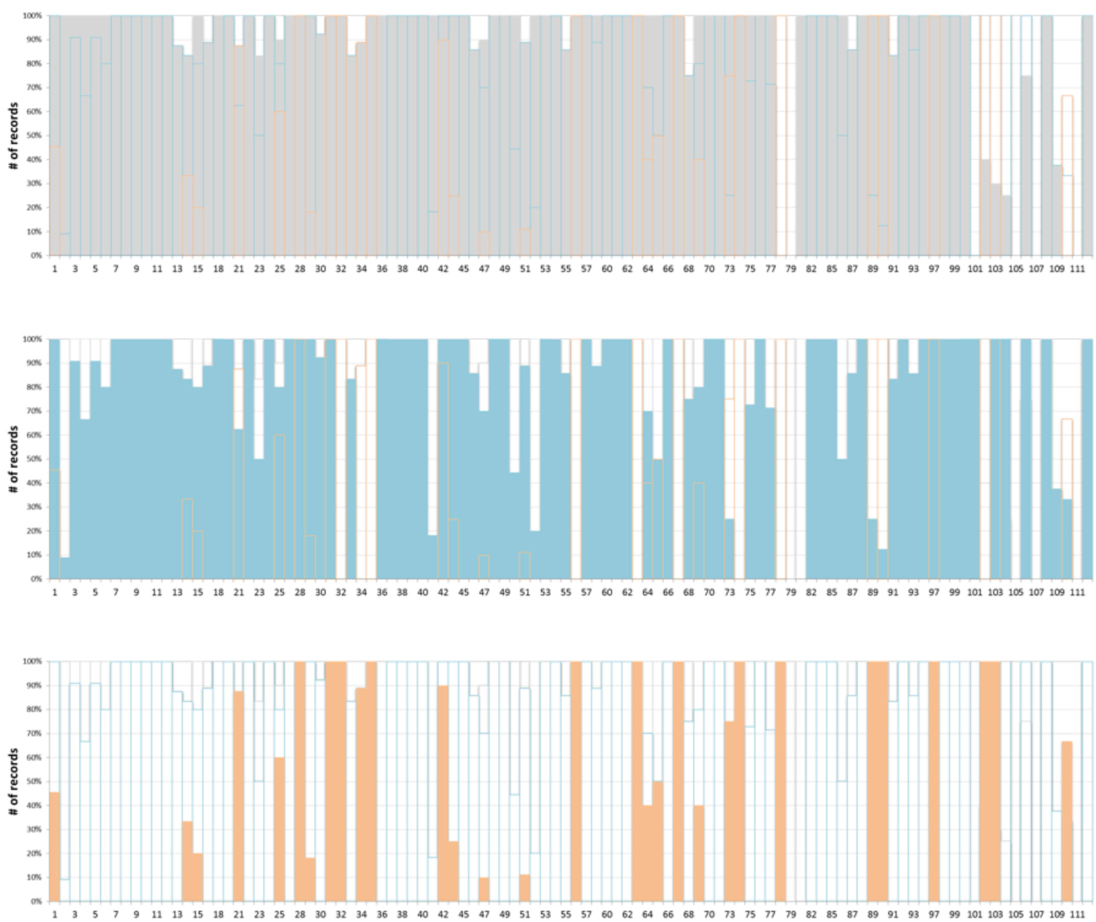


Figure 150: Frequency of electric lighting source use as a percentage of total observation records for each office. Top – corridor lights; Center – overhead office lighting; Bottom – task lighting.

Figure 151: Small occupant note posted on the sliding partition door of office #072 indicates the location of the light switch for corridor and open office overhead lighting.

Figure 152: Corridor and office lighting control in office #112 completely blocked by occupant's storage boxes.

In many cases, task lights are used in addition to overhead lights (observed in 21 offices, 20.6% of study population) and in some cases task lights are used in lieu of overhead lights (observed in 9 offices, 8.8% of study population. Occupants who are observed using a task light at least once during the study period on average exhibit higher overall electric lighting use than occupants who do not use task lights, although the difference is small, as seen in Table 39. Occupants of 4th floor offices who use task lights, however, exhibit lower overall electric lighting use than occupants of 4th floor offices who do not use task lights, perhaps suggesting there are other factors affecting electric lighting use choices.

Table 39: Difference in average electric lighting use by third and fourth floor occupants who use tasks lights and who do not use task lights.

		Avg. elec. lighting use	*% diff from average*
Uses Task Lights	ALL	1.585	
	3rd floor	1.783	*10.87%*
	4th floor	1.434	*-9.51%*
Does Not Use Task Lights	ALL	1.534	
	3rd floor	1.581	*3.11%*
	4th floor	1.496	*-2.48%*

<u>Interior Shade Use</u>

This section provides a brief overview of observed interior shade use behaviors. Data is described generally, reported on in aggregate at the floor level, by orientation and zone (perimeter or interior), as well as at the individual office level to identify trends in spatial and behavioral adjacencies. Interior shade use is documented throughout the study period during walkthrough observations resulting in 1,349 unique records for offices within the study population. As can be seen in Figure 153, there is a wide range of observed behaviors but that the 0% occlusion and 100% occlusion states are most commonly observed. This is at least partially due to the method used to code the state of the translucent partition door in open office cubicles, which is transcribed as either open (0) or closed (100). 38 offices keep their interior window at least partially occluded and 4 offices keep their partition door fully closed for the duration of the study period. 15 offices did not deploy their interior shade (0% occlusion) and 6 open offices kept their partition door fully open for the duration of the study period. Offices that were not occupied throughout the duration of the study period on average set their shades to a higher window occlusion state (61.26%) than offices that were occupied during the study period (42.03%).

While exterior shade use is directly related to illuminance and luminance outcomes and can be conceptualized as predominantly a response to exterior conditions, interior shade use is a bit more complicated. Interior shade use can be conceptualized as an expression of the need or desire for visual privacy, security, or the sense of enclosure, as well as a response to exterior conditions including glare from daylight or electric lighting. The data shows clear distinctions in interior shade use behaviors between perimeter and interior offices as well as between enclosed and open offices, indicating that different motivations and outcomes exist within different spatial groups. Figure 154 shows the number of records for each window occlusion state organized by floor level, office type and zone. The average occupancy rate is shown above the summary window occlusion data in order to demonstrate the different relationship between occupancy and interior shade use among the office subgroups shown in Figure 154. Open offices show a much stronger correlation between average interior window occlusion (partition door state) and occupancy rate (r^2 = - 0.670) than enclosed offices (r^2 = - 0.112), suggesting that these behaviors might be linked in open offices.

Interior offices are also exposed to difference adjacency conditions that may affect interior shade use. Daylight transmission from open office areas only partially relies on the perimeter occupants' use of their partition doors while daylight transmission from enclosed offices completely relies on the perimeter occupants' use of their interior shades. Figure 155 shows the frequency of observed window occlusion states for interior offices on the third and fourth floors grouped according to whether they are adjacent to open or enclosed offices. While there are marked differences between the incidence of un-occluded interior windows in 3rd and 4th floor offices within these subgroups, there are no clear indications that the type of adjacent perimeter office affects shade use behaviors in interior enclosed offices.

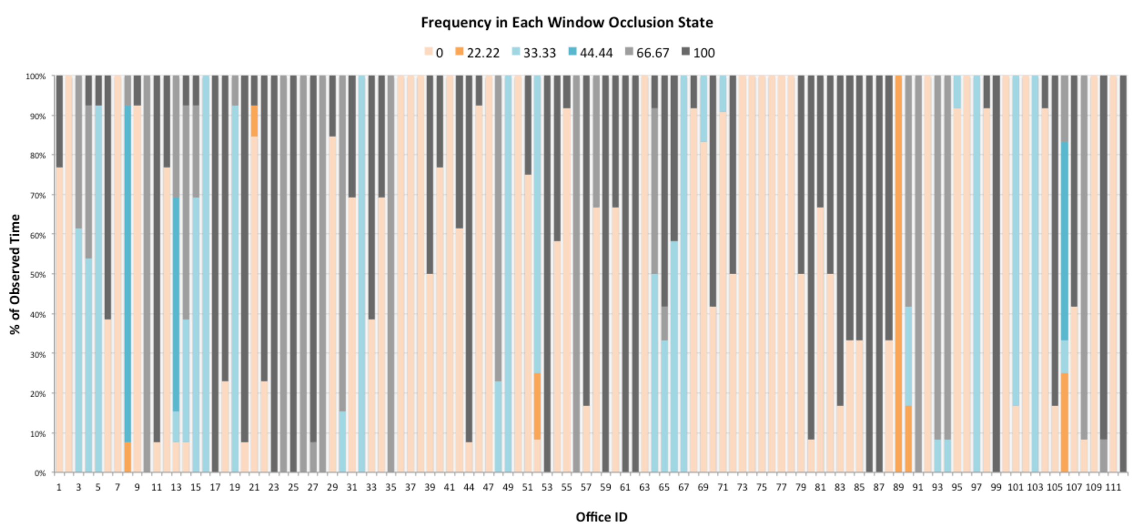


Figure 153: Frequency of observation for each interior window occlusion state for all offices in study population.

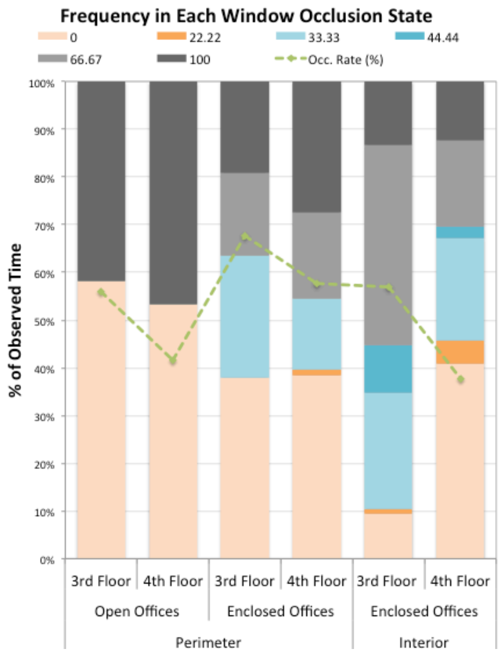


Figure 154: Interior window occlusion state frequency for 3rd and 4th floor enclosed and open offices in perimeter and interior zones. Occupancy rate for each office group is shown on top to demonstrate the different relationship between occupancy and interior window occlusion observed in the office subgroups.

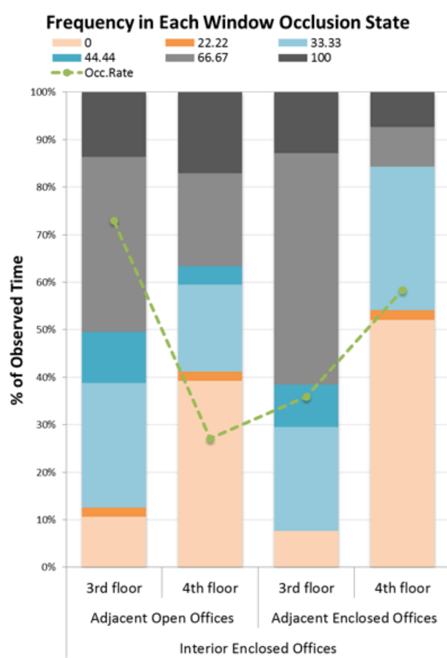


Figure 155: Interior window occlusion state frequency for interior offices on the 3rd and 4th floors grouped according to perimeter office type adjacency (open or enclosed). Average occupancy rate for each subgroup is shown to demonstrate the weak relationship between interior shade use and occupancy in these subgroups.

APPENDIX F

GLARE RESPONSE SENSITIVITY INDEX PARAMETER DEFINITION

Item Measure Analysis

This section provides brief overviews of questionnaire responses to each categorical item measure that is expected to relate to glare response sensitivity or tolerance. Results of this section will influence bivariate and multivariate analysis procedures included in the following sections.

Environmental Values & Awareness

In this item measure, respondents' baseline environmental values and awareness are recorded using a series of prompts that ask the respondent to indicate, on a 5-point scale, the degree to which they agree or disagree with the statement in the prompt. Prompts include statements related to the importance of daylight, environmental control, control over energy consumption, context of energy use, individual role in energy conservation and organizational role in energy conservation. The responses included in this section illustrate a few areas of general consensus within the study population. Large variations were not expected in the data and so this section focuses rather on subtle variations observed in the results specifically regarding respondents' views on daylight and environmental controls. Some variation is seen in responses to the question item 'the ability to control my environment is an important aspect of my workspace', seen in Figure 156, although there were no meaningful differences between building zones and floor levels. Figure 157 shows that while significant majorities of respondents in all office zones consider daylight an important aspect of their workspace, more than 97% of respondents in perimeter offices and only 54% of respondents in interior offices agree with the question prompt. Perimeter respondents were at least 3 times more likely than interior respondents to 'strongly agree' that 'daylight is an important aspect of my workspace'. Similar trends between perimeter and interior offices are seen when 3rd and 4th floor responses are compared, shown in Figure 158. While differences exist between respondents in the 3rd and 4th floor interior offices that 'agree' or 'strongly agree' with the statement, the only respondents that 'disagree' or 'strongly disagree' with the statement (n=3) are from 4th floor interior offices. Two of the three responses come from individuals who either don't have access to daylight or views due to the location of their office (on the east side of the building, #089) or due to the shade use behaviors of occupants in perimeter offices across the corridor. The disparity between responses of interior and perimeter occupants could suggest that individuals who do not value daylight in their workspace may be more likely to opt to use the interior offices, which feature significantly reduced access to daylight..

The remaining question items, which explore environmental awareness and values about energy conservation at the individual and group level (Figure 159), show little variation between items and respondents. No useful or significant variations are seen in responses regarding energy conservation or awareness, likely suggesting that shared cultural or organizational values influence responses. These items are not selected for further bivariate analysis to include them in the glare response / sensitivity index.

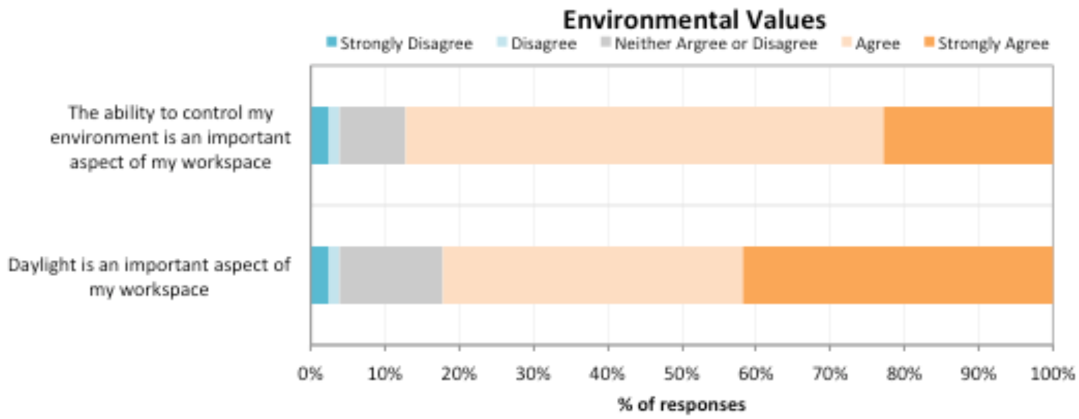


Figure 156: Reported environmental lighting values for all respondents.

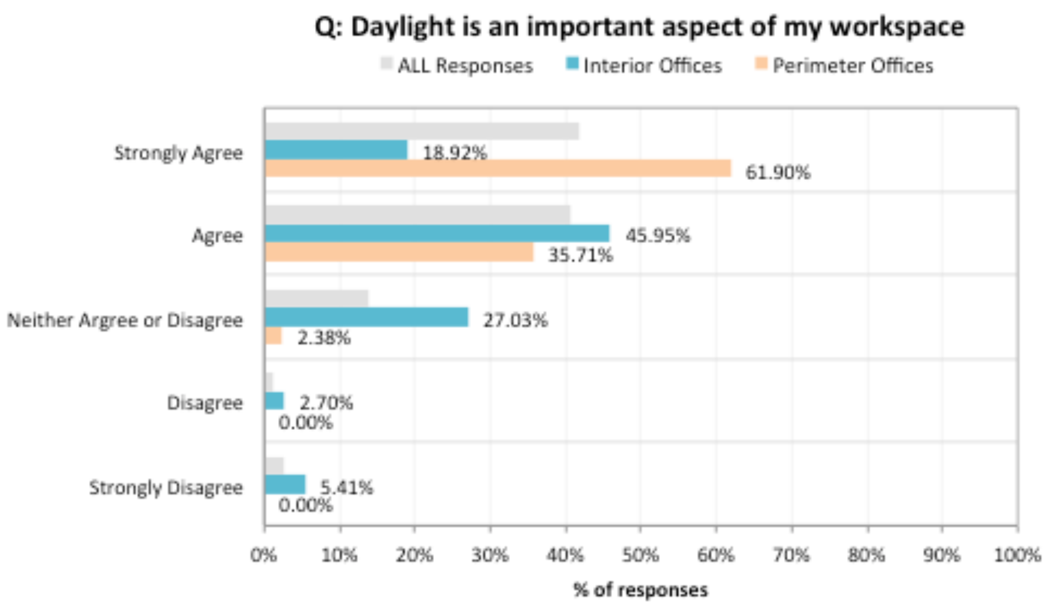


Figure 157: Responses indicating level of agreement with the statement 'Daylight is an important aspect of my workspace' for all responses, interior offices, and perimeter offices.

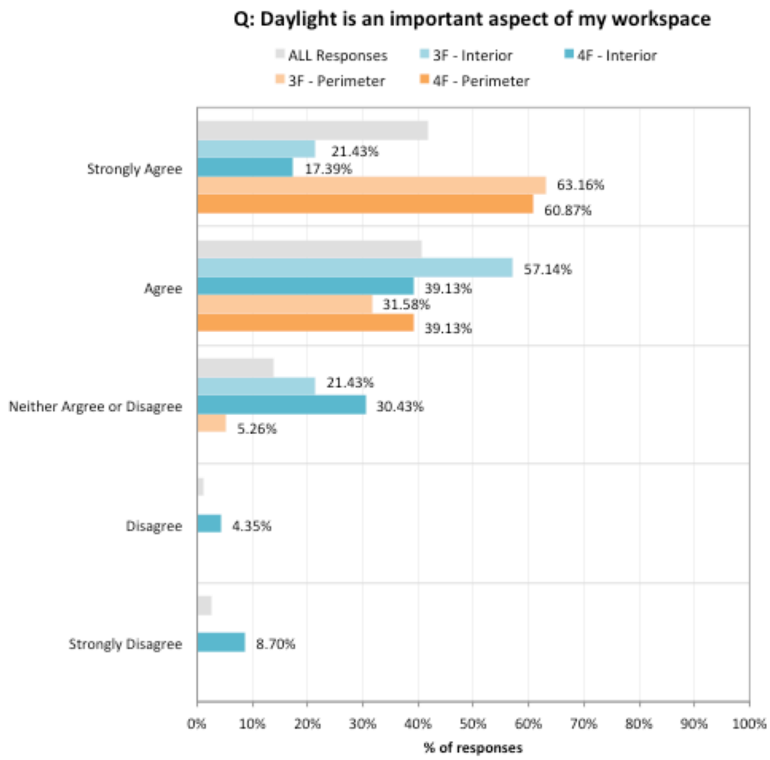


Figure 158: Responses indicating level of agreement with the statement 'Daylight is an important aspect of my workspace' for all responses, 3rd and 4th floor interior offices, as well as 3rd and 4th floor perimeter offices.

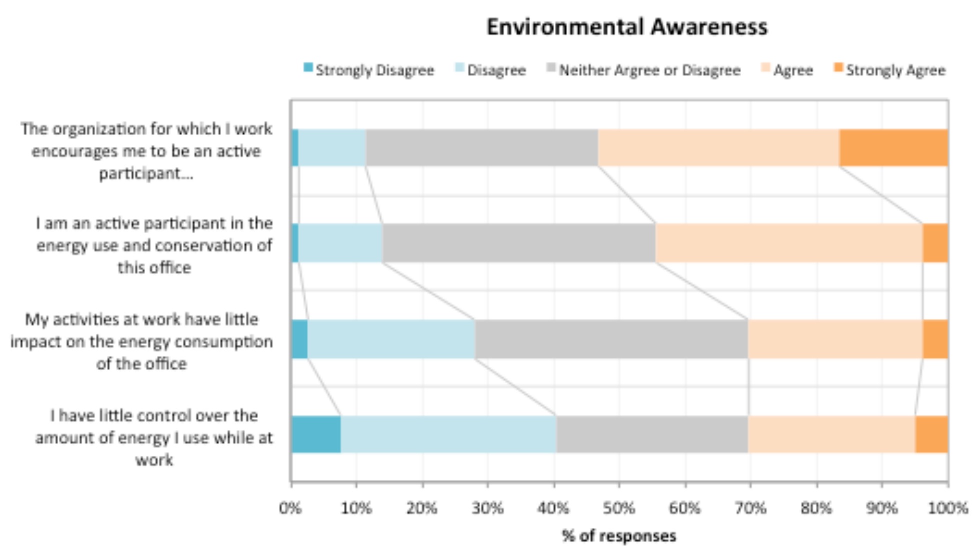


Figure 159: Reported environmental awareness for all respondents.

Semantic Differential Ratings

In this item measure, respondents' appraisal of daylight and electric lighting is recorded using semantic differential ratings featuring word pairs that describe qualitative attributes of the environment as well as the responses to those attributes. The word pairs include: 'clear – hazy', 'bright – dim', 'uniform – non-uniform', 'pleasant – unpleasant', 'relaxed – tense', 'satisfying – frustrating', and 'comfortable – uncomfortable'. Semantic differential ratings show respondents' appraisal of daylight and electric lighting in their workspace. Word pairs explore different qualitative descriptions of the daylight or electric lighting and subjective assessments of occupants' perception of the lighting. Positive descriptions and subjective assessments are placed on the left-hand vertical axis of the charts shown in Figure 160 while negative assessments and descriptions are placed on the right-hand axis. Some trends regarding respondents' perception of daylight compared to electric lighting are quickly observable in Figure 160. There are large variations between positive (+1, – 2) and negative (-1, – 2) appraisals of daylighting while there are fewer variations observed in appraisal of electric lighting. Electric lighting was appraised strongly negatively (-2) by 34.2% of respondents and was most often negatively appraised (-1, -2) as "frustrating" (37%) and "unpleasant" (34%), both of which suggest dislike rather than discomfort. Daylighting, on the other hand, was appraised strongly negatively (-2) by 20.3% of respondents and was most often negatively appraised (-1, -2) as "uncomfortable" (24%) and "frustrating" (24%), which could imply that these respondents feel they do not have control over discomfort arising from daylight.

Table 40 shows strong bivariate relationship (70.28% difference) between reporting discomfort and frustration with daylight in the workspace, indicating that most people who describe the daylight as uncomfortable also describe it as frustrating. The discrepancy in appraisal of daylight and electric lighting is further explored in the data shown in Table 41 and Table 42. The same descriptive scale 'clear-hazy' produces uneven resulting appraisals of 'comfortable – uncomfortable' when it is in reference to daylight than when it references electric lighting. The difference is slight, about 15-percentage points difference in one case, but can be observed across all of the semantic differential scales. The comparison shown in Table 42 makes clear that respondents were about 3 times more likely to assess electric lighting negatively (uncomfortable, unpleasant, frustrating, or tense) if they described it negatively (hazy, dim, non-uniform) than they were for daylight. This finding in some ways supports the notion that daylight generates a more affective response than electric lighting, but it also suggest that comparisons between daylight and electric lighting conditions or responses are likely to be biased. As a result, item measures regarding electric lighting are reported on generally but not included in the remainder of this analysis.

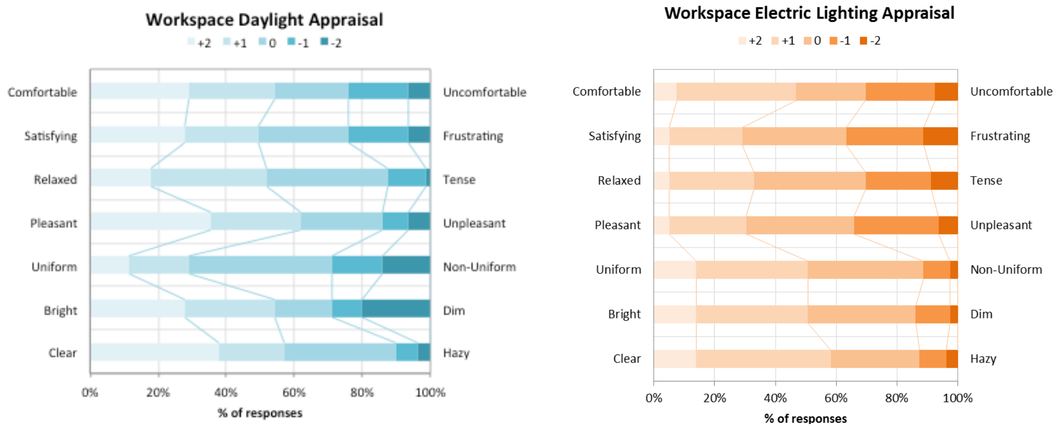


Figure 160: Semantic differential ratings of workspace daylighting (left) and electric lighting (right) for all respondents.

Table 40: Bivariate relationship between appraisal of daylight as 'comfortable - uncomfortable' and 'satisfying - frustrating'.

	Daylight Appraisal	
	Comfortable	Uncomfortable
Satisfying	**81.40%**	11.11%
Frustrating	18.60%	**88.89%**
	100.00%	100.00%
	(43)	(36)

Table 41: Bivariate relationships between 'clear - hazy' and 'comfortable - uncomfortable' for daylight (left) and electric lighting (right).

	Daylight Appraisal		Electric Lighting Appraisal	
	Comfortable	Uncomfortable	Comfortable	Uncomfortable
Clear	**83.72%**	25.00%	**78.38%**	40.48%
Hazy	16.28%	**75.00%**	21.62%	**59.52%**
	100.00%	100.00%	100.00%	100.00%
	43	36	37	42
	58.72%		**37.90%**	

Table 42: Comparison of negative qualitative descriptions versus negative subjective assessments of daylight and electric lighting.

	Workplace Appraisal	
	Daylight	Electric Lighting
negative description	9.76%	5.42%
(hazy, dim, non-uniform)	*(54)*	*(30)*
negative assessment (unpleasant,	10.67%	18.81%
tense, frustrating, uncomfortable)	*(59)*	*(104)*
percentage difference	**+ 0.90%**	**+ 13.38%**

Environmental Attributes & Amenities Preference Ranking

In this item measure, respondents' preferences are assessed using a rank-ordering exercise that asks respondents to order a series of environmental attributes or amenities by importance to their workspace environment. A summary of these results is seen in Figure 161. These attributes and amenities include: daylight quality, electric light quality, views to the outside, control over daylight, control over electric lighting, ability to re-configure workspace, glare-free working environment, and visual privacy.

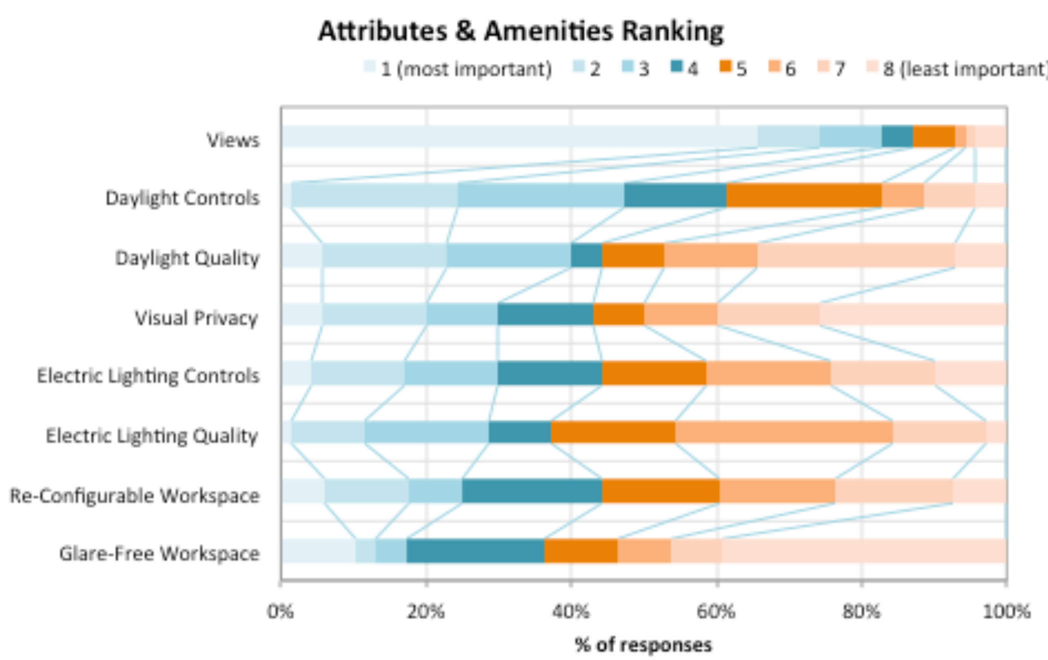


Figure 161: Summary of all respondents' ranking of environmental attributes and amenities in order of importance.

Environmental Satisfaction

In this item measure, respondents' appraisal of and satisfaction with their environmental amenities are recording using a Likert scale of 'very satisfied' to 'very dissatisfied'. A summary of these results is seen in Figure 162. The following environmental attributes and amenities are appraised: daylight quality, electric lighting quality, views to the outside, control over daylight, control over electric lighting, ability to re-configure workspace, glare from daylight, glare from electric lighting, and visual privacy.

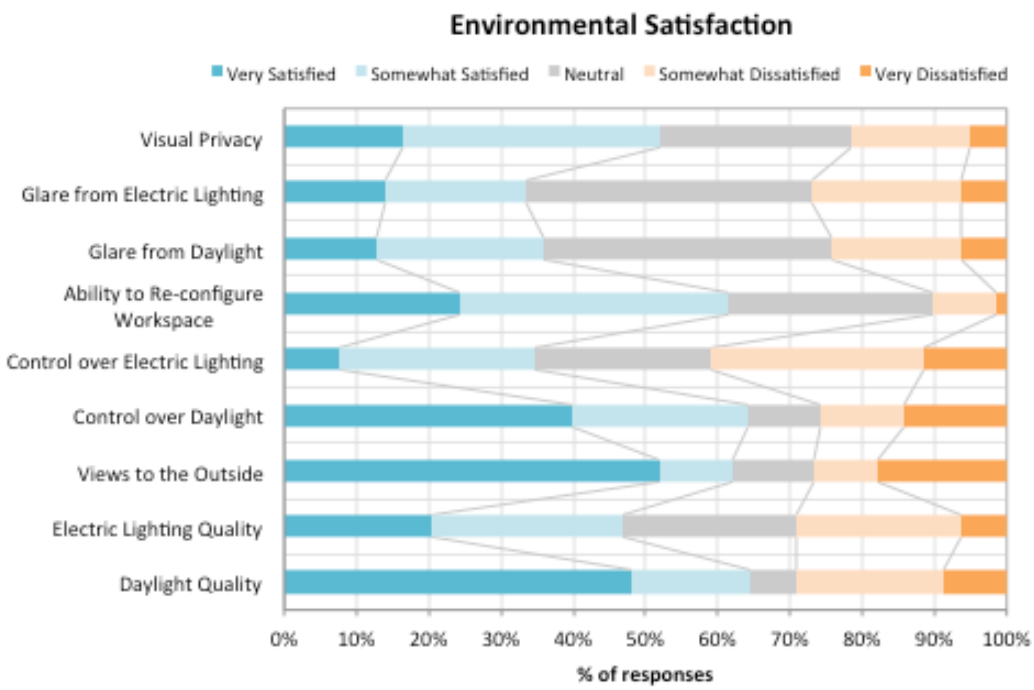


Figure 162: Reported satisfaction with workspace environment for all respondents.

Perceived Degree of Environmental Control

In this item measure, respondents' perceived levels of environmental control are assessed on a 5-point scale from 0 (no control) to 5 (high control). Questionnaire responses indicate perceived level of control over visual privacy, noise from other areas, workspace configuration, glare from daylight, interior shades, and electric lighting. As shown in Figure 163, respondents in general report the highest perceived level of control over interior shades and workspace configuration. Responses indicate similar perceived levels of control over glare from daylight, electric lighting, and visual privacy. As expected, few respondents perceive moderate or high levels of control over noise from other areas. This does not change appreciably among respondents in perimeter offices (Figure 164) or interior offices (Figure 165) although there are some differences between perceive level of control over interior shades, glare from daylight, and visual privacy. Respondents in perimeter offices are more likely to report higher level of control over interior shades and glare from daylight but lower control over visual privacy than are respondents from interior offices. This observation is perhaps a reflection of two things. First, respondents from interior offices perceive visual privacy to be the main attribute they control with their shades, rather than glare, which is affected by the corresponding perimeter office. Second, perimeter office occupants may connect their actions to secure visual privacy (closing the blinds on the corridor window) to the daylight and view impacts of neighboring interior office occupants and thus perceive that they have less control over how to secure visual privacy.

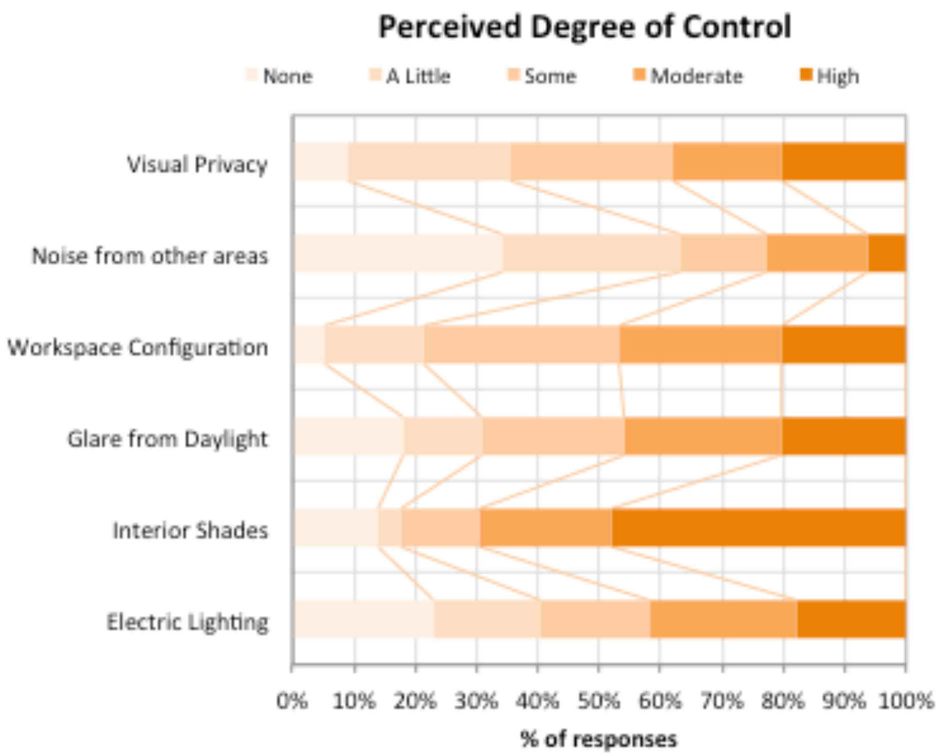


Figure 163: Perceived degree of environmental control as reported by all respondents.

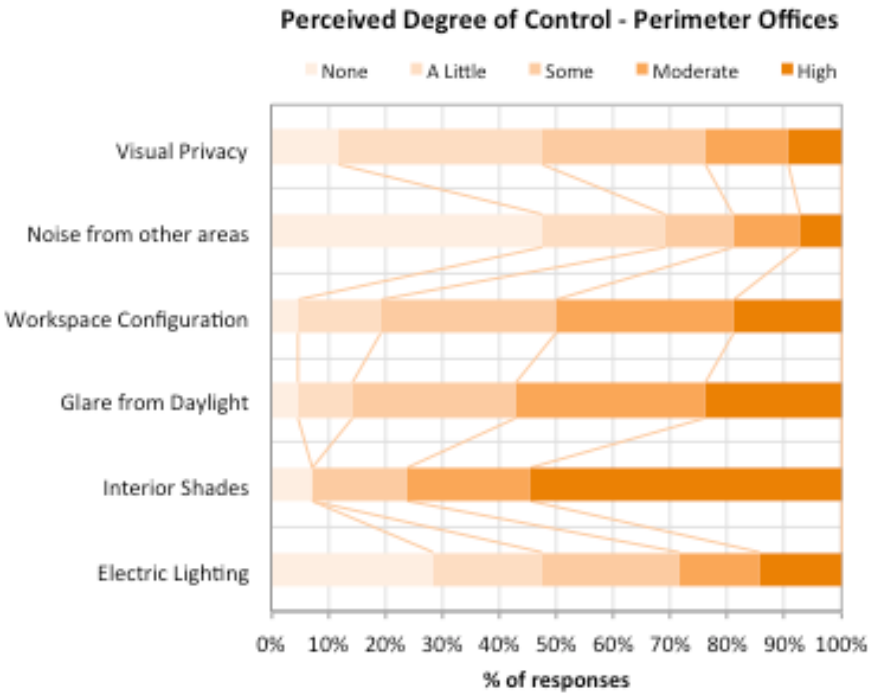


Figure 164: Perceived degree of environmental control as reported by occupants of perimeter offices only.

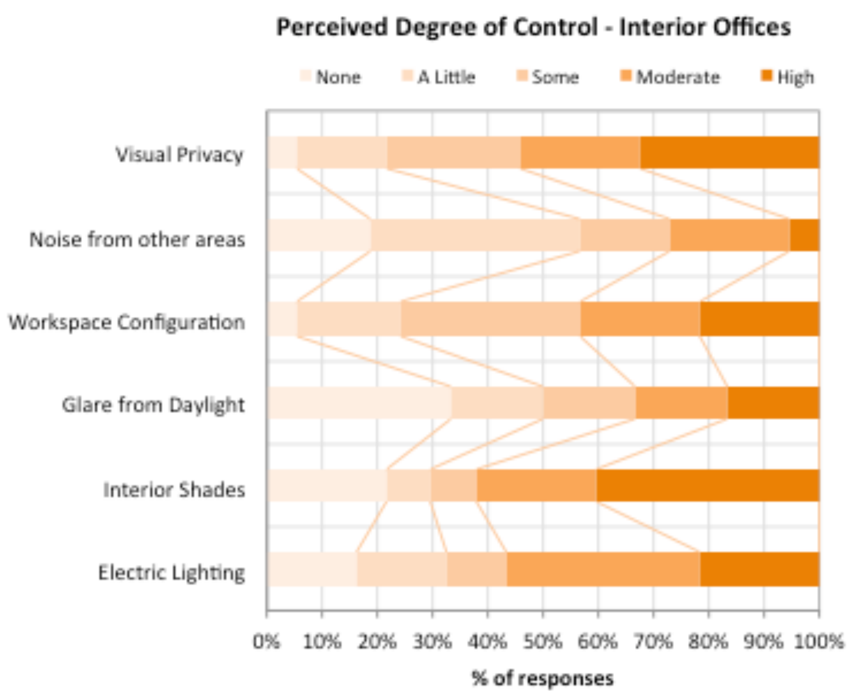


Figure 165: Perceived degree of environmental control as reported by occupants of interior offices only.

Environmental Lighting Outcomes and Desires

In this item measure, respondents' general evaluation of the environmental lighting conditions and desired remediation strategy are assessed using a series of statements to which the respondent indicates the degree to which they agree with the statement (1, strongly disagree to 5, strongly agree). Responses to the following statements are included: 'glare from daylight is a frequent issue', 'I would like more control over daylight', 'electric lighting is necessary for my work during the day', 'glare from electric lights is a frequent issue', discomfort from lighting interferes with my work', and 'I would like more control over my workspace arrangement'. A summary of results for all respondents is seen in Figure 166. There are marked variations in responses between spatial groupings to the item measures shown in Figure 167 (Q14-1 'Glare from daylight is a frequent issue'), Figure 168 (Q14-2 'I would like more control over daylight') and Figure 169 (Q14-6 'I would like more control over my workspace arrangement). There are few respondents across all spatial groupings that agree or strongly agree that glare from daylight is a frequent issue and many respondents either disagree or do not express an opinion on this statement. Despite this, much higher proportions of respondents across all spatial groupings agree or strongly agree that they would like more control over daylight as well as their workspace arrangement. This result seems to suggest that while glare may not be reported as a recognize issue for many respondents, there are clear indications that many respondents are have an issue with the current level of control over their environment. These measures are explored further in the bivariate and multivariate analysis to follow.

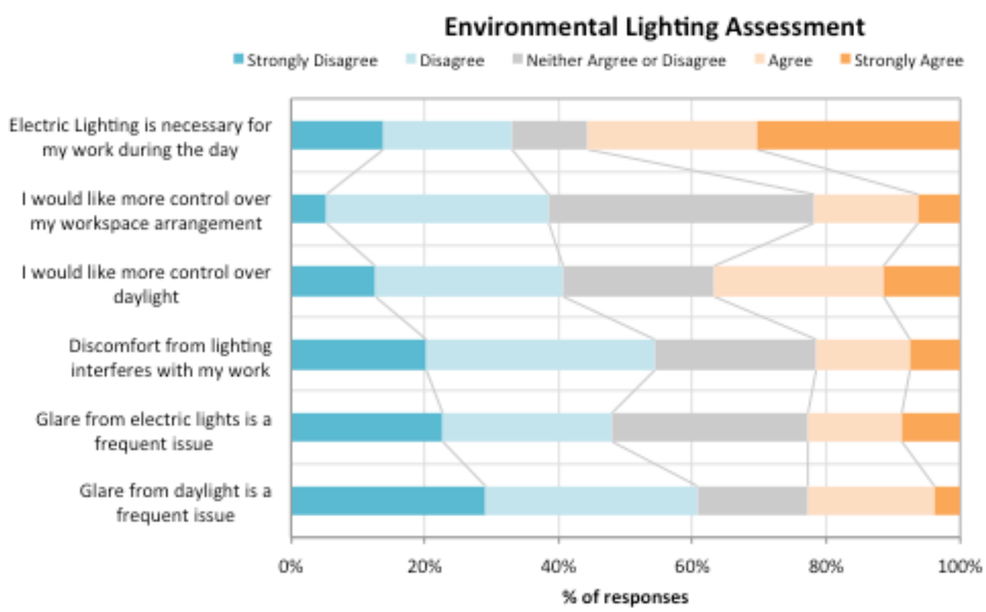


Figure 166: Reported environmental lighting conditions assessment and desired remediation strategies for all respondents.

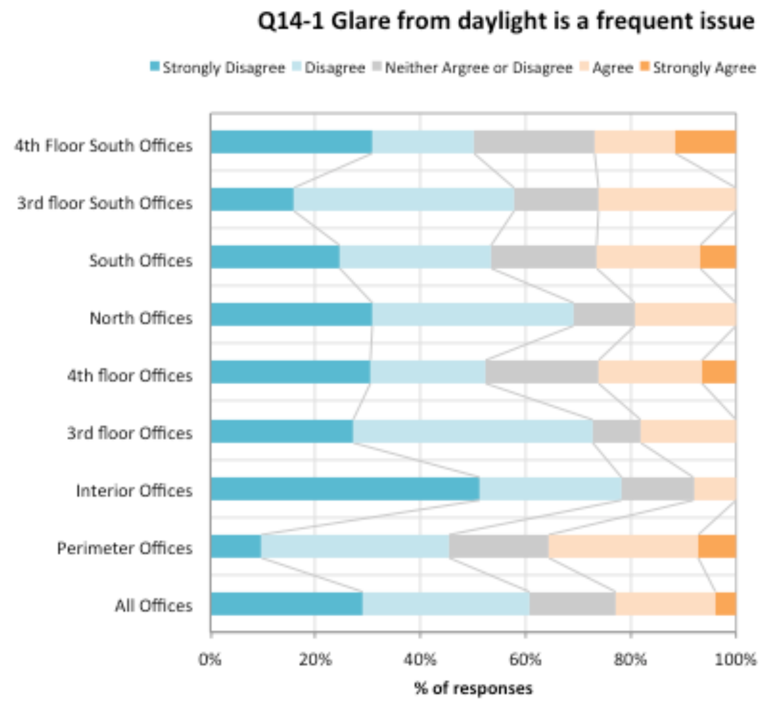


Figure 167: Responses to the statement that 'Glare from daylight is a frequent issue' by respondents in different building zones, floors, and orientations.

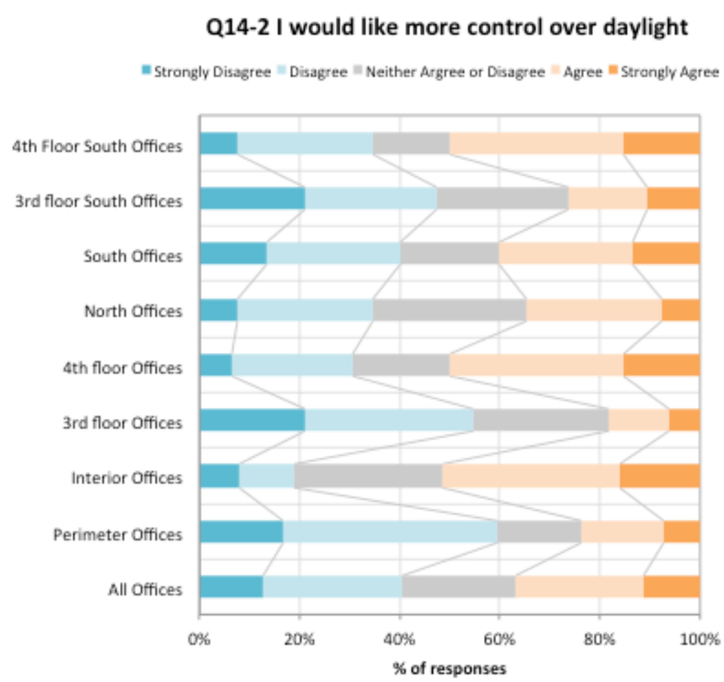


Figure 168: Responses to the statement that 'I would like more control over daylight' by respondents in different building zones, floors, and orientations.

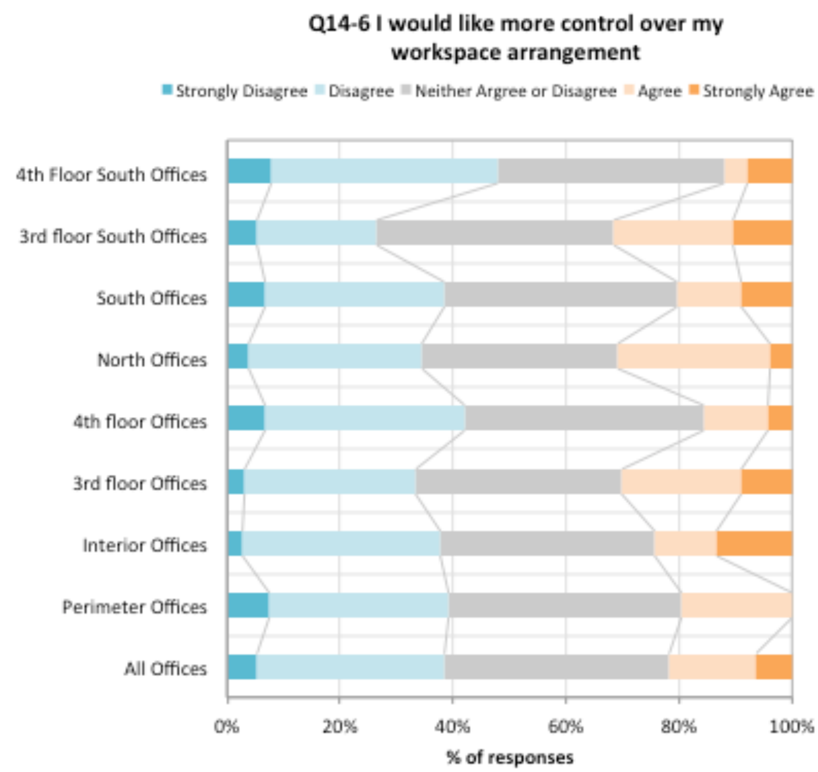


Figure 169: Responses to the statement that 'I would like more control over my workspace arrangement' by respondents in different building zones, floors, and orientations.

Reported Sources of Daylight Discomfort

In this item measure, respondents report on specific workspace lighting conditions on a 5-point scale from 1, never, to 5, always. These responses include the frequency of discomfort and distraction outcomes as well as frequency of different common sources of discomfort glare including ‘direct sun on interior surfaces’, ‘direct sun on desktop / work surface’, ‘direct sun on computer screen’, ‘interior surfaces are too bright’, ‘exterior surfaces are too bright’ and ‘ bright reflects off exterior surfaces’. Figure 170 shows a summary of response rates for each frequency item measure. While respondents report similar frequency of discomfort and distraction from glare as individual lighting conditions, few respondents report to never experience discomfort or distractions. When responses are compared between floors, as shown in Figure 171, few significant differences between reported lighting conditions are apparent. Direct sun on interior surfaces and the workspace are the most frequently reported conditions while exterior bright surfaces or reflections are the least frequently reported conditions. These results require further bivariate analysis to determine whether they are reliable measures of discomfort or adaptive behaviors.

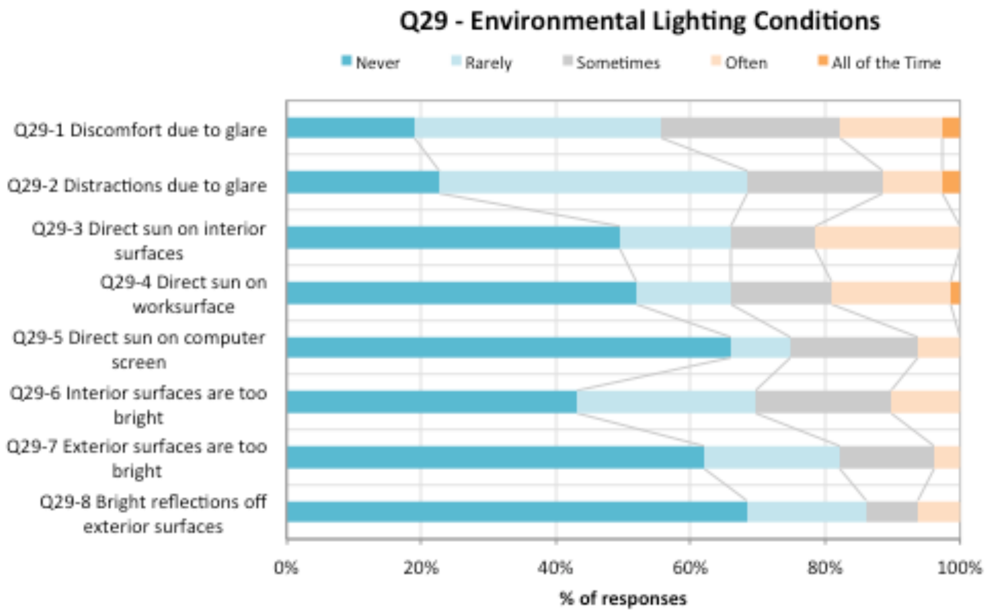


Figure 170: Responses indicating frequency of different discomfort sources for daylight conditions shown for all respondents.

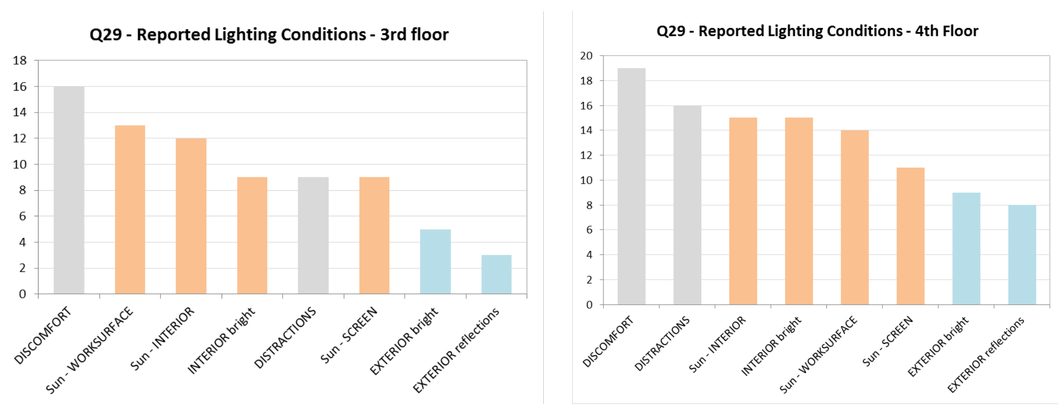


Figure 171: Total number of responses for each lighting condition in Q29 reported to occur at least sometimes in the respondents' workspace for 3rd floor offices (left) and 4th floor offices (right).

Reported Behavioral Reponses to Discomfort

In this item measure, respondents indicate the frequency with which they utilize a range of possible adaptive behavioral responses to perceived discomfort on a 5-point scale from 1, never, to 5, all the time. These responses include both source and subject adaptations. Frequency of use is reported for the following subject adaptations: ‘go work in another space in the office’, ‘go work outside the office’, ‘rotate or adjust computer screen’, ‘move seated position’, ‘put on sunglasses or a hat’, and ‘switch to a different task’. Frequency of use is also reported for the following source adaptations: ‘switch on/off the overhead lights’, ‘dim the overhead lights’, ‘switch on/off a task light’, ‘open/close the shades completely’ and ‘open/close the shades partially’. Respondents are also asked to identify the frequency with which they ‘do nothing’ in response to perceived discomfort. Reported behavioral responses for respondents in 3rd and 4th floor offices are seen in Figure 172. Exterior shade use is the most frequently reported behavioral response to discomfort. Few respondents report using subject adaptations at least sometimes in response to discomfort but 4th floor respondents are more likely to report using subject adaptations than 3rd floor respondents, specifically adjusting the computer screen and moving the seated position were the most frequently reported subject adaptation for 4th floor respondents. These results are evaluated further in relation to reported lighting conditions in the following section.

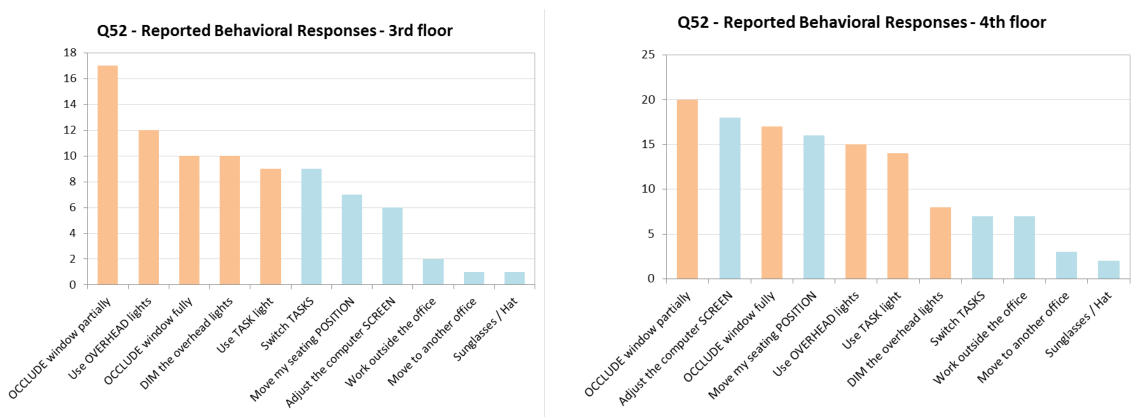


Figure 172: Total number of responses for each adaptive behavior reported in Q52 to be used at least sometimes in response to discomfort for 3rd floor offices (left) and 4th floor offices (right). Source adaptations are shown in orange and subject adaptation in blue.

<u>Bivariate Relationships</u>

If respondents’ stated preferences regarding their workspace environment are thought to affect their actual appraisal and interpretation of that environment, then significant differences should emerge among respondents who value different things. The series of bivariate relationship tables shown in Table 43 show the range of observed relationships between respondents’ reported preferences and their ensuing appraisal of their workspace. While item measure Q61-1 ‘Daylight is an important aspect…’ shows the strongest relationships with many of the environmental appraisal measures the vast majority of respondents agreed or strongly agreed with this statement, as shown in Figure 156. This agreeable statement thus offers no useful comparisons or indications regarding respondents' tolerance or sensitivity to glare. This result is seen in another item measure that demonstrates strong relationships with many of the appraisal measures.

The importance of views to the outside in relation to other environmental attributes or amenities (Q6-3, Table 43) displays strong relationships to respondents' appraisals of daylight as comfortable (45 percentage points), as well as satisfaction with the level of control over daylight (37 percentage points), but shows no relationship to satisfaction with glare from daylight (1 percentage point). Views to the outside are expected to moderate the impact of discomfort glare conditions on glare perception / reporting. Despite this expectation, or perhaps due to a general consensus among respondents, a sizeable majority of respondents identified views to the outside as one of the most important environmental attributes / amenities and as a result few meaningful comparisons could be made. This may have been the result of the design of this questionnaire item, which seemed to generate superfluous results across all item measures. However, measures of respondents' satisfaction with different aspects of their workspace environment retain face validity and produce useful comparisons confirming expectations to indicate tolerance or sensitivity to glare.

Following the logic laid out above, it respondents' perceived levels of control have bearing on their assessment of environmental lighting outcomes and desires, then the bivariate relationships between item measures shown in Table 44 should show consistent measures of tolerance and sensitivity. Item measures Q49-2 (control over interior shades) and Q49-3 (control over glare from daylight) show strong relationships with multiple measures including Q14-2, Q14-4, and Q14-5. Interestingly, the perceived level of control over glare from daylight seems to have no relationship to the reported frequency of glare from daylight. While on its face this result might indicate that measure Q14-1 should not be included in further analysis, this actually underscores a useful observation. Reported frequency of glare shows little relationship overall to perceived levels of environmental control, perhaps indicating independence of the measures. Independence of measures is a useful attribute of the GRS index parameters because the paired item measures that eventually make up the index should display a clear internal relationship but individual item measures should not be redundant across parameters, indicating that Q14-1 may warrant further evaluation in multivariate relationships. Further, the differences between Q49-2 and Q49-3 are minor in regards to strength of relationships between item measures. Q49-2 is quite specific to the controls layout (interior shades), but Q49-3 remains general enough (glare from daylight) not to omit affirmative responses across the study population.

Lastly, the set of bivariate relationships shown in Table 45 explore the relationships between reported types of lighting conditions and behavioral responses. These relationships are meant to identify the broadest categorical measures of lighting condition and behaviors.

Table 43: Bivariate relationships between measures of respondents' environmental values (Q61) / preferences (Q6) and appraisal (Q7) / satisfaction with workspace environment (Q50).

Strength of Bivariate Relationships between Environmental Preferences & Appraisal Measures		Q61 -1 Daylight is an important aspect…		Q61-2 Ability to control my environment is important…		Q6-1 Daylight Quality		Q6-2 Electric Lighting Quality		Q6-3 Views to the Outside		Q6-4 Control over Daylight		Q6-5 Control over Electric Lighting		Q6-6 Ability to re-configure workspace		Q6-7 Glare Free Working Environment		Q6-8 Visual Privacy		
		Agree	Disagree	Agree	Disagree	in top 3	not in top 3	in top 3	not in top 3	in top 3	not in top 3	in top 3	not in top 3	in top 3	not in top 3	in top 3	not in top 3	in top 3	not in top 3	in top 3	not in top 3	average
Q7-1 Daylight Appraisal	Clear	*64.62%*	*21.43%*	*57.97%*	*50.00%*	*56.76%*	*57.14%*	*44.83%*	*64.00%*	*62.69%*	*25.00%*	*61.90%*	*51.35%*	*56.67%*	*57.14%*	*57.69%*	*56.60%*	*47.62%*	*60.34%*	*36.67%*	*69.39%*	
	Hazy	*35.38%*	*78.57%*	*42.03%*	*50.00%*	*43.24%*	*42.86%*	*55.17%*	*36.00%*	*37.31%*	*75.00%*	*38.10%*	*48.65%*	*43.33%*	*42.86%*	*42.31%*	*43.40%*	*52.38%*	*39.66%*	*63.33%*	*30.61%*	
	strength	**-43.19%**		**-7.97%**		**0.39%**		**19.17%**		**-37.69%**		**5.32%**		**0.55%**		**-8.98%**		**12.73%**		**32.72%**		**16.87%**
Q7-2 Daylight Appraisal	Bright	*64.62%*	*7.14%*	*59.42%*	*20.00%*	*54.05%*	*54.76%*	*44.83%*	*60.00%*	*59.70%*	*25.00%*	*64.29%*	*43.24%*	*53.33%*	*55.10%*	*53.85%*	*54.72%*	*52.38%*	*55.17%*	*43.33%*	*61.22%*	
	Dim	*35.38%*	*92.86%*	*40.58%*	*80.00%*	*45.95%*	*45.24%*	*55.17%*	*40.00%*	*40.30%*	*75.00%*	*35.71%*	*56.76%*	*46.67%*	*44.90%*	*46.15%*	*45.28%*	*47.62%*	*44.83%*	*56.67%*	*38.78%*	
	strength	**-57.47%**		**-39.42%**		**0.71%**		**15.17%**		**-34.70%**		**10.09%**		**-1.26%**		**-2.34%**		**2.79%**		**17.89%**		**18.18%**
Q7-6 Daylight Appraisal	Comfortable	*58.46%*	*35.71%*	*57.97%*	*30.00%*	*51.35%*	*57.14%*	*51.72%*	*56.00%*	*61.19%*	*16.67%*	*54.76%*	*54.05%*	*60.00%*	*51.02%*	*50.00%*	*56.60%*	*47.62%*	*56.90%*	*33.33%*	*67.35%*	
	Uncomfortable	*41.54%*	*64.29%*	*42.03%*	*70.00%*	*48.65%*	*42.86%*	*48.28%*	*44.00%*	*38.81%*	*83.33%*	*45.24%*	*45.95%*	*40.00%*	*48.98%*	*50.00%*	*43.40%*	*52.38%*	*43.10%*	*66.67%*	*32.65%*	
	strength	**-22.75%**		**-27.97%**		**5.79%**		**4.28%**		**-44.53%**		**5.95%**		**-1.02%**		**-8.98%**		**9.28%**		**34.01%**		**16.46%**
Q50-1 Daylight Quality	Satisfied	*73.85%*	*57.14%*	*72.46%*	*60.00%*	*67.57%*	*73.81%*	*62.07%*	*76.00%*	*74.63%*	*50.00%*	*73.81%*	*67.57%*	*73.33%*	*69.39%*	*73.08%*	*69.81%*	*71.43%*	*70.69%*	*60.00%*	*77.55%*	
	Dissatisfied	*26.15%*	*42.86%*	*27.54%*	*40.00%*	*32.43%*	*26.19%*	*37.93%*	*24.00%*	*25.37%*	*50.00%*	*26.19%*	*32.43%*	*26.67%*	*30.61%*	*26.92%*	*30.19%*	*28.57%*	*29.31%*	*40.00%*	*22.45%*	
	strength	**-16.70%**		**-12.46%**		**6.24%**		**13.93%**		**-24.63%**		**5.77%**		**3.69%**		**1.62%**		**-0.74%**		**17.55%**		**10.33%**
Q50-2 Electric Lighting Quality	Satisfied	*43.08%*	*64.29%*	*46.38%*	*50.00%*	*48.65%*	*45.24%*	*48.28%*	*46.00%*	*44.78%*	*58.33%*	*52.38%*	*40.54%*	*46.67%*	*46.94%*	*61.54%*	*39.62%*	*57.14%*	*43.10%*	*50.00%*	*44.90%*	
	Dissatisfied	*56.92%*	*35.71%*	*53.62%*	*50.00%*	*51.35%*	*54.76%*	*51.72%*	*54.00%*	*55.22%*	*41.67%*	*47.62%*	*59.46%*	*53.33%*	*53.06%*	*38.46%*	*60.38%*	*42.86%*	*56.90%*	*50.00%*	*55.10%*	
	strength	**21.21%**		**3.62%**		**-3.41%**		**-2.28%**		**13.56%**		**6.13%**		**14.60%**		**17.52%**		**-14.04%**		**-5.10%**		**10.15%**
Q50-3 Views to the Outside	Satisfied	*80.00%*	*42.86%*	*76.81%*	*50.00%*	*70.27%*	*76.19%*	*65.52%*	*78.00%*	*77.61%*	*50.00%*	*80.95%*	*64.86%*	*73.33%*	*73.47%*	*76.92%*	*71.70%*	*76.19%*	*72.41%*	*66.67%*	*77.55%*	
	Dissatisfied	*20.00%*	*57.14%*	*23.19%*	*50.00%*	*29.73%*	*23.81%*	*34.48%*	*22.00%*	*22.39%*	*50.00%*	*19.05%*	*35.14%*	*26.67%*	*26.53%*	*23.08%*	*28.30%*	*23.81%*	*27.59%*	*33.33%*	*22.45%*	
	strength	**-37.14%**		**-26.81%**		**5.92%**		**12.48%**		**-27.61%**		**8.47%**		**3.45%**		**4.49%**		**-3.78%**		**10.88%**		**14.10%**
Q50-4 Control over Daylight	Satisfied	*69.23%*	*42.86%*	*66.67%*	*50.00%*	*67.57%*	*61.90%*	*55.17%*	*70.00%*	*70.15%*	*33.33%*	*71.43%*	*56.76%*	*63.33%*	*65.31%*	*61.54%*	*66.04%*	*61.90%*	*65.52%*	*56.67%*	*69.39%*	
	Dissatisfied	*30.77%*	*57.14%*	*33.33%*	*50.00%*	*32.43%*	*38.10%*	*44.83%*	*30.00%*	*29.85%*	*66.67%*	*28.57%*	*43.24%*	*36.67%*	*34.69%*	*38.46%*	*33.96%*	*38.10%*	*34.48%*	*43.33%*	*30.61%*	
	strength	**-26.37%**		**-16.67%**		**-5.66%**		**14.83%**		**-36.82%**		**6.58%**		**-3.77%**		**-4.13%**		**3.61%**		**12.72%**		**13.12%**
Q50-5 Control over Electric Lighting	Satisfied	*35.38%*	*35.71%*	*36.23%*	*30.00%*	*40.54%*	*30.95%*	*41.38%*	*32.00%*	*35.82%*	*33.33%*	*35.71%*	*35.14%*	*43.33%*	*30.61%*	*42.31%*	*32.08%*	*23.81%*	*39.66%*	*30.00%*	*38.78%*	
	Dissatisfied	*64.62%*	*64.29%*	*63.77%*	*70.00%*	*59.46%*	*69.05%*	*58.62%*	*68.00%*	*64.18%*	*66.67%*	*64.29%*	*64.86%*	*56.67%*	*69.39%*	*57.69%*	*67.92%*	*76.19%*	*60.34%*	*70.00%*	*61.22%*	
	strength	**0.33%**		**-6.23%**		**-9.59%**		**-9.38%**		**-2.49%**		**8.20%**		**11.70%**		**-8.27%**		**15.85%**		**8.78%**		**8.08%**
Q50-6 Ability to re-configure workspace	Satisfied	*60.00%*	*71.43%*	*63.77%*	*50.00%*	*67.57%*	*57.14%*	*48.28%*	*70.00%*	*62.69%*	*58.33%*	*69.05%*	*54.05%*	*50.00%*	*69.39%*	*73.08%*	*56.60%*	*52.38%*	*65.52%*	*56.67%*	*65.31%*	
	Dissatisfied	*40.00%*	*28.57%*	*36.23%*	*50.00%*	*32.43%*	*42.86%*	*51.72%*	*30.00%*	*37.31%*	*41.67%*	*30.95%*	*45.95%*	*50.00%*	*30.61%*	*26.92%*	*43.40%*	*47.62%*	*34.48%*	*43.33%*	*34.69%*	
	strength	**11.43%**		**-13.77%**		**-10.42%**		**21.72%**		**-4.35%**		**-4.05%**		**3.69%**		**-4.22%**		**13.14%**		**8.64%**		**9.54%**
Q50-7 Glare from Daylight	Satisfied	*41.54%*	*0.00%*	*36.23%*	*20.00%*	*29.73%*	*38.10%*	*27.59%*	*38.00%*	*34.33%*	*33.33%*	*42.86%*	*24.32%*	*30.00%*	*36.73%*	*38.46%*	*32.08%*	*52.38%*	*27.59%*	*36.67%*	*32.65%*	
	Dissatisfied	*58.46%*	*100.00%*	*63.77%*	*80.00%*	*70.27%*	*61.90%*	*72.41%*	*62.00%*	*65.67%*	*66.67%*	*57.14%*	*75.68%*	*70.00%*	*63.27%*	*61.54%*	*67.92%*	*47.62%*	*72.41%*	*63.33%*	*61.22%*	
	strength	**-41.54%**		**-16.23%**		**8.37%**		**10.41%**		**-1.00%**		**5.68%**		**1.73%**		**20.31%**		**-24.79%**		**2.11%**		**13.22%**
Q50-8 Glare from Electric Lighting	Satisfied	*29.23%*	*57.14%*	*31.88%*	*50.00%*	*32.43%*	*35.71%*	*37.93%*	*32.00%*	*34.33%*	*33.33%*	*38.10%*	*29.73%*	*46.67%*	*26.53%*	*50.00%*	*26.42%*	*42.86%*	*31.03%*	*26.67%*	*38.78%*	
	Dissatisfied	*70.77%*	*42.86%*	*68.12%*	*50.00%*	*67.57%*	*64.29%*	*62.07%*	*68.00%*	*65.67%*	*66.67%*	*61.90%*	*70.27%*	*53.33%*	*73.47%*	*50.00%*	*73.58%*	*57.14%*	*68.97%*	*73.33%*	*61.22%*	
	strength	**27.91%**		**18.12%**		**3.28%**		**-5.93%**		**-1.00%**		**16.94%**		**23.47%**		**16.44%**		**-11.82%**		**12.11%**		**13.70%**
Q50-9 Visual Privacy	Satisfied	*50.77%*	*57.14%*	*52.17%*	*50.00%*	*59.46%*	*45.24%*	*44.83%*	*56.00%*	*50.75%*	*58.33%*	*64.29%*	*37.84%*	*50.00%*	*53.06%*	*65.38%*	*45.28%*	*57.14%*	*50.00%*	*60.00%*	*46.94%*	
	Dissatisfied	*49.23%*	*42.86%*	*47.83%*	*50.00%*	*40.54%*	*54.76%*	*55.17%*	*44.00%*	*49.25%*	*41.67%*	*35.71%*	*62.16%*	*50.00%*	*46.94%*	*34.62%*	*54.72%*	*42.86%*	*50.00%*	*40.00%*	*53.06%*	
	strength	**6.37%**		**-2.17%**		**-14.22%**		**11.17%**		**7.59%**		**12.16%**		**12.32%**		**11.86%**		**-7.14%**		**-13.06%**		**9.81%**
		26.03%		**15.95%**		**6.17%**		**11.73%**		**19.66%**		**7.94%**		**6.77%**		**9.10%**		**9.98%**		**14.63%**		

Table 44: Bivariate relationships between measures of environmental preferences (Q49) and environmental outcomes / desires (Q14).

Strength of Bivariate Relationships between Perceived Environmental Control & Outcomes / Desires		Q49-1 Perceived control over electric lighting		Q49-2 Perceived control over interior shades		Q49-3 Perceived control over glare from daylight		Q49-4 Perceived control over workspace configuration		Q49-5 Perceived control over noise from other areas		Q49-6 Perceived control over visual privacy		
		Mod/High	Low	Mod/High	Low	Mod/High	Low	Mod/High	Low	Mod/High	Low	Mod/High	Low	average
Q14-1 Glare from Daylight is a frequent issue	Agree	*18.18%*	*26.09%*	*20.00%*	*29.17%*	*22.22%*	*23.26%*	*24.32%*	*21.43%*	*22.22%*	*22.95%*	*16.67%*	*26.53%*	
	Disagree	*81.82%*	*73.91%*	*80.00%*	*70.83%*	*77.78%*	*76.74%*	*75.68%*	*78.57%*	*77.78%*	*77.05%*	*83.33%*	*73.47%*	
	strength	**7.91%**		**9.17%**		**1.03%**		**-2.90%**		**0.73%**		**9.86%**		**5.27%**
Q14-2 I would like more control over daylight	Agree	*42.42%*	*32.61%*	*30.91%*	*50.00%*	*25.00%*	*46.51%*	*35.14%*	*38.10%*	*38.89%*	*36.07%*	*50.00%*	*28.57%*	
	Disagree	*57.58%*	*67.39%*	*69.09%*	*50.00%*	*75.00%*	*53.49%*	*64.86%*	*61.90%*	*61.11%*	*63.93%*	*50.00%*	*71.43%*	
	strength	**-9.82%**		**19.09%**		**21.51%**		**2.96%**		**-2.82%**		**-21.43%**		**12.94%**
Q14-3 Electric lighting is necessary for my work during the day	Agree	*72.73%*	*43.48%*	*58.18%*	*50.00%*	*52.78%*	*58.14%*	*56.76%*	*54.76%*	*55.56%*	*55.74%*	*66.67%*	*48.98%*	
	Disagree	*27.27%*	*56.52%*	*41.82%*	*50.00%*	*47.22%*	*41.86%*	*43.24%*	*45.24%*	*44.44%*	*44.26%*	*33.33%*	*51.02%*	
	strength	**-29.25%**		**-8.18%**		**5.36%**		**-1.99%**		**0.18%**		**-17.69%**		**10.44%**
Q14-4 Glare from electric lights is a frequent issue	Agree	*18.18%*	*26.09%*	*16.36%*	*37.50%*	*13.89%*	*30.23%*	*13.51%*	*30.95%*	*16.67%*	*24.59%*	*13.33%*	*28.57%*	
	Disagree	*81.82%*	*73.91%*	*83.64%*	*62.50%*	*86.11%*	*69.77%*	*86.49%*	*69.05%*	*83.33%*	*75.41%*	*86.67%*	*71.43%*	
	strength	**7.91%**		**21.14%**		**16.34%**		**17.44%**		**7.92%**		**15.24%**		**14.33%**
Q14-5 Discomfort from lighting interferes with my work	Agree	*18.18%*	*23.91%*	*12.73%*	*41.67%*	*8.33%*	*32.56%*	*16.22%*	*26.19%*	*22.22%*	*21.31%*	*16.67%*	*24.49%*	
	Disagree	*81.82%*	*76.09%*	*87.27%*	*58.33%*	*91.67%*	*67.44%*	*83.78%*	*73.81%*	*77.78%*	*78.69%*	*83.33%*	*75.51%*	
	strength	**5.73%**		**28.94%**		**24.22%**		**9.97%**		**-0.91%**		**7.82%**		**12.93%**
Q14-6 I would like more control over my workspace arrangement	Agree	*9.09%*	*30.43%*	*9.09%*	*50.00%*	*8.33%*	*32.56%*	*10.81%*	*30.95%*	*11.11%*	*24.59%*	*16.67%*	*24.49%*	
	Disagree	*90.91%*	*69.57%*	*90.91%*	*50.00%*	*91.67%*	*67.44%*	*89.19%*	*69.05%*	*88.89%*	*75.41%*	*83.33%*	*75.51%*	
	strength	**21.34%**		**40.91%**		**24.22%**		**20.14%**		**13.48%**		**7.82%**		**21.32%**
		13.66%		**21.24%**		**15.45%**		**9.23%**		**4.34%**		**13.31%**		

There are some variations among the reported lighting conditions and how strongly they relate to the types of adaptive behaviors reported but some general conclusions emerge from this data. Reported behaviors are expected to show consistent relationships with the types of lighting conditions reported and those item measures that show consistent relationships are identified for further analysis. First, the two item measures for shade use in response to discomfort (Q52-10 and Q52-11) show strong relationships to exterior lighting conditions (Q29-7 and Q29-8). In addition, shade use appears to relate strongly to multiple other lighting conditions and thus suggests it may be a good indicator of the typical source adaptation behaviors. Measures of subject adaptation use show less consistent relationships but item measures Q52-3 (rotate computer screen) and Q52-4 (move seated position) are among the strongest and consistently reported subject adaptations. While Q52-3 displays slightly stronger overall relationships with environmental lighting conditions, there is no corroborating observational data on adjustments to the computer screen. For this reason, Q52-4 is a more applicable measure to include in the next analysis phase. An additional item measure (Q29#) is included to determine whether the specific lighting conditions reported can be generalized in order to avoid omitting reported sources of discomfort from segments of the study population. Q29# shows moderately strong relationships to the reported source and subject adaptations mentioned above and thus can present a useful way to capture a threshold of discomfort source frequency where a respondent would need to report at least 3 sources of discomfort occurring at least sometimes to fall within the affirmative category of environmental lighting conditions responses.

Table 45: Bivariate relationship table showing strengths of relationships between each item in Q29 - Sources of Daylight Discomfort and Q52 - Behavioral Responses to Discomfort.

Strength of Bivariate Relationships between reported sources of discomfort and behavioral responses		Q29-1 Discomfort due to glare		Q29-2 Distraction due to glare		Q29-3 Direct sun on interior surfaces		Q29-4 Direct sun on work surface		Q29-5 Direct sun on computer screen		Q29-6 Interior surfaces too bright		Q29-7 Exterior surfaces too bright		Q29-8 Bright reflections off exterior surfaces		Q29 # of discomfort sources		average
		≥ sometimes	Rarely / Never	≥ sometimes	Rarely / Never	≥ sometimes	Rarely / Never	≥ sometimes	Rarely / Never	≥ sometimes	Rarely / Never	≥ sometimes	Rarely / Never	≥ sometimes	Rarely / Never	≥ sometimes	Rarely / Never	more than 3	fewer than 3	
Q52-1 Go work in another space in the office	≥ sometimes	*8.57%*	*2.27%*	*8.00%*	*3.70%*	*0.00%*	*7.69%*	*0.00%*	*7.69%*	*0.00%*	*6.78%*	*4.17%*	*5.45%*	*0.00%*	*6.15%*	*0.00%*	*5.88%*	*0.00%*	*8.00%*	
	Rarely / Never	*91.43%*	*97.73%*	*92.00%*	*96.30%*	*100.00%*	*92.31%*	*100.00%*	*92.31%*	*100.00%*	*93.22%*	*95.83%*	*94.55%*	*100.00%*	*93.85%*	*100.00%*	*94.12%*	*100.00%*	*92.00%*	
	strength	**-6.30%**		**-4.30%**		**7.69%**		**7.69%**		**6.78%**		**-5.45%**		**-6.15%**		**-5.88%**		**8.00%**		**6.47%**
Q52 - 2 Go work outside the office	≥ sometimes	*14.29%*	*9.09%*	*20.00%*	*7.41%*	*11.11%*	*11.54%*	*11.11%*	*11.54%*	*15.00%*	*10.17%*	*20.83%*	*7.27%*	*21.43%*	*9.23%*	*27.27%*	*8.82%*	*10.34%*	*12.00%*	
	Rarely / Never	*85.71%*	*90.91%*	*80.00%*	*92.59%*	*88.89%*	*88.46%*	*88.89%*	*88.46%*	*85.00%*	*89.83%*	*79.17%*	*92.73%*	*78.57%*	*90.77%*	*72.73%*	*91.18%*	*89.66%*	*88.00%*	
	strength	**-5.19%**		**-12.59%**		**0.43%**		**0.43%**		**-4.83%**		**14.16%**		**18.04%**		**1.52%**		**1.66%**		**6.54%**
Q52-3 Rotate or Adjust the computer screen	≥ sometimes	*40.00%*	*22.73%*	*44.00%*	*24.07%*	*44.44%*	*23.08%*	*44.44%*	*23.08%*	*50.00%*	*23.73%*	*54.17%*	*20.00%*	*50.00%*	*26.15%*	*45.45%*	*27.94%*	*44.83%*	*22.00%*	
	Rarely / Never	*60.00%*	*77.27%*	*56.00%*	*75.93%*	*55.56%*	*76.92%*	*55.56%*	*76.92%*	*50.00%*	*76.27%*	*45.83%*	*80.00%*	*50.00%*	*73.85%*	*54.55%*	*72.06%*	*55.17%*	*78.00%*	
	strength	**-17.27%**		**-19.93%**		**-21.37%**		**-21.37%**		**-26.27%**		**30.00%**		**19.30%**		**16.89%**		**-22.83%**		**21.69%**
Q52-4 Move my Seated Position	≥ sometimes	*34.29%*	*25.00%*	*40.00%*	*24.07%*	*37.04%*	*25.00%*	*37.04%*	*25.00%*	*35.00%*	*27.12%*	*45.83%*	*21.82%*	*64.29%*	*21.54%*	*63.64%*	*23.53%*	*41.38%*	*22.00%*	
	Rarely / Never	*65.71%*	*75.00%*	*60.00%*	*75.93%*	*62.96%*	*75.00%*	*62.96%*	*75.00%*	*65.00%*	*72.88%*	*54.17%*	*78.18%*	*35.71%*	*78.46%*	*36.36%*	*76.47%*	*58.62%*	*78.00%*	
	strength	**-9.29%**		**-15.93%**		**-12.04%**		**-12.04%**		**-7.88%**		**42.47%**		**42.10%**		**17.85%**		**-19.38%**		**19.88%**
Q52-5 Put on sunglasses or a hat	≥ sometimes	*8.57%*	*0.00%*	*8.00%*	*1.85%*	*7.41%*	*1.92%*	*7.41%*	*1.92%*	*5.00%*	*3.39%*	*12.50%*	*0.00%*	*14.29%*	*1.54%*	*18.18%*	*1.47%*	*10.34%*	*0.00%*	
	Rarely / Never	*91.43%*	*100.00%*	*92.00%*	*98.15%*	*92.59%*	*98.08%*	*92.59%*	*98.08%*	*95.00%*	*96.61%*	*87.50%*	*100.00%*	*85.71%*	*98.46%*	*81.82%*	*98.53%*	*89.66%*	*100.00%*	
	strength	**-8.57%**		**-6.15%**		**-5.48%**		**-5.48%**		**-1.61%**		**14.29%**		**16.64%**		**8.87%**		**-10.34%**		**8.61%**
Q52-6 Switch to a Different Task	≥ sometimes	*22.86%*	*18.18%*	*24.00%*	*18.52%*	*25.93%*	*17.31%*	*25.93%*	*17.31%*	*25.00%*	*18.64%*	*33.33%*	*14.55%*	*28.57%*	*18.46%*	*36.36%*	*17.65%*	*24.14%*	*18.00%*	
	Rarely / Never	*77.14%*	*81.82%*	*76.00%*	*81.48%*	*74.07%*	*82.69%*	*74.07%*	*82.69%*	*75.00%*	*81.36%*	*66.67%*	*85.45%*	*71.43%*	*81.54%*	*63.64%*	*82.35%*	*75.86%*	*82.00%*	
	strength	**-4.68%**		**-5.48%**		**-8.62%**		**-8.62%**		**-6.36%**		**14.03%**		**17.90%**		**6.49%**		**-6.14%**		**8.70%**
Q52-7 Switch on/off the overhead lights	≥ sometimes	*45.71%*	*25.00%*	*48.00%*	*27.78%*	*40.74%*	*30.77%*	*40.74%*	*30.77%*	*40.00%*	*32.20%*	*33.33%*	*34.55%*	*28.57%*	*35.38%*	*27.27%*	*35.29%*	*34.48%*	*34.00%*	
	Rarely / Never	*54.29%*	*75.00%*	*52.00%*	*72.22%*	*59.26%*	*69.23%*	*59.26%*	*69.23%*	*60.00%*	*67.80%*	*66.67%*	*65.45%*	*71.43%*	*64.62%*	*72.73%*	*64.71%*	*65.52%*	*66.00%*	
	strength	**-20.71%**		**-20.22%**		**-9.97%**		**-9.97%**		**-7.80%**		**-5.97%**		**-8.11%**		**-0.81%**		**-0.48%**		**9.34%**
Q52-8 Dim the overhead lights	≥ sometimes	*25.71%*	*20.45%*	*20.00%*	*24.07%*	*25.93%*	*21.15%*	*25.93%*	*21.15%*	*30.00%*	*20.34%*	*8.33%*	*29.09%*	*21.43%*	*23.08%*	*18.18%*	*23.53%*	*20.69%*	*24.00%*	
	Rarely / Never	*74.29%*	*79.55%*	*80.00%*	*75.93%*	*74.07%*	*78.85%*	*74.07%*	*78.85%*	*70.00%*	*79.66%*	*91.67%*	*70.91%*	*78.57%*	*76.92%*	*81.82%*	*76.47%*	*79.31%*	*76.00%*	
	strength	**-5.26%**		**4.07%**		**-4.77%**		**-4.77%**		**-9.66%**		**-7.66%**		**-4.90%**		**-2.84%**		**3.31%**		**5.25%**
Q52-9 Switch on/off a task light	≥ sometimes	*31.43%*	*27.27%*	*36.00%*	*25.93%*	*33.33%*	*26.92%*	*37.04%*	*25.00%*	*30.00%*	*28.81%*	*37.50%*	*25.45%*	*35.71%*	*27.69%*	*36.36%*	*27.94%*	*31.03%*	*28.00%*	
	Rarely / Never	*68.57%*	*72.73%*	*64.00%*	*74.07%*	*66.67%*	*73.08%*	*62.96%*	*75.00%*	*70.00%*	*71.19%*	*62.50%*	*74.55%*	*64.29%*	*72.31%*	*63.64%*	*72.06%*	*68.97%*	*72.00%*	
	strength	**-4.16%**		**-10.07%**		**-6.41%**		**-12.04%**		**-1.19%**		**10.26%**		**8.67%**		**3.09%**		**-3.03%**		**6.55%**
Q52-10 Open/Close the shades completely	≥ sometimes	*51.43%*	*20.45%*	*56.00%*	*24.07%*	*66.67%*	*17.31%*	*66.67%*	*17.31%*	*65.00%*	*23.73%*	*58.33%*	*23.64%*	*78.57%*	*24.62%*	*81.82%*	*26.47%*	*68.97%*	*14.00%*	
	Rarely / Never	*48.57%*	*79.55%*	*44.00%*	*75.93%*	*33.33%*	*82.69%*	*33.33%*	*82.69%*	*35.00%*	*76.27%*	*41.67%*	*76.36%*	*21.43%*	*75.38%*	*18.18%*	*73.53%*	*31.03%*	*86.00%*	
	strength	**-30.97%**		**-31.93%**		**-49.36%**		**-49.36%**		**-41.27%**		**54.94%**		**57.20%**		**42.49%**		**-54.97%**		**45.83%**
Q52-11 Open/close the shades partially	≥ sometimes	*57.14%*	*38.64%*	*52.00%*	*44.44%*	*85.19%*	*26.92%*	*85.19%*	*26.92%*	*80.00%*	*35.59%*	*66.67%*	*38.18%*	*85.71%*	*38.46%*	*81.82%*	*41.18%*	*82.76%*	*26.00%*	
	Rarely / Never	*42.86%*	*61.36%*	*48.00%*	*55.56%*	*14.81%*	*73.08%*	*14.81%*	*73.08%*	*20.00%*	*64.41%*	*33.33%*	*61.82%*	*14.29%*	*61.54%*	*18.18%*	*58.82%*	*17.24%*	*74.00%*	
	strength	**-18.51%**		**-7.56%**		**-58.26%**		**-58.26%**		**-44.41%**		**47.53%**		**43.36%**		**41.58%**		**-56.76%**		**41.80%**
Q52-12 Do Nothing	≥ sometimes	*45.71%*	*59.09%*	*48.00%*	*55.56%*	*44.44%*	*57.69%*	*44.44%*	*57.69%*	*50.00%*	*54.24%*	*45.83%*	*56.36%*	*21.43%*	*60.00%*	*27.27%*	*57.35%*	*41.38%*	*60.00%*	
	Rarely / Never	*54.29%*	*40.91%*	*52.00%*	*44.44%*	*55.56%*	*42.31%*	*55.56%*	*42.31%*	*50.00%*	*45.76%*	*54.17%*	*43.64%*	*78.57%*	*40.00%*	*72.73%*	*42.65%*	*58.62%*	*40.00%*	
	strength	**13.38%**		**7.56%**		**13.25%**		**13.25%**		**4.24%**		**-34.94%**		**-32.73%**		**-15.97%**		**18.62%**		**17.10%**
		12.02%		**12.15%**		**16.47%**		**16.94%**		**13.52%**		**23.47%**		**22.93%**		**13.69%**		**17.13%**		

Glare Response Sensitivity Index

This section outlines the results of the process by which the Glare Response Sensitivity (GRS) Index is created. Assumptions establishing the face validity of each parameter can be found in section III.D.ii. above. In brief, this process relies on transposing expectations of behavioral outcomes to an operative definition of glare sensitivity. Glare sensitivity represents the likelihood that a glare event would register discomfort in an occupant and that the occupant would respond to the discomfort by modifying the environment as the source of the discomfort. In addition, this definition expects that individuals who are sensitive to glare are more likely to exhibit preventative or reactionary behaviors that decrease daylight utilization and increase energy impacts than are those individuals who are tolerant to glare. The results of this process are organized into three main parameters – environmental preferences and appraisal, reported discomfort, and reported behavioral responses. This section presents results of survey responses to items included in each of the parameters and examines bivariate and multivariate relationship among parameter items and between index parameters. Additional data on personal or social factors that may mediate or supersede results of the previous categories is included where appropriate in order to understand outliers or contradictory results. 79 respondents are included in this section and analysis, approximately 66% of the total occupants in the study area.

In the previous section within-group comparisons of bivariate relationships identified a number of questionnaire measures that may reliable assess respondents' tendency to tolerate or be sensitive to glare according to assumptions arising from the conceptual model. Measures that produce inconsistent results or do not relate across multiple measures in a way suggesting they related to glare sensitivity are not included in this portion of the analysis. The results of multivariate relationship tests between the following measures are outlined in this section.

- Items measuring respondents' appraisal of their workspace environment include:
    - Q50-1 Satisfaction with daylight quality
- Items measuring respondents' perceived level of control over their environment include:
    - Q49-3 Perceived control over glare from daylight
- Items measuring respondents' perceived outcomes of environmental conditions include:
    - Q14-1 Glare from daylight is a frequent issue
    - Q14-2 I would like more control over daylight

- Items measuring respondents' reported sources of discomfort from daylight in their workspace include:
    - Q29-# reporting at least 3 sources of discomfort from daylight
- Items measuring respondents' reported adaptive behaviors in response to discomfort include:
    - Q52-4 Move my seated position
    - Q52-11 Open/close the shades partially

Multivariate Analysis of Item Measures

To begin, the relationships between respondents' satisfaction with daylight quality (Q50), perceived frequency of discomfort glare (Q14) and the desire for more control over daylight (Q14) are examined. Respondents who report to be satisfied with daylight quality, agree that glare from daylight is a frequent issues, and do not want more control over daylight are assumed to be displaying indications of glare tolerance. Whereas respondents who report infrequent glare from daylight yet desire more control over daylight are assumed to be sensitive to glare. Table 46 shows the resulting percentage table from which it is clear that significant relationships persist between these three measures. As expected, among respondents who report frequent glare from daylight and dissatisfaction with daylight quality, 100% would like more daylight controls in their workspace. Tolerance to glare is indicated by the inverse of the value seen in the top left box of Table 46, whereby 53.33% of respondents who report frequent glare from daylight and are satisfied with daylight quality do not desire more control over daylight. Among those respondents who report infrequent glare from daylight and are dissatisfied with daylight quality, 70% would like more daylight controls in their workspace. This result seems to indicate glare sensitivity, but it remains to be seen whether the desire for more control over daylight is driven by discomfort or rather insufficient daylight access to do the behaviors of others, as would be expected in interior offices. Among those who report being satisfied with daylight quality the relationship between frequency of glare from daylight and the desire for more control over daylight is 35 percentage points, stronger than the originally observed relationship (24 percentage points). A slightly weaker relationship, 30 percentage points, is observed among those who report being dissatisfied with daylight quality although this is stronger than the originally observed relationship. Among those who report frequent glare from daylight, the relationship between satisfaction with daylight quality and the desire for more control over daylight is 53 percentage points, slightly stronger than the originally observed relationship (47 percentage points). A stronger relationship, 58 percentage points, is observed among those who report infrequent glare from daylight, indicating that dissatisfaction with daylight is likely to spur the desire for more control over daylight irrespective of feelings of discomfort. Taken together, these results indicate that each of these items measure glare tolerance and glare sensitivity in a similar manner, suggesting they may be appropriate to include in the final index.

Table 46: Percentage table showing trivariate relationship between Q14-2 Desire for more control over daylight, Q14-1 Reported frequency of problematic glare and Q50 Satisfaction with daylight quality.

Q14 More Daylight Controls - Agree

		Q14 Glare from Daylight	
		Frequent	Infrequent
Q50 Daylight Quality	Satisfied	46.67%	12.20%
	34.47%	(15)	(41)
	Dissatisfied	100.00%	70.00%
	30.00%	(3)	(20)
		53.33%	*57.80%*

Next, the relationships between the number of reported source of discomfort listed in response to item measures included in Q29, the desire for more control over daylight (Q14-2), and respondents' satisfaction with daylight quality (Q50-1) are examined in order to compare between the relationships seen in Table 46 and assess reliability of the self-reported glare measure in Q14. This comparison is expected to show that respondents who report less than 3 sources of discomfort and desire more control over daylight are less likely to be satisfied with the daylight quality, indicating sensitivity to glare. In addition, respondents who report at least 3 sources of discomfort but do not desire more control over daylight are expected to be more satisfied with daylight quality, indicating tolerance to glare. Table 47 shows the resulting percentage table and highlights there may be an additional factor influencing the relationships shown herein. As expected, 100% of respondents who report at least 3 sources of discomfort in their workspace and do not want more control over daylight are also satisfied or very satisfied with the daylight quality in their workspace. This result indicates tolerance to glare and supports the observation noted above with a larger sample of responses. In addition, 79.31% of respondents who report less than 3 sources of discomfort and do not want more control over daylight are satisfied or very satisfied with daylight quality, indicating moderate tolerance of glare. The remaining 20.69% of respondents in this quadrant (bottom right) can be described as sensitive to glare due to the disproportionality of the desire for more control and reported sources of discomfort. As expected, among those who report less than 3 sources of discomfort yet desire more control over daylit, only 28.57% are satisfied or very satisfied with daylight quality in their workspace. These responses, and particularly the remaining 71.43% who are dissatisfied with daylight quality, indicate high sensitivity to glare due to the predominant desire for additional remediation of glare despite only reporting a few discomfort sources. Contrary to expectations, 75% of those who report more than 3 sources of discomfort and want more control over daylight are also satisfied or very satisfied with daylight quality in their workspace. These responses indicate apparent moderate sensitivity to glare. Among those who report at least 3 sources of discomfort in their workspace the relationship between desire for more control over daylight and satisfaction with daylight quality is 25 percentage points, significantly less than originally observed (53 percentage points) but still shows a similar trends in satisfaction between those who do and do not want more control over daylight. A stronger relationship, 51 percentage points, is observed among those who report fewer than 3 sources of discomfort. Among those who want more control over daylight in their workspace, the relationship between satisfaction with daylight quality and the number of reported sources of discomfort is 46 percentage points, similar to the strength of the originally observed relationship (40 percentage points) but in this case those reporting at least 3 sources of discomfort are more likely to be satisfied or very satisfied with daylight quality in their workspace. A weaker relationship, 21 percentage points, is observed among those who do not want more control over daylight in their workspace. This result seems to indicate that those respondents who do not want more control over daylight remain satisfied with the daylight quality due to other reasons, perhaps related to the perceived level of control they already have over daylight in their workspace.

Table 47: Percentage table showing trivariate relationship between Q50-1 Satisfaction with daylight quality, Q14-2 Desire for more control over daylight and Q29 number of reported sources of daylight discomfort.

Q50 Daylight Quality - Satisfied

		Q14 More Control over Daylight	
		Agree	Disagree
Q29 # of Discomfort Indicators	At least 3	75.00%	100.00%
	-25.00%	(8)	(21)
	Less than 3	28.57%	79.31%
	-50.74%	(21)	(29)
		-46.43%	*-20.69%*

The next test is constructed in order to examine the role perceived level of control over glare from daylight has on the relationship between the number of reported sources of discomfort (Q29) and the desire for more control over daylight. This comparison is expected to show that respondents who report less than 3 sources of discomfort and desire more control over daylight will be less likely to perceive moderate or high level of control over glare from daylight, indicating sensitivity to glare, than those respondents who report at least 3 sources of discomfort and do not desire more control over daylight, indicating tolerance to glare. Of those respondents who do not desire more control over daylight and do not already perceive moderate or high level of control over glare, respondents who report at least 3 sources of discomfort are exhibiting more significant tolerance of glare than those who report less than 3 source of discomfort. Table 48 show the resulting percentage table from which it can be seen that perceived level of control over glare from daylight affects the relationship between number of sources of discomfort and desire for more control over daylight in both expected and unexpected ways. As expected, a minority of respondents who want more control over daylight in their workspace perceive themselves to have a high level of control over glare from daylight. A higher proportion, 50%, of those who report at least 3 sources of discomfort and desire more control over daylight perceive higher level of control than those who report fewer sources of discomfort, 23.81%. These responses indicate sensitivity to glare, as they can be interpreted to say that while they already think they have a relatively high level of control over glare from daylight they would like more control nonetheless. This is especially true of those who report fewer sources of discomfort. As expected, a majority of respondents who do not want more control over daylight in their workspace already perceive themselves to have a high level of control over glare from daylight. These responses indicate tolerance of glare, particularly for those respondents who are not shown here but perceive low levels of control over glare, report at least 3 sources of discomfort and yet still do not desire more control over daylight (inverse of the bottom left, 42.86%). Among those who want more control over daylight the relationship between perceived level of control over glare from daylight and number of reported sources of discomfort is 26 percentage points, stronger than observed in the original bivariate relationship (14 percentage points). However, the observed relationship among those who want more control over daylight is flipped from the original whereby a higher proportion of those who report at least 3 sources of discomfort perceive higher levels of control over glare from daylight than those who report fewer sources of discomfort. A weaker and similar relationship, 5 percentage points, is observed among those who do not desire more control over daylight. Among those who report at least 3 sources of discomfort in their workspace the relationship between the desire for more control over daylight and their perceived level of control over glare from daylight is 7 percentage points, weaker than originally observed (22 percentage points) yet similar in that a higher portion of respondents who do not want more control over daylight perceive high level of control compared to those who do want more control. A stronger and similar relationship, 28 percentage points, is observed among those to report fewer than 3 sources of discomfort.

Table 48: Percentage table showing trivariate relationship between Q49-3 Perceived level of control over glare from daylight, Q29 reported number of sources of discomfort from daylight and Q14-2 Desire for more control over daylight.

Q49 Glare Control - High

		Q29 # of Discomfort Indicators	
		At least 3	Less than 3
Q14 More Control over Daylight	Agree	50.00%	23.81%
	26.19%	(8)	(21)
	Disagree	57.14%	51.72%
	5.42%	(21)	(29)
		7.14%	*27.91%*

This seems to indicate that existing perceptions about environmental controls have a smaller impact on reasoning about how to remediate discomfort when more sources of discomfort are reported to occur more frequently. In this regard, perceived level of control over glare from daylight is a useful indication of tolerance or sensitivity to glare when combined with measures about the frequency of glare or the respondents' preferred response to discomfort. This can be seen in the example shown in Table 49 whereby a stronger relationship between reporting to use a source adaptation (Q52-11 Open/close the shades partially) and the desire for more control over daylight (Q14-2) occurs when perceived level of control over glare from daylight is included than originally seen in the bivariate relationship (Table 50).

Table 49: Percentage table showing trivariate relationship between Q49-3 Perceived level of control over glare from daylight, Q52-11 Open/close shades partially in response to discomfort and Q14-2 Desire for more control over daylight.

Q49 Glare Control - High/Mod

		Q52 Shades Open/Close partially	
		at least sometimes	rarely or never
Q14 More Control over Daylight	Agree	36.36%	27.78%
	8.59%	(11)	(18)
	Disagree	65.38%	41.67%
	23.72%	(26)	(24)
		29.02%	*13.89%*

Table 50: Percentage table showing bivariate relationship between Q52-11 Open/close shades partially in response to discomfort and Q14-2 Desire for more control over daylight.

		Q52 Shades Open/Close partially	
		at least sometimes	rarely or never
Q14 More Daylight Controls	Agree	29.73%	42.86%
	Disagree	70.27%	57.14%
	-13.13%	100.00%	100.00%
		(37)	(42)

Expanding on this notion about the effect of number of sources and frequency of discomfort, the next tests examines the relationship between the number of sources of discomfort reported in Q29, the reported frequency of problematic glare from daylight (Q14-1) and the reported frequency of behavioral response including using shades to partially occlude the window in response to discomfort (Q52-11) and moving one's seated position in response to discomfort (Q52-4). This first comparison is expected to show that those who report that glare is a frequent issue and at least sometimes use the shades to partially occlude the window will be more likely to report more sources of discomfort. Further, those who report that glare is not a frequent issue and rarely or never use the shades will be less likely to report more than 3 sources of discomfort. Table 51 shows the resulting percentage table. As expected, among respondents who frequently experience glare from daylight and at least sometimes partially occlude their windows in response to discomfort, more than 80% report at least 3 sources of discomfort. Additionally, among respondents who infrequently experience glare from daylight and rarely or never partially occlude their windows in response to discomfort, only 7.69% report at least 3 discomfort glare indicators. These responses are indicative of moderate sensitivity (top left) and moderate tolerance (bottom right) to glare due to the relative proportionality of response to perceived environmental lighting condition. Among respondents who report frequent glare from daylight and rarely or never partially occlude their windows, 66.67% report at least 3 discomfort glare indicators. This response is indicative of tolerance to glare. A lower percentage of respondents, 54.55%, who report infrequent glare from daylight and at least sometimes partially occlude their windows also report at least 3 sources of discomfort. The respondents in this category, as well as those who report less than 3 sources of discomfort from daylight and still occlude their windows, display indications of glare sensitivity. Among those who report frequent glare the relationship between partial window occlusion and number of discomfort glare indicators is 13 percentage points, significantly less than originally observed (53 percentage points). However, among those who report infrequent glare from daylight the observed relationship, 47 percentage points, is similar to the original observation. In that regard, it is clear that window occlusion displays a stronger relationship to number of discomfort indicators among respondents who infrequently experience glare from daylight than among respondents who frequently experience glare from daylight. Among those respondents who at least sometimes partially occlude their window the relationship between the number of reported discomfort glare indicators and the reported frequency of glare from daylight is 26 percentage points, weaker than the original observation (40 percentage points) but still similar. A strong relationship, 59 percentage points, is seen among those respondents who report to rarely or never occlude their windows. This result seems to indicate that glare may be underreported or perhaps unrecognized among respondents that at least sometimes occlude their windows and report at least 3 sources of discomfort from daylight.

Table 51: Percentage table showing trivariate relationship between Q29 Number of sources of discomfort from daylight, Q52-11 Open/close shades partially in response to discomfort and Q14-1 Frequency of problematic glare from daylight.

Q29 Reported Sources of Discomfort ≥3

		Q52 Shades Open/Close partially	
		at least sometimes	rarely or never
Q14 Glare from DL	Frequent	80.00%	66.67%
	13.33%	(15)	(3)
	Infrequent	54.55%	7.69%
	46.85%	(22)	(39)
		-25.45%	*-58.97%*

The relationships documented in the above example are not expected to change significantly when the behavioral response is a subject rather than source adaptation, except that tolerance to glare is indicated by at least sometimes displaying the subject behavior and higher tolerance is exhibited when more frequent glare or more sources of discomfort are reported. Table 52 shows the resulting percentage table and while many similarities exist between the previous examples, some important distinctions emerge. As expected, among respondents who report frequent glare from daylight and at least sometimes move their seated position in response, 88.89% report more than 3 sources of discomfort glare are at least sometimes present in their workspace. This response indicates tolerance of glare. In addition, of those respondents who report frequent glare from daylight and rarely or never move their seated position in response, 66.67% report more than 3 sources of discomfort glare are present in their workspace at least sometimes. This response does not necessarily indicate glare sensitivity, unless a source adaptation was used in lieu of this subject adaptation. Among respondents who report infrequent glare from daylight and at least sometimes move their seated position in response to discomfort, 28.57% report at least 3 source of discomfort glare are at least sometimes present in their workspace. This response indicates moderate tolerance of glare, though whether this tolerance occurs at the perceptual level (not recognizing sources of glare as uncomfortable) or the behavioral level (by utilizing a subject adaptation) is unclear. Among respondents who both infrequently experience glare from daylight and rarely or never move their seated position, 23.4% indicate that at least 3 sources of discomfort glare are at least sometimes present in their workspace. Again, whether this response indicates tolerance of glare is unclear because source adaptations may still take place in lieu of this subject adaptation. Among those who report frequent glare from daylight the relationship between adjustments in seated position and number of discomfort glare sources is 22 percentage points, nearly identical to the originally observed relationship (22 percentage points). However, a much weaker relationship, 5 percentage points, is observed among those who report infrequent glare from daylight. This could show that when glare doesn't occur frequently, the number of different sources of discomfort glare does not significantly affect the behaviors that occupants express. Among those who report at least sometimes adjusting their seated position in response to discomfort the relationship between the number of sources of discomfort and the frequency of glare from daylight is 60 percentage points, stronger than the originally observed relationship (40 percentage points). A similarly strong relationship, 43 percentage points, is observed among those respondents who rarely or never adjust their seated position in response to discomfort. This result seems to indicate that the use of a subject adaptation is, in contrast to the use of a source adaptation, more strongly related to the actual / reported environmental conditions.

Table 52: Percentage table showing trivariate relationship between Q29 Number of sources of discomfort from daylight, Q52-4 Move seated position in response to discomfort and Q14-1 Frequency of problematic glare from daylight.

Q29 Reported Sources of Discomfort ≥3

		Q52 Move seated position	
		at least sometimes	rarely or never
Q14 Glare from DL	Frequent	88.89%	66.67%
	22.22%	(9)	(9)
	Infrequent	28.57%	23.40%
	5.17%	(14)	(47)
		-60.32%	*-43.26%*

While the previous test cases demonstrate the apparent differences between those who utilize source and subject adaptations, they raise the question of whether these behaviors are linked. If they are linked, that is, if those respondents who report to utilize a subject adaptation in response to discomfort also report to use source adaptations in response to discomfort, then in order to include these item measures in the index there must be some way to differentiate tolerance of glare from sensitivity to glare. The following test compares respondents who report using their shades to partially occlude the window as well as adjusting their seated position in response to discomfort with the number of reported sources of discomfort from daylight. This comparison is expected to show that respondents who report more sources of discomfort will be more likely to display both source and subject adaptations but that those who do not report adjusting their seated position will be more likely to use their shades than those who report adjusting their seated position at least sometimes. Table 53 shows the results of this comparison, and contrary to expectations, among respondents who report at least 3 source of discomfort from daylight and who at least sometimes adjust their seated position in response to discomfort, 91.67% indicate that they also at least sometimes partially occlude their window in response to discomfort. The inverse of this response, those who do not partially occlude their windows, indicates tolerance to glare but this is only seen in 1 response. As expected, of those respondents who report at least 3 sources of discomfort and rarely or never adjust their seated position in response to discomfort, 76.47% at least sometimes partially occlude their windows, indicating moderate sensitivity to glare. Among those who report less than 3 sources of discomfort and at least sometimes adjust seated position in response to discomfort, only 36.36% report at least sometimes partially occluding their window in response to discomfort. The remaining responses that rarely or never partially occlude their window in response to discomfort indicate moderate tolerance to glare. In addition, 23.08% of respondents who report less than 3 sources of discomfort and rarely or never adjust seated position at least sometimes partially occlude the window in response to discomfort. This result indicates high glare sensitivity because the respondent reports source adaptations but no subject adaptations and indicates only a minimum of discomfort sources. Among those who report at least 3 sources of discomfort from daylight the relationship between adjustments in seated position and partially occluding the window in response to discomfort is 15 percentage points, only slightly less than originally observed (22 percentage points) but not altogether dissimilar. A similar relationship, 13 percentage points, is seen among those who report fewer than 3 sources of discomfort, perhaps indicating that the mechanism controlling the expression of subject adaptations is linked to that of source adaptations - that exhibiting one type of adaptation in response to discomfort increases the likelihood that an individual will display another type of adaptation, maybe in the case of disabling or salient glare events. Among those who report at least sometimes adjusting their seated position in response to discomfort the relationship between at least sometimes partially occluding the window and the number of discomfort glare indicators is 55 percentage points, similar to the originally observed relationship (53 percentage points). A nearly identical relationship, 53 percentage points, is observed among those who rarely or never adjust their seated position in response to discomfort. These results demonstrate much stronger relationships between window occlusion and number of discomfort glare indicators than are seen when reported frequency of discomfort glare is included in the sample (13 - 47 percentage points among those reporting frequent and infrequent glare from daylight).

Table 53: Percentage table showing trivariate relationship between Q52-11 Open/closed shades partially, Q52-4 Adjust seated position and Q29 number of reported sources of discomfort from daylight.

Q52 Shades Open/Close Partially

		Q52 Move seated position	
		at least sometimes	rarely or never
Q29 # of Discomfort Indicators	At least 3	91.67%	76.47%
	15.20%	(12)	(17)
	Less than 3	36.36%	23.08%
	13.29%	(11)	(39)
		-55.30%	*-53.39%*

While using subject adaptations and source adaptation are somewhat related, the previous test showed moderate differences between them indicating that they can be useful measures of tolerance or sensitivity when combined with measures of environmental conditions. The last tests included in this analysis explore the relationship between type of adaptive response, number of reported sources of discomfort and satisfaction with daylight quality in order to determine the extent to which respondents' positive appraisal affects what behaviors are reported in response to discomfort. These tests are expected to show that respondents who report higher number of sources of discomfort and rarely or never exhibit source or subject adaptations are more likely to be satisfied with daylight quality than those who report to use source or subject adaptations in response to discomfort. The results of the first test, including shade use as the target behavioral response, are seen in Table 54. Contrary to expectations, respondents who report the lowest satisfaction with daylight quality, 48.65%, are those who report less than 3 sources of discomfort glare present in their workspace and who rarely or never partially occlude their windows in response to discomfort. This response should indicate moderate tolerance to glare but in this case there seems to be a similar portion of respondents dissatisfied as there are satisfied, potentially questioning the role satisfaction with daylight has in relation to actual environmental conditions and whether satisfaction with daylight is a function of the number of sources of discomfort or a function of the perception that those sources of glare can be remediated somehow. This result seems to suggest the latter. Among those who report at least 3 sources of discomfort present in their office and at least sometimes partially occlude their windows, 95.83% report being satisfied or very satisfied with the daylight quality in their workspace. This response indicates moderate sensitivity to glare, but the effects of that apparent sensitivity on overall appraisal of lighting conditions seems to be limited. Contrary to expectations, although not necessarily a contradiction, among those who report less than 3 sources of discomfort present in their office and at least sometimes partially occlude their windows, 84.62% report being satisfied or very satisfied with the daylight quality in their workspace. This response indicates high sensitivity to glare due to the disparity between reported conditions and behavioral responses, but it also underscores the question posed above. Among those who report at least 3 sources of discomfort present in their office the relationship between partially occluding the window in response to discomfort and satisfaction with daylight quality is 16 percentage points, much weaker than the originally observed relationship (48 percentage points). A stronger and similar relationship to the original, 36 percentage points, is observed among those who report less than 3 source of discomfort present in their workspace however. This suggests that satisfaction with daylight has little bearing on the relationship between environmental conditions and the use of source adaptations when there are more than 3 sources of discomfort reported. This result could also highlight a tendency among glare sensitivity respondents to over report the severity or frequency of discomfort sources in their workspace. Among those who report at least sometimes partially occluding their window in response to discomfort, the relationship between satisfaction with daylight quality and number of reported sources of discomfort present in the workspace is 11 percentage points, significantly weaker and dissimilar from the originally observed relationship (53 percentage points) where respondents reporting fewer discomfort sources also reported higher satisfaction with daylight quality. A stronger, but again dissimilar relationship, 31 percentage points, is observed among those who rarely or never partially occlude their window in response to discomfort. The small sample of respondents who rarely or never occlude their window and report more than 3 source of discomfort (n=5) could account for this result, but also underscores the strong relationship between number of reported sources of discomfort and the use of shades to partially occlude the window in response to discomfort.

Table 54: Percentage table showing trivariate relationship between Q50-1 Satisfaction with daylight quality, Q52-11 Open/close shades partially in response to discomfort and Q29 number of reported sources of discomfort from daylight.

Q50 Daylight Quality - Satisfied

		Q52 Shades Open/Close partially	
		at least sometimes	rarely or never
Q29 # of Discomfort Indicators	At least 3	95.83%	80.00%
	15.83%	(24)	(5)
	Less than 3	84.62%	48.65%
	35.97%	(13)	(37)
		-11.22%	*-31.35%*

The next test examines the dynamics above with regards to subject adaptations. If the choice to use subject adaptations in lieu of source adaptations is indeed indicative of tolerance to glare, then this test should produce different results from the previous. In particular, this test is expected to show that those who rarely or never exhibit the subject adaptation report higher overall satisfaction with daylight quality irrespective of the number of reported sources of discomfort from daylight. This expectation is confirmed in the results shown in Table 55, which shows that 100% of respondents who report rarely or never adjusting their seated position in response to discomfort and report at least 3 sources of discomfort are satisfied with daylight quality in their workspace. In accordance with previous results shown in Table 53 above, 23.53% of those respondents also report to rarely or never use the shades to partially occlude the window in response to daylight, indicating high tolerance of glare. This result shows an opposite dynamic observed in the previous test whereby higher satisfaction with daylight quality is seen among those who report using their shades to partially occlude the window more frequently. Contrary to expectations, those who report fewer than 3 sources of discomfort are less likely to be satisfied with daylight quality than those who report 3 or more sources of discomfort. Among those who at least sometimes adjust their seated position, the relationship between satisfaction with daylight and number of discomfort indicators present in the workspace is 38 percentage points, weaker than the original observation (53 percentage points) although in this comparison those who report more sources of discomfort are nearly twice as likely to be satisfied or very satisfied with daylight quality than those who report fewer sources of discomfort. A similar relationship and trend, 39 percentage points, is observed among those who rarely or never adjust their seated position. This same trend is observed among those who report rarely or never using source adaptations in Table 54, perhaps indicating that utilizing a source adaptation may result in a weaker relationship between sources of discomfort and satisfaction with daylight. Responses in the bottom left quadrant of the percentage table in Table 54 indicate sensitivity to glare where as those in the top right indicate tolerance to glare. In the previous test case above satisfaction with daylight quality seems to result from the use of the source adaptation, whereas in this test satisfaction with daylight seems to increase among those who do not use the subject adaptation (indicating tolerance to glare). These results suggest that respondents' satisfaction with daylight quality is an unclear and inconsistent indicator of glare tolerance or sensitivity when combined with reported behavioral responses to discomfort.

Table 55: Percentage table showing trivariate relationship between Q50-1 Satisfaction with daylight quality, Q52-4 Adjust seated position in response to discomfort and Q29 number of reported sources of discomfort from daylight.

Q50 Daylight Quality - Satisfied

		Q52 Move seated position	
		at least sometimes	rarely or never
Q29 # of Discomfort Indicators	At least 3	83.33%	100.00%
	-16.67%	(12)	(17)
	Less than 3	45.45%	61.54%
	-16.08%	(11)	(39)
		-37.88%	*-38.46%*

In sum, many of the relationships between the item measures examined above showed important variations that in some cases confirmed expectations regarding measures that indicate sensitivity or tolerance of glare. The relationships between satisfaction with daylight quality (Q50-1), frequency of problematic glare (Q14-1), and the desire for more control over daylight (Q14-2) indicate glare tolerance and sensitivity as expected. The perceived level of control over glare from daylight (Q49-3) and the desire for more control over daylight (Q14-2) indicate glare tolerance and sensitivity as expected but important dimensions of tolerance and sensitivity are identified when these item measures are combined with reported number of sources of discomfort (Q29) and reported behavioral response to discomfort (Q52). Lastly, the reported number of sources of discomfort (Q29), frequency of glare (Q14-1), and reported behavioral responses to discomfort (Q52) indicates tolerance and sensitivity to glare as expected.

Index Construction

The results of the multivariate analysis identify item measures indicating tolerance and sensitivity to glare as expected by the conceptual model. This section will show the index construction according to those results and show internal and external validity of the index results. The series of item measure pairs shown in Table 56 are used to tally respondents' tolerance or sensitivity to glare using the scoring metrics indicated at the top of the table on a scale of 1 (most tolerant) to 4 (most sensitive). A summary of internal validity tests for each these parameters are shown using percentage tables in Table 57. As can be seen, parameters 1 and 3 are displaying identical results and are thus the two parameters are not adding anything to the overall index when they are reported separately. Based on these results and the previously demonstrated weakness of satisfaction with daylight quality (Q50-1) to meet expectation, parameter 1 is not included in the final index tabulation resulting in a final index scale ranging from 0.75 (most tolerant) to 3 (most sensitive). For the purposes of the validity tests and cluster analysis to follow, index rankings higher than 1.5, which are only possible if at least one parameter is rated sensitive, are grouped with higher rankings indicating sensitivity to glare. Parameter 3 does not show strong relationships between either parameter 2 or parameter 4 but the results of the internal validity test in Table 57 shows that the parameters tend to agree in terms of measuring tolerance and sensitivity to glare. This result is not ideal in terms of likely strength of the index to consistently assess glare sensitivity, but shortcomings in the questionnaire design may limit the reliability of the index overall to measure tolerance and sensitivity consistently.

Table 56: Index parameters based on paired item measures indicating sensitivity or tolerance to glare.

	Sensitive		Tolerant	
	+ 0.75	+ 1	+ 0.5	+ 0.25
[P1] Q50-1 Satisfaction with Daylight Quality	*Dissatisfied*	*Satisfied*	*Satisfied*	*Dissatisfied*
[P1] Q14-2 Desire more control over Daylight	*Agree*	*Agree*	*Disagree*	*Disagree*
[P2] Q29 Number of report sources of discomfort	*≥ 3*	*< 3*	*< 3*	*≥ 3*
[P2] Q14-1 Frequency of problematic glare	*Frequent*	*Frequent*	*Infrequent*	*Infrequent*
[P3] Q49-3 Perceived Control over Glare from Daylight	*Low / None*	*Mod / High*	*Mod / High*	*Low*
[P3] Q14-2 Desire more control over Daylight	*Agree*	*Agree*	*Disagree*	*Disagree*
[P4] Q52-11 Open/close shades partially	*≥ sometimes*	*≥ sometimes*	*Rarely/Never*	*Rarely/Never*
[P4] Q52-4 Adjust seated position	*Rarely/Never*	*≥ sometimes*	*Rarely/Never*	*≥ sometimes*

Table 57: Results of internal validity test for initial index parameters.

Internal Validity		Parameter 1		Parameter 2		Parameter 3		Parameter 4	
		Tolerant (≤ 0.5)	Sensitive (> 0.5)	Tolerant (≤ 0.5)	Sensitive (> 0.5)	Tolerant (≤ 0.5)	Sensitive (> 0.5)	Tolerant (≤ 0.5)	Sensitive (> 0.5)
Parameter 1	Tolerant (≤ 0.5)	-	-	*68.85%*	*44.44%*	*100.00%*	*0.00%*	*57.14%*	*70.27%*
	Sensitive (> 0.5)	-	-	*31.15%*	*55.56%*	*0.00%*	*100.00%*	*42.86%*	*29.73%*
	strength	**-**		**24.41%**		**100.00%**		**-13.13%**	
Parameter 2	Tolerant (≤ 0.5)	*84.00%*	*65.52%*	-	-	*84.00%*	*65.52%*	*92.86%*	*59.46%*
	Sensitive (> 0.5)	*16.00%*	*34.48%*	-	-	*16.00%*	*34.48%*	*7.14%*	*40.54%*
	strength	**18.48%**		**-**		**18.48%**		**33.40%**	
Parameter 3	Tolerant (≤ 0.5)	*100.00%*	*0.00%*	*68.85%*	*44.44%*	-	-	*57.14%*	*70.27%*
	Sensitive (> 0.5)	*0.00%*	*100.00%*	*31.15%*	*55.56%*	-	-	*42.86%*	*29.73%*
	strength	**100.00%**		**24.41%**		**-**		**-13.13%**	
Parameter 4	Tolerant (≤ 0.5)	*48.00%*	*62.07%*	*63.93%*	*16.67%*	*48.00%*	*62.07%*	-	-
	Sensitive (> 0.5)	*52.00%*	*37.93%*	*36.07%*	*83.33%*	*52.00%*	*37.93%*	-	-
	strength	**-14.07%**		**47.27%**		**-14.07%**		**-**	

Results of external validity tests show that results of individual parameters are strongly related to specific corresponding measures in the questionnaire data. The relationship between Parameter 2, comprised of item measures including the number of reported sources of discomfort from daylight in Q29 and frequency of problematic glare (Q14-1), and Q50-7 Satisfaction with glare from daylight is 33 percentage points (Table 58). As expected, respondents rated as tolerant are more likely to express satisfaction with glare from daylight than those rated as sensitive. While respondents rated as tolerant by Parameter 2 are only slightly more likely to express dissatisfaction than satisfaction with glare from daylight, respondents rated as sensitive are significantly more likely to express dissatisfaction with glare from daylight. The relationship between Parameter 3, comprised of item measures including perceived level of control over glare from daylight (Q49-3) and desire for more control over daylight (Q14-2), and Q50-4 Satisfaction with level of control over daylight is 48 percentage points (Table 59). As expected, respondents rated as tolerant by Parameter 3 are more likely to express satisfaction with the level of control over daylight than those rated as sensitive. In addition, respondents rated as tolerant are significantly more likely to express satisfaction than dissatisfaction with level of control over daylight while respondents rated as sensitive by Parameter 3 are significantly more likely to be dissatisfied with their level of control over daylight. Respondents rated as tolerant by Parameter 4, which comprises reported use of subject adaptations (adjusting seat position) and source adaptations (partially occluding the window), are expected to be more likely to report using another subject adaptation while those rated as sensitive are expected to be more likely to report using another source adaptation. The results of the external validity test of Parameter 4, showing relationships between Q52-3 and Q52-12, can be seen in Table 60. As expected, those rated as sensitive according to Parameter 4 are more likely to report using another source adaptation (completely occluding their window) at least sometimes in response to discomfort than are those rated as tolerant. Respondents rated as tolerant by Parameter 4 are less likely, however, to report using another subject adaptation (adjusting the computer screen) at least sometimes in response to discomfort than are those rated as sensitive. While this result is not expected, it can be explained in that those rated as tolerant are more likely to not exhibit an adaptive behavior in response to discomfort than those rated as sensitive.

Table 58: Percentage table showing results of external validity test between Parameter 2 and Q50-7 Satisfaction with Glare from Daylight.

		Parameter 2	
		≤0.5 (tolerant)	> 0.5 (sensitive)
Q50-7 Glare from Daylight	Satisfied	44.26%	11.11%
	Dissatisfied	55.74%	88.89%
	33.15%	*100.00%*	*100.00%*
		(61)	(18)

Table 59: Percentage table showing results of external validity test between Parameter 3 and Q50-4 Satisfaction with Level of Control over Daylight

		Parameter 3	
		≤0.5 (tolerant)	> 0.5 (sensitive)
Q50-4 Level of Control over Daylight	Satisfied	82.00%	34.48%
	Dissatisfied	18.00%	65.52%
	47.52%	*100.00%*	*100.00%*
		(50)	(29)

Table 60: Percentage tables showing results of external validity tests between Parameter 4 and Q52-3 Adjust computer screen (top) and Q52-12 Open/close shades completely (bottom).

		Parameter 4	
		≤0.5 (tolerant)	> 0.5 (sensitive)
Q52-3 Adjust computer screen	≥ sometimes	14.29%	48.65%
	rarely or never	85.71%	51.35%
	-34.36%	*100.00%*	*100.00%*
		(42)	(37)

		Parameter 4	
		≤0.5 (tolerant)	> 0.5 (sensitive)
Q52-12 Open/close shades completely	≥ sometimes	7.14%	64.86%
	rarely or never	92.86%	35.14%
	57.72%	*100.00%*	*100.00%*
		(42)	(37)

While each parameter is seen to strongly correspond to similar item measures not included in the index, the results of external validity tests of the final Glare Response & Sensitivity Index demonstrate consistent measurement of tolerant and sensitive outcomes across the same item measures (Table 61). The relationship between index results and satisfaction with glare from daylight (Q50-7) is 22 percentage points, slightly weaker than observed between Parameter 2 and Q50-7. As expected though, respondents rated as tolerant in the final index are more likely to be satisfied with glare from daylight than those rated as sensitive while those sensitive respondents are also more likely to be dissatisfied with glare from daylight than tolerant respondents. A similar result occurs when index results are compared to Q50-4, in that the observed relationship, 11 percentage points, is weaker than seen between Parameter 3 and Q50-4 but tolerant respondents are more likely to report satisfaction with the level of control over daylight than are sensitive respondents. In addition, a higher proportion (41.03%) of sensitive respondents are dissatisfied with their level of control over daylight than seen among tolerant respondents (30%). Index results show strong and very similar results when compared to item measures Q52-3 and Q52-12 regarding likelihood of tolerant and sensitive respondents to report using additional subject or source adaptations.

Table 61: Percentage tables showing results of external validity tests between final Glare Response & Sensitivity Index and Q50-7 (top), Q50-4 (middle, top), Q52-3 (middle, bottom), and Q52-12 (bottom).

		Glare Response & Sensitivity Index	
		<1. 5 (tolerant)	≥1. 5 (sensitive)
Q50-7 Glare from Daylight	Satisfied	47.50%	25.64%
	Dissatisfied	52.50%	74.36%
	21.86%	*100.00%*	*100.00%*
		(40)	(39)
Q50-4 Level of Control over Daylight	Satisfied	70.00%	58.97%
	Dissatisfied	30.00%	41.03%
	11.03%	*100.00%*	*100.00%*
		(40)	(39)
Q52-3 Adjust computer screen	≥ sometimes	20.00%	54.17%
	rarely or never	80.00%	45.83%
	-34.17%	*100.00%*	*100.00%*
		(40)	(39)
Q52-12 Open/close shades completely	≥ sometimes	23.64%	58.33%
	rarely or never	76.36%	41.67%
	-34.70%	*100.00%*	*100.00%*
		(40)	(39)

APPENDIX G

AGGREGATE QUESTIONNAIRE RESPONSES

Q53. I have read and understood the information contained above and desire of my own free will to participate in this study.

#	Answer	Bar	Response	%
1	Yes		93	100%
2	No		0	0%
	Total		93	

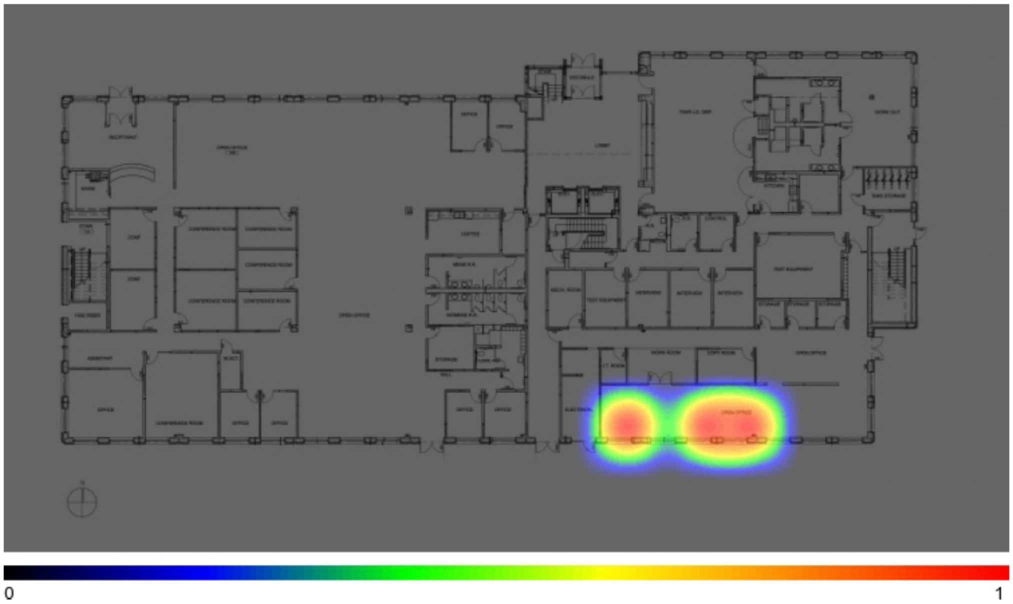
Statistic	Value
Min Value	1
Max Value	1
Mean	1.00
Variance	0.00
Standard Deviation	0.00
Total Responses	93

Q56. On what floor is your primary workspace located?

#	Answer	Bar	Response	%
1	Ground Floor		3	3%
2	Second Floor		2	2%
3	Third Floor		37	40%
4	Fourth Floor		51	55%
	Total		93	

Statistic	Value
Min Value	1
Max Value	4
Mean	3.46
Variance	0.49
Standard Deviation	0.70
Total Responses	93

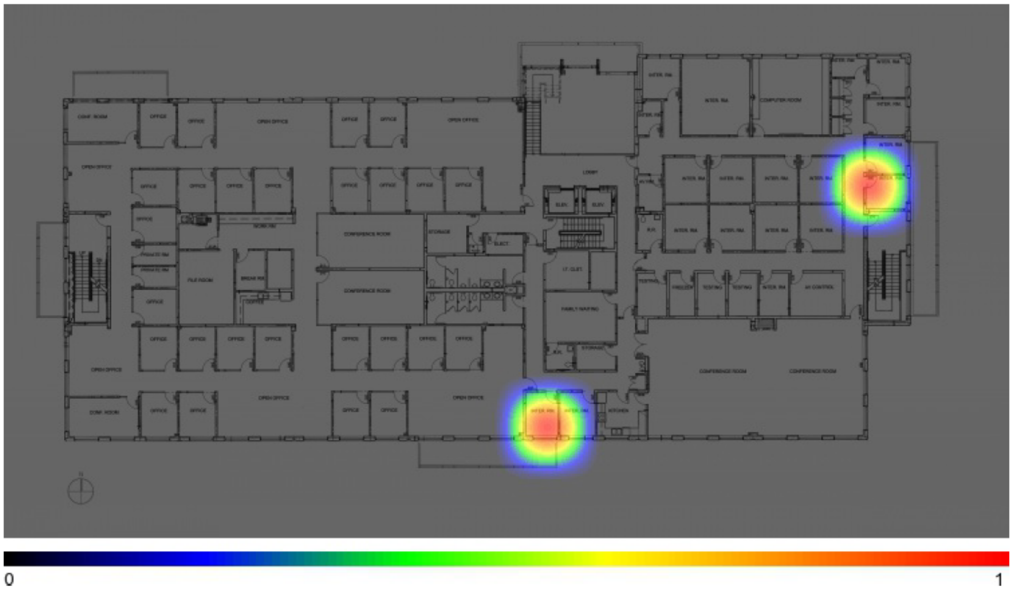
Q57. Please mark the location of your current workspace on the floor plan below.



Region	Bar	Response	%
Other Org. Space		-	0%
ValidRegion		3	100%
Other		-	0%

Statistic	Value
Total Responses	3

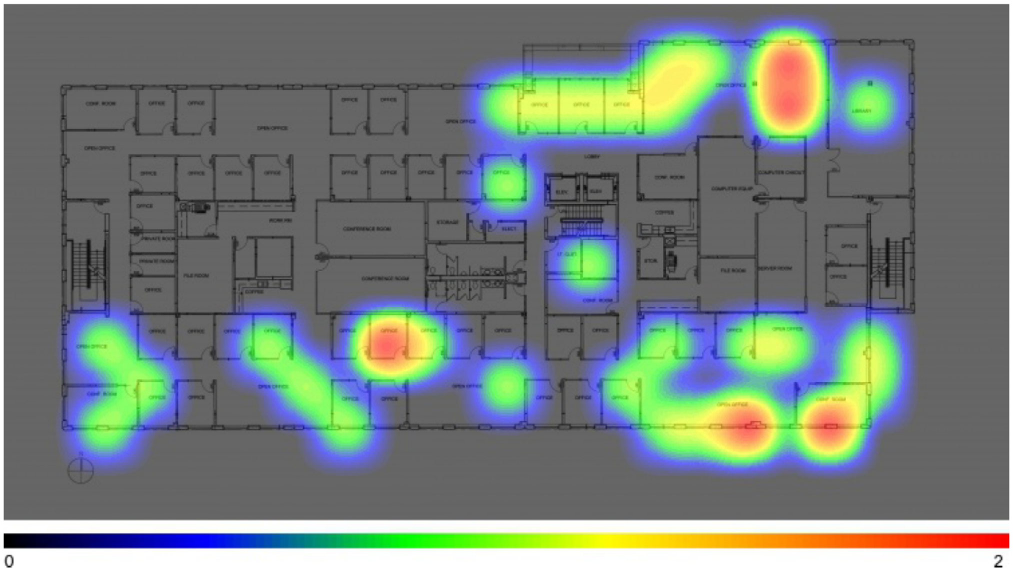
Q59. Please mark the location of your current workspace on the floor plan below.



Region	Bar	Response	%
Other Org. Space		-	0%
Core		-	0%
ValidRegion		2	100%
Other		-	0%

Statistic	Value
Total Responses	2

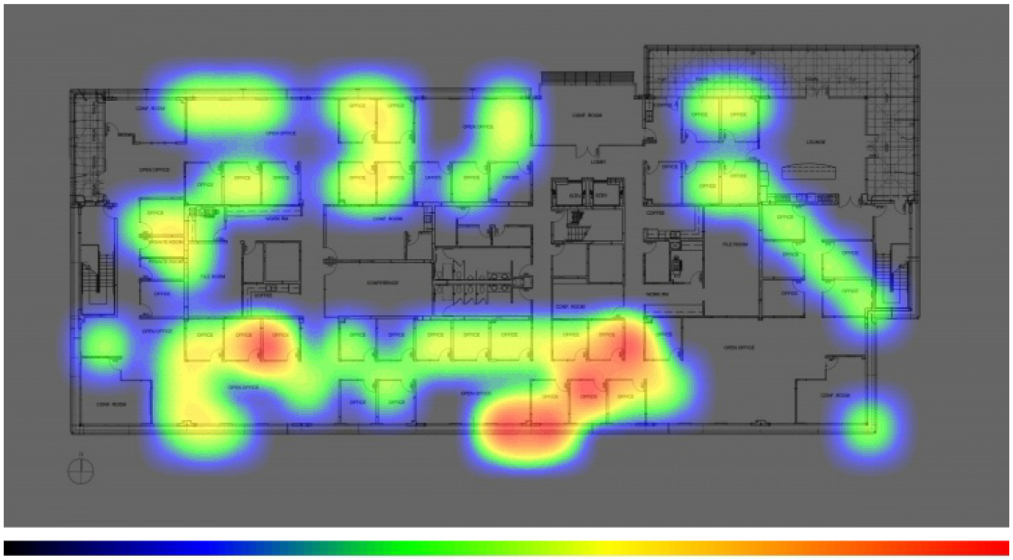
Q58. Please mark the location of your current workspace on the floor plan below.



Region	Bar	Response	%
Other Org. Space		2	6%
Core		1	3%
ValidRegion		36	100%
Other		-	0%

Statistic	Value
Total Responses	36

Q60. Please mark the location of your current workspace on the floor plan below.



Region	Bar	Response	%
Core		-	0%
ValidRegion		50	100%
Other		-	0%

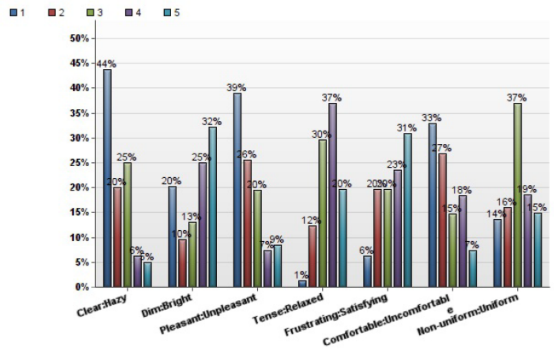
Statistic	Value
Total Responses	50

Q63. How is your primary work area oriented within your workspace?

#	Answer	Bar	Response	%
1	Facing an exterior window		22	25%
2	Facing an exterior wall next to the window		6	7%
3	Facing an interior wall		37	43%
4	Facing an interior window with a view out an exterior window		15	17%
5	Facing an interior window without a view out an exterior window		7	8%
	Total		87	

Statistic	Value
Min Value	1
Max Value	5
Mean	2.76
Variance	1.53
Standard Deviation	1.24
Total Responses	87

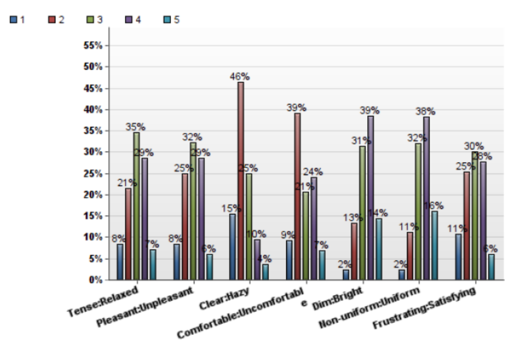
Q7. How would you describe the daylight at your current workspace?



#	Question	1	2	3	4	5	Total Responses	Mean
1	Clear:Hazy	35	16	20	5	4	80	2.09
2	Dim:Bright	17	8	11	21	27	84	3.39
3	Pleasant:Unpleasant	32	21	16	6	7	82	2.21
4	Tense:Relaxed	1	10	24	30	16	81	3.62
5	Frustrating:Satisfying	5	16	16	19	25	81	3.53
6	Comfortable:Uncomfortable	27	22	12	15	6	82	2.40
7	Non-uniform:Uniform	11	13	30	15	12	81	3.05

Statistic	Clear:Hazy	Dim:Bright	Pleasant:Unpleasant	Tense:Relaxed	Frustrating:Satisfying	Comfortable:Uncomfortable	Non-uniform:Uniform
Min Value	1	1	1	1	1	1	1
Max Value	5	5	5	5	5	5	5
Mean	2.09	3.39	2.21	3.62	3.53	2.40	3.05
Variance	1.40	2.31	1.62	0.96	1.65	1.72	1.50
Standard Deviation	1.18	1.52	1.27	0.98	1.29	1.31	1.22
Total Responses	80	84	82	81	81	82	81

Q9. How would you describe the electric lighting at your current workspace?



#	Question	1	2	3	4	5	Total Responses	Mean
1	Tense:Relaxed	7	18	29	24	6	84	3.05
2	Pleasant:Unpleasant	7	21	27	24	5	84	2.99
3	Clear:Hazy	13	39	21	8	3	84	2.39
4	Comfortable:Uncomfortable	8	34	18	21	6	87	2.80
5	Dim:Bright	2	11	26	32	12	83	3.49
6	Non-uniform:Uniform	2	9	26	31	13	81	3.54
7	Frustrating:Satisfying	9	21	25	23	5	83	2.93

Statistic	Tense:Relaxed	Pleasant:Unpleasant	Clear:Hazy	Comfortable:Uncomfortable	Dim:Bright	Non-uniform:Uniform	Frustrating:Satisfying
Min Value	1	1	1	1	1	1	1
Max Value	5	5	5	5	5	5	5
Mean	3.05	2.99	2.39	2.80	3.49	3.54	2.93
Variance	1.13	1.12	0.96	1.25	0.96	0.95	1.21
Standard Deviation	1.06	1.06	0.98	1.12	0.98	0.98	1.10
Total Responses	84	84	84	87	83	81	83

Q65. Is there any other way you would describe the daylight at your current workspace?

Text Response
it's dark
I rely on the outside window for light as a co-worker dims the hallway (including my overhead lights) to a low during the work hours.
Bright indirect light
No natural light in my work space, would really like to have a more natural, bright work environment
Ample daylight. I do receive glare on my workstation and computer monitors during this time of the year.
Wonderful
Variable; Mornings and midday are often bright and clear - afternoon sun can be obnoxious since it shines on my computer screen causing a glare.
There isn't any
Folks with outside windows usually have their blinds partly down so the view from the interior offices is often blocked.....my office is an interior office so I would say...blocked or not always available/visable.
Varies greatly by time of day and year -- sometimes it is great but this time of year I'm having to pull the blinds down to not be squinting
Wish I got more of it!
Modifiable (with blinds)
I work mostly at home, so I chose an unpleasant office that gets NO daylight
I chose my office location to minimize the brightness from outside, because I find sunlight an unpleasant migraine trigger.
Minimal, I have access to daylight through another person's office
Unpredictable
It can be very bright when the sun shines in. My window faces south.
depending on what others on window side of the building are doing (closing doors, closint blinds) it is sometimes much darker and I often don't have a view outside
Minimal since I have no direct line of sight toward daylight with the location of my office.
It's dark, I can't work without turning lights on.
There is no way to control the brightness on sunny days, leading to a glare that triggers headaches for me. The blinds do not adequately shut it out. At the same time, the person in the office across from me (rightfully so) wants access to the light so it feels wrong to keep the blinds closed.
It all depends on the weather outside. I adjust the electric lighting accordingly.
none
I have covered the overhead lighting panel so it doesn't go on and have purchased multiple small lights to make the space warm feeling.
I only get indirect sunlight from the windows in offices across the hall. They usually have their blinds closed. It is unsatisfying.
sometimes,, but not recently, there is a strange yellow globe int he sky that is so bright i can't look at it
There is no direct daylight in my current workspace, though there was meant to be - or rather, I was told there would be.
It's Oregon. I dont' get daylight unless ti's summer or an accidental sunny day.
more of it would be nice
non-existent
enjoyable
Too bright at mid-day but otherwise very nice
Varies greatly from too-bright (making me squint, close blilnds, wear sunglasses) to neutral.
I love having a window in my workspace!!!
I usually have to lower the blinds due to direct sunlight in afternoon
sometimes it has glare that is not acceptable, but I use the shades to accomodate for tthat
Calming
filtered through office window across the hall
Nice
largely non-existent, though if the cubicles across from me open their blinds and sliding doors, then I get a lot more and it is pleasant
In winter causes glare
Two walls are big windows and its fantasitic, if the sun comes in too much the blinds work great; I love it.
I have bright days but mostly pleasant lighting
It is very good. I can work without the lights on in my office until sunset.
I bring the blinds part way down my window to sheild off some of the sky because otherwise it's too bright for my eyes to be comfortable looking at my computer screen. But I've found a balance that allows in enough light but not too much, and retains my nice view.

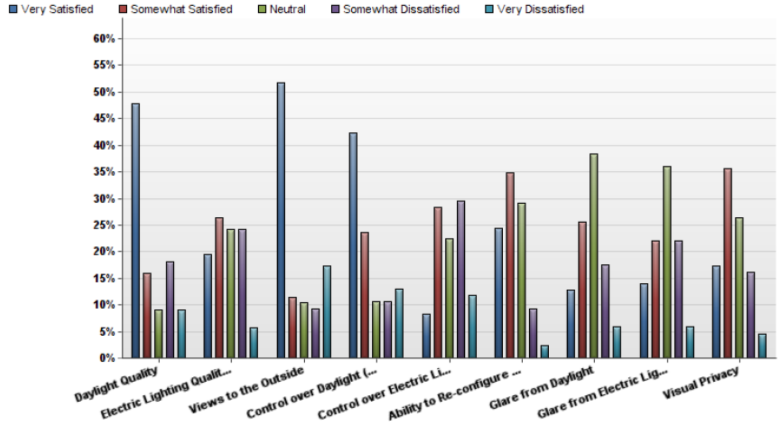
Statistic	Value
Total Responses	45

Q66. Is there any other way you would describe the electric lighting at your current workspace?

Text Response
i use two lamps to avoid the flouresent overhead lights
Mind numbing
My co-worker can't handle the lights on full, so she dims the lights each morning when she comes in. It's ok in the summer but too dim in the winter for me.
harsh
On occassion the electric lighting turns off for no apparant reason.
I only use lamps in my office and do not like the overhead lighting as I feel it is too harsh.
The bulbs are annoying and mess with my vision. Makes seeing blurry and hazy.
I only use task lighting and never turn on the overhead lights.
I use 2 table lamps, not the overhead flourescents
Very harsh -- I don't use it. I have a couple of standing lamps I use instead of the overhead lights.
Bit too bright, very yellow. Fatigue by the end of the day.
Uncontrollable
I really don't like it. I hate the way it turns off every few minutes also.
My positive answers above are from using my floor lamp instead of the lights from the ceiling -- I keep those turned off all the time, and it's annoying that they have an automatic sensor to turn them on, because then I have to get up and turn them off again.
Pleasant. There are enough personal choices (I decide how many overhead lights stay on) to make it comfortable for me.
I prefer natural light to electric light.
Bright
One person on my floor (who has her own exterior office with a window and solid walls) controls the overhead lights for the hallway and those of us in open offices. She consistently keeps the overhead lights on their 'dimmed' setting, something I don't like but I am afraid to talk to her about it because everyone else seems to go along with it. I would rather have the overhead lights be bright, especially when it is gray outside.
satisfactory. I never use the overhead lights, they are horrible
I do not respond well to fluorescent lights. The flickering triggers headaches. I try to keep the light off while I am working
It depends which lights are on (ceiling or lamps) and how many. I answered for the two ceiling lights.
often too bright.
piercing
Harder to maintain my focus and enjoyment of my work space
The overhead lights in the hallway and in my office are glaring and too bright. I keep my office lights turned off, and use two tall lamps and two table lamps. We usually turn the hallway overheads down as much as possible.
i find my light on some times when I come in, though I swear I turned it offf when i left.
Flourescent. Buzzing. Headache inducing. Bothersome. Inadequate. Unfriendly.
It is painful. It causes headaches from squinting and it causes a lot of glare on my computer screen.
i'm right below a light strip, so its beating down on me all day
1/2 on 1/2 off
a bit overpowering
No way to vary the electric lighting in open spaces. Sometimes it's too bright and I wish I could change it. Fluorescent light is cold and makes a high-pitched sound that is annoying.
No way to control individual office lighting
Actually it seems just right.
With all the natural daylight we get in our area there's no need for the electric lighting.
cold
A little too bright at times
designed to my own personal preference...ambiant.
Adjustable
When its daylight I dont want them on at all. When they do come on during the day I dont like it. It's fine at night but not as good.
I dislike flourescent lights
It is timed to shut off every 10-15 minutes after hours. That's terrible when I'm here working. Floor lamp solved the problem.
I have the light bulbs disconnected on the overhead lights so I like that
It nicely supplements the natural daylight.

Statistic	Value
Total Responses	44

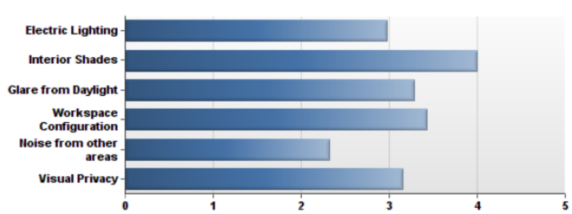
Q50. How would you rate your level of satisfaction with your workspace in the following areas?



#	Question	Very Satisfied	Somewhat Satisfied	Neutral	Somewhat Dissatisfied	Very Dissatisfied	Total Responses	Mean
1	Daylight Quality	42	14	8	16	8	88	2.25
2	Electric Lighting Quality	17	23	21	21	5	87	2.70
3	Views to the Outside	45	10	9	8	15	87	2.29
4	Control over Daylight (blinds, shades, etc.)	36	20	9	9	11	85	2.28
5	Control over Electric Lighting (switching, dimming, etc.)	7	24	19	25	10	85	3.08
6	Ability to Re-configure Workspace (furniture, seating, etc.)	21	30	25	8	2	86	2.30
7	Glare from Daylight	11	22	33	15	5	86	2.78
8	Glare from Electric Lighting	12	19	31	19	5	86	2.84
9	Visual Privacy	15	31	23	14	4	87	2.55

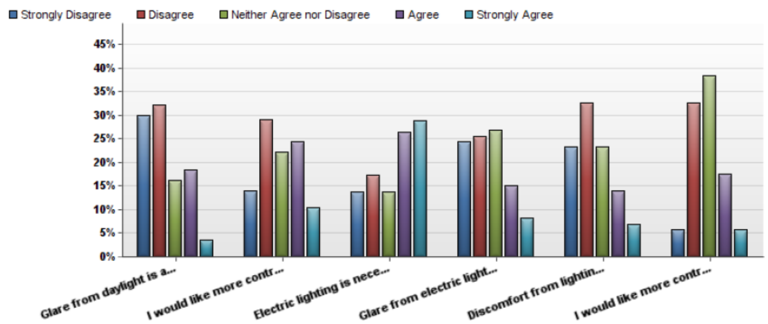
Statistic	Daylight Quality	Electric Lighting Quality	Views to the Outside	Control over Daylight (blinds, shades, etc.)	Control over Electric Lighting (switching, dimming, etc.)	Ability to Re-configure Workspace (furniture, seating, etc.)	Glare from Daylight	Glare from Electric Lighting	Visual Privacy
Min Value	1	1	1	1	1	1	1	1	1
Max Value	5	5	5	5	5	5	5	5	5
Mean	2.25	2.70	2.29	2.28	3.08	2.30	2.78	2.84	2.55
Variance	2.07	1.44	2.49	2.06	1.39	1.04	1.14	1.22	1.20
Standard Deviation	1.44	1.20	1.58	1.44	1.18	1.02	1.07	1.10	1.10
Total Responses	88	87	87	85	85	86	86	86	87

Q49. Please rate the level of control you have over the following aspects of your workspace (1 is No Control and 5 is High Level of Control).



#	Answer	Min Value	Max Value	Average Value	Standard Deviation	Responses
1	Electric Lighting	1.00	5.00	2.98	1.42	87
2	Interior Shades	1.00	5.00	4.00	1.33	83
3	Glare from Daylight	1.00	5.00	3.28	1.38	85
4	Workspace Configuration	1.00	5.00	3.43	1.16	86
5	Noise from other areas	1.00	5.00	2.33	1.27	86
6	Visual Privacy	1.00	5.00	3.15	1.26	87

Q14. Do you agree or disagree with the following statements regarding your current working environment?



#	Question	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Total Responses	Mean
1	Glare from daylight is a frequent issue	26	28	14	16	3	87	2.33
2	I would like more control over daylight	12	25	19	21	9	86	2.88
3	Electric lighting is necessary for my work during the day	12	15	12	23	25	87	3.39
4	Glare from electric lights is a frequent issue	21	22	23	13	7	86	2.57
5	Discomfort from lighting interferes with my work	20	28	20	12	6	86	2.49
6	I would like more control over my workspace arrangement	5	28	33	15	5	86	2.85

Statistic	Glare from daylight is a frequent issue	I would like more control over daylight	Electric lighting is necessary for my work during the day	Glare from electric lights is a frequent issue	Discomfort from lighting interferes with my work	I would like more control over my workspace arrangement
Min Value	1	1	1	1	1	1
Max Value	5	5	5	5	5	5
Mean	2.33	2.88	3.39	2.57	2.49	2.85
Variance	1.41	1.52	2.01	1.54	1.43	0.95
Standard Deviation	1.19	1.23	1.42	1.24	1.20	0.98
Total Responses	87	86	87	86	86	86

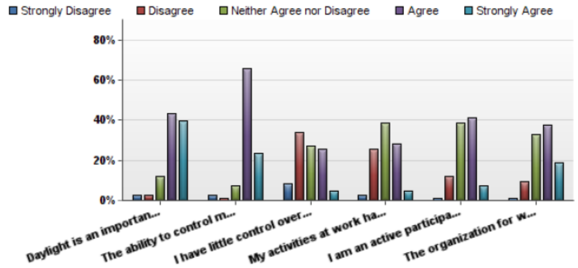
Q6. Please rank the following in order of importance to your workspace environment. (1 is most important; 9 is least important)

#	Answer	1	2	3	4	5	6	7	8	9	Total Responses
1	Daylight Quality	5	12	13	3	7	18	19	6	0	83
2	Electric Lighting Quality	1	7	12	14	13	22	12	2	0	83
3	Views to the Outside	56	8	6	3	4	1	2	3	0	83
4	Control over Daylight (blinds, shades, etc.)	1	25	20	11	15	3	5	3	0	83
5	Control over Electric Lighting (switching, dimming, etc.)	3	11	9	11	17	14	10	8	0	83
6	Ability to Re-configure Workspace	4	8	13	15	14	11	10	6	2	83
7	Glare-free Working Environment	8	2	3	13	8	6	5	37	1	83
8	Visual Privacy	5	10	7	10	5	8	20	18	0	83
10	Other (please specify)	0	0	0	3	0	0	0	0	80	83
	Total	83	83	83	83	83	83	83	83	83	-

Other (please specify)
Quiet
this part of survey does not work -- the ratings are not mine
couldn't set responses properly; here's my ranking: 1=views to outside, 2=daylight quality, 3=electric light quality, 4=glare-free working environment, 5=control over electric lighting, 6= control over daylight, 7=ability to reconfigure workspace, 8=visual privacy
I can't figure out how to change these numbers
quiet environment
glare off of metal shelf outside window on 4th floor south
Wish for hallway/door noise reduction at times.
I'm not sure how use this part of the survey
noise
noise

Statistic	Daylight Quality	Electric Lighting Quality	Views to the Outside	Control over Daylight (blinds, shades, etc.)	Control over Electric Lighting (switching, dimming, etc.)	Ability to Re-configure Workspace	Glare-free Working Environment	Visual Privacy	Other (please specify)
Min Value	1	1	1	1	1	1	1	1	4
Max Value	8	8	8	8	8	9	9	8	9
Mean	4.87	4.87	2.00	3.70	4.81	4.71	5.89	5.34	8.82
Variance	4.75	2.77	3.46	2.94	3.86	4.06	5.85	5.47	0.88
Standard Deviation	2.18	1.67	1.86	1.72	1.97	2.02	2.42	2.34	0.94
Total Responses	83	83	83	83	83	83	83	83	83

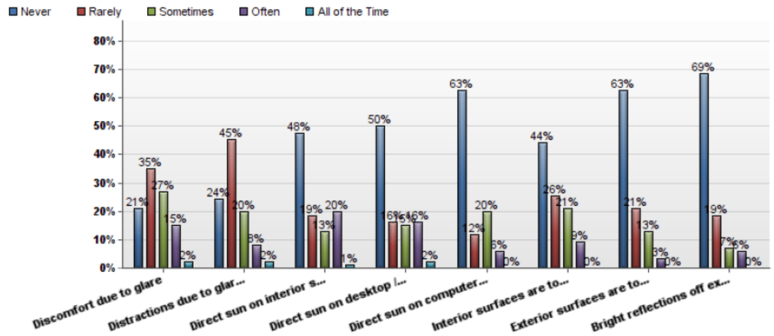
Q61. Do you agree or disagree with the following statements regarding your current working environment?



#	Question	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Total Responses	Mean
6	Daylight is an important aspect of my workspace	2	2	10	37	34	85	4.16
7	The ability to control my environment is an important aspect of my workspace	2	1	6	56	20	85	4.07
8	I have little control over the amount of energy I use while at work	7	29	23	22	4	85	2.85
9	My activities at work have little impact on the energy consumption of the office	2	22	33	24	4	85	3.07
10	I am an active participant in the energy use and conservation of this office	1	10	33	35	6	85	3.41
11	The organization for which I work encourages me to be an active participant in the energy conservation of this office	1	8	28	32	16	85	3.64

Statistic	Daylight is an important aspect of my workspace	The ability to control my environment is an important aspect of my workspace	I have little control over the amount of energy I use while at work	My activities at work have little impact on the energy consumption of the office	I am an active participant in the energy use and conservation of this office	The organization for which I work encourages me to be an active participant in the energy conservation of this office
Min Value	1	1	1	1	1	1
Max Value	5	5	5	5	5	5
Mean	4.16	4.07	2.85	3.07	3.41	3.64
Variance	0.81	0.57	1.11	0.83	0.70	0.88
Standard Deviation	0.90	0.75	1.05	0.91	0.84	0.94
Total Responses	85	85	85	85	85	85

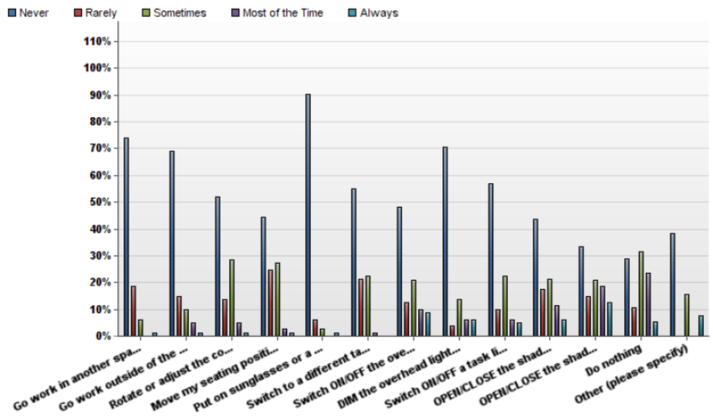
Q29. How frequently do the following conditions occur in your current workspace during a regular workday?



#	Question	Never	Rarely	Sometimes	Often	All of the Time	Total Responses	Mean
1	Discomfort due to glare	18	30	23	13	2	86	7.43
2	Distractions due to glare	21	39	17	7	2	86	7.19
3	Direct sun on interior surfaces	41	16	11	17	1	86	7.08
4	Direct sun on desktop / work surface	43	14	13	14	2	86	7.05
5	Direct sun on computer screen	54	10	17	5	0	86	6.69
6	Interior surfaces are too bright	38	22	18	8	0	86	6.95
7	Exterior surfaces are too bright	54	18	11	3	0	86	6.57
8	Bright reflections off exterior surfaces (such as windows of adjacent buildings or windshields of cars)	59	16	6	5	0	86	6.50

Statistic	Discomfort due to glare	Distractions due to glare	Direct sun on interior surfaces	Direct sun on desktop / work surface	Direct sun on computer screen	Interior surfaces are too bright	Exterior surfaces are too bright	Bright reflections off exterior surfaces (such as windows of adjacent buildings or windshields of cars)
Min Value	6	6	6	6	6	6	6	6
Max Value	10	10	10	10	9	9	9	9
Mean	7.43	7.19	7.08	7.05	6.69	6.95	6.57	6.50
Variance	1.12	0.95	1.51	1.53	0.97	1.03	0.72	0.75
Standard Deviation	1.06	0.98	1.23	1.24	0.99	1.02	0.85	0.86
Total Responses	86	86	86	86	86	86	86	86

Q52. You indicated that the lighting in your workspace may occasionally cause you discomfort or disrupt your work. When this occurs, how frequently do you take the following action in response?



#	Question	Never	Rarely	Sometimes	Most of the Time	Always	Total Responses	Mean
1	Go work in another space in the office	60	15	5	0	1	81	1.36
2	Go work outside of the office	56	12	8	4	1	81	1.54
3	Rotate or adjust the computer screen	42	11	23	4	1	81	1.90
4	Move my seating position	36	20	22	2	1	81	1.91
5	Put on sunglasses or a hat	73	5	2	0	1	81	1.16
6	Switch to a different task	44	17	18	1	0	80	1.70
7	Switch ON/OFF the overhead lights	39	10	17	8	7	81	2.19
9	DIM the overhead lights	57	3	11	5	5	81	1.74
10	Switch ON/OFF a task light	46	8	18	5	4	81	1.93
12	OPEN/CLOSE the shades completely	35	14	17	9	5	80	2.19
13	OPEN/CLOSE the shades partially	27	12	17	15	10	81	2.62
16	Do nothing	22	8	24	18	4	76	2.66
17	Other (please specify)	5	0	2	0	1	8	2.00

Other (please specify)
I don't have control over the lighting
Shelving over monitors fixed most glare from electric lighting. Wish I had more daylight.
I work at home, so am rarely in my office. I would get a different office if I spent all my time at ORI
My office doesn't have too much sunlight but I do sometimes wear sunglasses in the hallway and some conference rooms.
I haven't indicated any discomfort
Other people need the lights sol dont' get to think only about my needs.
place items to block glare off of metal ledge
it doesnt both me very much

Statistic	Go work in another space in the office	Go work outside of the office	Rotate or adjust the computer screen	Move my seating position	Put on sunglasses or a hat	Switch to a different task	Switch ON/OFF the overhead lights	DIM the overhead lights	Switch ON/OFF a task light	OPEN/CLOSE the shades completely	OPEN/CLOSE the shades partially	Do nothing	Other (please specify)
Min Value	1	1	1	1	1	1	1	1	1	1	1	1	1
Max Value	5	5	5	5	5	4	5	5	5	5	5	5	5
Mean	1.36	1.54	1.90	1.91	1.16	1.70	2.19	1.74	1.93	2.19	2.62	2.66	2.00
Variance	0.51	0.90	1.12	0.93	0.34	0.74	1.85	1.59	1.49	1.65	2.04	1.61	2.36
Standard Deviation	0.71	0.95	1.06	0.96	0.58	0.86	1.36	1.26	1.22	1.28	1.43	1.27	1.54
Total Responses	81	81	81	81	81	80	81	81	81	80	81	76	13

Q55. Please indicate your overall sensitivity to each of the environmental factors listed below. (1 is not sensitive at all and 5 is extremely sensitive)

#	Answer	Min Value	Max Value	Average Value	Standard Deviation	Responses
1	Indoor Air Quality (odors, perfumes, etc.)	1.00	5.00	2.94	1.29	86
2	Environmental Noise (traffic, doors, talking, etc.)	1.00	5.00	3.29	1.10	86
3	Indoor Climate (temperature, humidity, drafts, etc.)	1.00	5.00	3.34	1.01	86
4	Indoor Lighting Quality (brightness, flicker, etc.)	1.00	5.00	3.43	1.04	86
5	Other (please specify)	1.00	5.00	2.71	1.89	7

Other (please specify)
Sunlight (if I had any)
inability to see outside; no ability to breath fresh air
Noise

Q15. Which of the following tasks are you required to do (at least once a week for at least an hour at a time) as a part of your job? Select all that apply

#	Answer	Bar	Response	%
1	Talk on the Phone		47	55%
2	Write / Read Emails		84	98%
3	Meet with Colleagues		75	87%
4	Meet with Clients		26	30%
5	Research on the Internet		68	79%
6	Edit Print Documents		62	72%
7	Edit Digital Documents		56	65%
8	Read Contracts or Reports		52	60%
9	Write Contracts or Reports		40	47%
10	Data Entry		48	56%
11	Other (please specify):		7	8%

Other (please specify):
Programming and data management
write press releases and content for the external website
use a calculator
assessments
calculations, budgets, analyses
Data Analysis
video editing

Statistic	Value
Min Value	1
Max Value	11
Total Responses	86

Q62. Which of the following do you have or regularly use within your workspace? Select all that apply.

#	Answer	Bar	Response	%
1	Standing Desk		39	51%
2	Indoor Plants		39	51%
3	Task Lighting		25	32%
4	Desk / Floor Lamp		39	51%
5	Personal Space Heater		21	27%
6	Personal Fan		22	29%
7	Pet / Companion Animal		13	17%
8	Telephone Headset		16	21%

Statistic	Value
Min Value	1
Max Value	8
Total Responses	77

Q17. For how long have you worked at your current workspace?

#	Answer	Bar	Response	%
1	Less than 6 months		9	10%
2	6 months to 1 year		16	19%
3	1 to 2 years		45	52%
4	2 to 4 years		16	19%
	Total		86	

Statistic	Value
Min Value	1
Max Value	4
Mean	2.79
Variance	0.76
Standard Deviation	0.87
Total Responses	86

Q31. How much of your typical workday do you spend at your workspace?

#	Answer	Bar	Response	%
1	Less than 25%		10	12%
2	25 - 50%		12	14%
3	50 - 75%		25	29%
4	75 - 100%		39	45%
	Total		86	

Statistic	Value
Min Value	1
Max Value	4
Mean	3.08
Variance	1.06
Standard Deviation	1.03
Total Responses	86

Q47. How old are you?

#	Answer	Bar	Response	%
1	Less than 30 years old		6	7%
2	30 - 60 years old		53	62%
3	More than 60 years old		27	31%
	Total		86	

Statistic	Value
Min Value	1
Max Value	3
Mean	2.24
Variance	0.33
Standard Deviation	0.57
Total Responses	86

Q49. Do you wear prescription lenses?

#	Answer	Bar	Response	%
1	Yes, all the time		41	48%
2	Yes, for reading		16	19%
3	No		28	33%
	Total		85	

Statistic	Value
Min Value	1
Max Value	3
Mean	1.85
Variance	0.80
Standard Deviation	0.89
Total Responses	85

Q64. Is there anything else you would like to mention regarding your current workspace that you think affects your responses to the previous questions? Please be as specific as possible.

Text Response
While being in an interior office, it is difficult to obtain daylight when the exterior offices close their interior shade, exterior shade or door.
My office is located on the inside of the building, therefore we do not get any direct sunlight. It feels cramped, stuffy and drains my energy. I have not brought plants in the office, for fear that they may die, due to very little, if no direct sunlight. I do not have a standing desk, therefore sit at my computer and work. I take frequent breaks, but dream of an office with a window.
I have a great window space with an awkward open office. The only time I have control over my interior lighting is before 8 in the morning. The sound from my office mates can be really loud and distracting.
Having a window improves my day. I'm doubly fortunate because my view is spectacular.
I usually telecommute from my home (in Portland); I'm only in the office about 4 days a month. Also I do not use the overhead flourescent lights at all when I'm working, only 2 desk lamps Finally I chose to have an office with no outside windows precisely because I hate the glare from sunlight
Overall electric lighting is too bright, but I have no control. I get minimal daylight diagonally through my door, but I wish I had more.
I prefer full spectrum lights or dimmer fluorescent lights (with full spectrum bulbs in a lamp) to the bright flourescents.
I am not a good candidate for your study because I work at home where everything is perfect. I just have this office because I am so little at ORI. having an interior office is horrible, having the lights turn off every few minutes is annoying. My office is small cramped, and feels just dark. But...I don't spend time there so, probably don't count this survey.
I specifically chose an office that doesn't have an outside window, and that would be at a quiet end of the building, with a door. Fortunately, since I'm a scientist, I had the authority to make a choice like that within my workgroup. I also telecommute from home almost all the time. I really do not like too much light, and I wear sunglasses outside at least 300 days a year. It would be nice to have an outside view, but only if I were guaranteed cloudy days for every work day...
The glare from the bright sunlight coming in my window is easy to fix by lowering my blinds. The large window enhances my mood.
Since my current workspace does not have direct exposure to daylight, I have several lamps with full spectrum bulbs, which I often use in lieu of the overhead fluorescent lights.
i love having an exterior window, both for the natural light and the view and the feeling of expansiveness. The electric lights are often too bright and bother my contact lenses.
Poor vision; need good light to see well.
People across the hall with outside windows frequently, though not all the time, close their blinds so i can't see outside; they often have window blinds closed, too. It is very uncomfortable feeling so dependent on the behavior of others to have access to an outdoor view resource. I'm claustrophobic so it makes me real uncomfortable working in my current office. The other issue is that there isn't enough light in the inner offices for plants, which is also difficult,
I primarily work on the computer or with paper documents. The harsh light of the overhead fluorescents hurts my eyes, and flickers drive me crazy, so I really can't work with them on. I get migraines if I leave them on. I had to put something over the motion sensor on my office light so that it will stay off. I leave my blinds wide open to try to catch some of the daylight from the exterior offices, but they usually have their blinds drawn so I don't get much. I use floor lamps and table lamps to light my office with a warmer light. I can't use a space heater or I blow the fuses on this side of the hallway, so I wear sweaters and heavy socks in the winter.
not about my office.... I find myself turning off the lights in Beaver and Duck very frequently. people should not leave them on. also, why do people leave their screens and lights on in their offices. we should be saving energy!
I have control of the lighting in my office space but the lights are for the hallway and other offices. Other people need the lights on so I can't keep them off just so it works out for me. I try to work from home as much as possible but I have to be here some of the time. The glare is really a problem. Getting natural light from the outside is not always possible. The person across from me can't see her computer screen if her blinds are open.
My office is like an airless closet
The brightest and most distracting glare is from the reflection off of the metal sill outside of my window. Even with blinds partway down, this is still an issue at certain times of the day. I often wonder if these sills could be painted with anti-glare matte paint. In my workspace I am at the conjunction of two hallways, one opening to a kitchenette and 2 conference rooms. The majority of noise comes from the conference rooms when people forget to close the doors, and from the kitchen when people are using the sink and microwave and chatting. There is no privacy at all in my open office. I feel compelled to go to another room to make calls or meet with project staff, even for a quick conversation. If someone calls me here, I try to keep my voice very low. Even given all this, I love the view and having the nice daylight in my current workspace.
I love my current workspace because I have a south window and I can have plants in here. If it is too bright, I pull down the shade. hat usually only happens in the fall and spring when the sun tracks lower across the sky. I also like having one solid wall. It makes it a little quieter. Actually lighting is much less of a problem for me than noise level.
Even though I have a north-facing office, I experience significant glare form the outside light at times. It depends on the cloud cover. When the sky is clear, I perceive very little glare. High or light clouds, however, cause much more distraction and discomfort, likely due to the scattering of light. Dark clouds dim the light and reduce the glare. Thus, I tend to change my blinds during periods of bright outside light. I could rearrange my office, but options are rather limited. Due to the various trade-offs, while the lighting might improve, it would not necessarily improve my ability to work.
I don't care much for overhead lighting, so when we moved into this building, I asked our building folks to dim or turn off the lighting directly over my workspace, and they did, and I really think that makes a difference. I think I need minimal lightling in my office due to the natural light from the large window, but we do need lighting by copiers, in interview rooms, bathrooms, etc.
The lighting is great because I value daylight and I have an abundance of it. Also for me, the blinds give me enough variable control that I have never had a frustration issue with the daylight. I do find it annoying when the automatic lights turn on while I'm working during the day. It adds a yellow tint to the otherwise blue light which I don't like. Mostly though all I can see is $$ when the light is on because I do not need it whatsoever during the day.
My office has a motion sensor which controls the lighting. I am not able to over ride the system and when I work after hours, the lights shut off every fifteen minutes or so.
again, I have the light bulbs above me disconnected so I was not sure how to answer some of the questions. If they were NOT disconnected I would be very dissatisfied with lighting
I experience few problems because I have set up my lighting environment to work for me, with blinds set to just the right position and the ability to turn on and off the electric lights as needed. Since I face North, I don't have to worry about having too much sun or glare, so I'm fortunate in that regard. Also fortunate in that I have a closed office so that I have full control over my lighting.

Statistic	Value
Total Responses	26

Q67. Is there anything else you would like to mention regarding your previous workspace that you think affects your responses to the previous questions? Please be as specific as possible.

Text Response
I was in an interior office until recently, and felt like I was in a cave. Now in an exterior office it is often too bright, and I feel a bit guilty putting the blinds down as that impacts the light for the interior office across the hallway, but I often have to lower the blinds to not be squinting as I work.
I was previously in an open office. The lighting was terrible and the noise factor was off the charts. The overhead lighting for the three open offices was a single control. So if one office needed/wanted more light the others had to have it too or visa versa.
My previous workspace
I have had all variations of office configurations over the years at ORI: inan open cube in a large room,in external private offices, in internal private offices. I now have an open office with an exterior window. I think my office is too small for the meetings I sometimes have with "customers" (researchers), but I do not mind being in an open office. I am not bothered by hallway noise. I sometimes feel I am too loud while on the phone for work, and i usally go to an empty room for private phone calls (doctor's appointments, etc.).
My previous workspace was an intereior office in the middle of the building on the third floor. It was across from a bank of open offices so I had more access to daylight, except when the occupants of that bank closed the blinds because it was too bright for them. It was a busier hall with less privacy and a lot more noise. I'd have to close the blinds to create a privacy barrier for my project tasks so I wound up using the bright overhead lights often.
I did previously have a closed window office prior to moving with our sublet of other ORI space. I know the glare can be a real problem for people and I appreciate the need to close their blinds.
I miss my old office, where I had a big window, and I just used that light to work by. Unfortunately, the open offices here with windows also are open on the top to the fluorescents, so there is no way to escape them. I chose a closed office so I could get away from them, and also due to noise and privacy concerns.
I had an office with it's own lighting. It worked fine. It was an interior office and the person across from me never allowed the blinds to be open. That was a pain. I didn't have glare there, just depresswing lighting. This is better but painful. There ya have it.
I really liked the individual offices in the old building...
I have worked in a windowless office as well as an office with an exterior window. Currently, I have an interior office that still gets natural daylight, which I greatly appreciate. My preference is to have an exterior window, but compared to having no windows, this is a huge improvement.
Previously I was in an interior office across from high-walled cubicles. It was very depressing: very little light, no view of the outdoors, no control over whether the window shades were open or closed, and the glass wall made it feel like working in a fishbowl, so I closed the blinds all the time, which made it even more dark. I requested to move to exterior to get some light and a slight amount of privacy, even though the noise increased and the glare is an issue.
My previous workspace was right next door and had a great window too, but with 2 low temporary walls, it was much noisier.
I couldn't even see outdoors at my previous workspace so I very much like my window.
When we were in the old Franklin building, I did not have access to a window, and I very much appreciate it now and know it increases my productivity and work comfort level. I felt like I was in a cave at the other location, and sometimes it was such a shock to go outside, not knowing at all what the weather was doing, etc. Even though I just look at a big building next door from my window, I am very thankful for the natural light, and that I can see what's going on outside, etc. :)

Statistic	Value
Total Responses	14

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