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The Benefits of Glass

A Literature Review on the Qualitative Benefits of Glass on Building Occupants

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THE BENEFITS OF GLASS

Executive Summary

This literature review, completed by the University of Michigan Taubman College of Architecture and Urban Planning for Guardian Industries Corp., focuses on the non-energy-related benefits of glass, with a focus on how glass used in buildings provides health, psychological and social benefits to human occupants. An important component of the goals for a sustainable built environment is that it must include not only energy and resource sustainability but healthy environments and social sustainability as well as productive environments and economic sustainability.

This review is by no means exhaustive; instead, it is the goal of the authors to compile recent, commonly cited literature on the benefits of glass described above in order to identify consistently proven research outcomes and opportunities for further analysis. The review therefore summarizes peer-reviewed articles, a number of industry-specific books, government-sponsored resource websites and a number of earlier literature reviews completed on similar topics. All of the resources are further detailed in the annotated bibliography.

Peer-reviewed articles were selected based on the frequency with which they were cited by others in addition to their relevance to the topics under investigation. The online journal database at the University of Michigan was used to find articles with key search terms including: daylight, glazing, windows, health, productivity and views. The University's online database offers access to nearly 10,000 journals, magazines and newspapers totaling over ½ billion articles. Key journals include: *Lighting Research and Technology*, *Environment and Behavior*, and *Building Research and Information*. The majority of research investigated dates from 1999 onward, with only key studies prior to that date included, and identifies both the state of current knowledge in this area, as well as gaps and opportunities for further work.

The literature review is presented in six sections on the topic of glass as a material, the image of glass, daylight and views, productivity, health and potential research opportunities. The first three sections help to introduce the terms by which productivity and health might be understood within the context of glass in buildings: *1.0 Glass in Buildings: Drivers in Decision-Making* introduces the roles of the designer, the building owner and current building codes and standards in the selection and use of glass in building design today; *2.0The Image of Glass* describes the way in which glass is chosen to present a specific image or brand, and used as a symbol to convey meaning; *3.0 Daylight and Views* introduces the two terms as they are

situated in architectural design and building construction today as beneficial characteristics of buildings.

The following sections present research on productivity and health, respectively, linked to the use of glass in buildings and therefore the presence of daylight and views. In section *4.0 Productivity*, literature reviewed consistently proves the value of daylight and views in spaces for working, shopping and learning. Key findings include cognitive test score improvements up to 20% in daylight and view zones in offices (Wang and Boubekri 2011), an additional 39 work hours per occupant in new LEED Gold and Platinum offices (Singh, et al. 2010), an average 0-6% improvement in monthly sales performance in retail buildings with daylight (Heschong-Mahone Group 2003 Retail), and a 21% improvement in test scores within one academic year for California students in grades 3-6 who spend the majority of their time in a daylit classroom (Heschong-Mahone Group 2003 Classrooms).

In section *5.0 Health*, the literature reviewed also presents consistencies with respect to the highly beneficial nature of daylight and views on the health of people in general and specifically in healthcare settings. Key findings include the importance of light in the maintenance of the human circadian system (Boyce and Rea 2001, Baker 2000, Edwards and Torcellini 2002), the innate attraction people have to the natural environment (Baker 2000, Ulrich 2008, Loftness 2008), increased incidents of jaundice in maternity units without windows, a 2.6-day reduction in hospital stay for patients in sunny rooms, and 22% less pain medication used by post-spinal surgery patients in sunny rooms (Ulrich 2008).

The final section, *6.0 Further Research Opportunities* serves as a gap analysis and presents five potential areas for further research identified throughout the literature review: personal control, better technology, thermal comfort, various climate conditions, and the positive effect that glass has on the urban condition and communities.

January 3 2012

THE BENEFITS OF GLASS
A Literature Review of the Qualitative Benefits of Glass on Building Occupants

INTRODUCTION

"The use of glass does compel us to go new ways."
(Mies van der Rohe)

In considering the benefits of glass in the field of architecture, a number of key characteristics come to mind. Foremost is the material's transparency which allows abundant daylight, expansive views, and passive heat gain in cold climates, as well as the productivity gains and health benefits that daylight and views are believed to engender. This literature review is focused on the qualitative, non-energy related, benefits of the use of glass in buildings. The body of literature encompasses recent research on the following topics: the image of glass used physically and symbolically; the importance of and preference for daylight and views; the attempts to quantify improvements in both human productivity and health as a result of both natural daylight and views. The majority of research investigated dates from 1999 onward (only key studies prior to that date are included for context) and identifies both the state of current knowledge in this area, as well as gaps and opportunities for further work.

Within the context of sustainability, current environmental questions related to glass are mostly concerned with energy performance, like the use of shading devices to mediate heat gain and glare and insulated or treated glass to reduce the energy demand and therefore environmental impact of a building. This document presents research more in line with questions of social sustainability in terms of occupants' health and well-being, on the one hand, and economic sustainability, on the other, in terms of productivity gains rather than energy cost savings. The performance of a building, one of the most important descriptions of a building today, is understood here in terms of its occupants and human community as a result of the use of glass rather than its material construction alone.

1.0 GLASS IN BUILDINGS: DRIVERS IN DECISION MAKING

In a series of focus groups conducted by Spectrum Associates Market Research, building design professionals, developers, owners and managers were asked to identify the ultimate decision-maker on the use of glass as it relates to daylight. These discussions led to this statement by Spectrum: "The final decision about using daylighting is a financial decision made by building owners/developers. However, designers frequently provide the inspiration for daylighting and often it is their explanation of its benefits that overcome the owners'/developers'

reluctance to spend the money needed for daylighting" (Spectrum 2003, iii). Numerous participants pointed to the important role designers have in educating building owners. One building end-user in Charlotte states: "I think designers are the first line. I rely on them to come with the latest research and at least present the coolest ideas." Of the barriers identified in the same focus groups, further discussed in the last section of this document, two of the three top perceived barriers to the implementation of daylighting design include the lack of daylighting design tools for architects and engineers and the need for better communication of benefits to owners and developers, further reinforcing the importance of the designer's role (Spectrum, 2003).

To the extent that there are current design guidelines and regulatory practices in place – above and beyond building code requirements for window size and location that have more to do with life safety than with qualitative benefits of glass – the authors of a recent article titled "Design Recommendations Based on Cognitive, Mood and Preference Assessments in a Sunlit Workspace," cite a number of examples: The International Building Code requires a minimum net area of glazing such that it equals at least 8% of the floor area; the British Standard (BS 8206 part 2) recommends 20-35% window area on an external wall based on the depth of the room it is serving; the Recommended Practice of Daylighting by IESNA includes a suggestion for a continuous window of at least 1 meter high as a minimum for offices; and the US Green Building Council offers credits in the LEED green building rating tool that require a certain level of access to daylight and views for 75-90% of regularly occupied areas (Wang and Boubekri 2011).

2.0 THE IMAGE OF GLASS

> *"…glass architecture, which admits the light of the moon, and of the stars into the rooms, not only through a few windows, but through as many walls as feasible, these to consist entirely of glass…" (Paul Scheerbart, 1914)*

More than any other building material, the use of glass in buildings is associated with modernity, both because it was not until close to the mid-20th century that developments in technology allowed the manufacture of large panels of glass that were structurally sound, but also because glass, in many ways, is associated with the modern ethos in architecture of lightness, airiness, transparency and variability. In the *Glass Construction Manual* published by Birkhäuser, the poet author Paul Scheerbart is referenced for his descriptions of glass as synonymous with openness and lightness; perceptual qualities of the material that still remain today. The authors continue: "Glass curtain walls became the status symbol of confident companies and the silhouette of glass towers the sign of a prosperous city" (Schittich, et al 1999, 35), and "…today

there is hardly a prestige project that is not characterized by this material to some extent" (Schittich, et al 1999, 42).

For Günter Behnisch, architect of the new parliament plenary chamber for the German Bundestag in Bonn, glass was chosen as the material best suited to satisfy claims of democracy. The transparency of the building is described as a metaphor for the transparency of elected representatives in a democratic government (Schittich, et al 1999). The new glass dome at the Reichstag in Berlin by Norman Foster, completed in 1999, six years after Behnisch's chamber building, uses glass to enable panoramic view of the city as well as views down into the parliamentary chamber room. The architects emphasize the importance of glass in their description of the project on their website: "Emphasising values of clarity and transparency, the glazed cupola is a new landmark for Berlin, and a symbol of the vigour of the German democratic process" (http://www.fosterandpartners.com).

In another book published by Birkhäuser for architects and engineers, titled *In Detail: Building Skins*, the authors discuss the ways in which contemporary uses of glass exist within a range from transparency to translucency by way of designs that incorporate overlapping, layering of perforated materials, printing, etching and coating. "Glass," the authors state, "like few other materials, is the very symbol of the modern façade" – in fact, it is "a building material that seems more suited than any other to represent the complexity of modern society" (Schittich, et al. 2002, 18).

Both of the Birkhäuser publications also point out the aesthetic and creative opportunities for the use of glass as a communicative medium in buildings. Especially noted are the many uses in significant buildings of glass that is translucent, etched, sandblasted, enamel coated, screen printed or coated with holographic or dichroic films (Schittich, et al 1999, 44-46; Schittich, et al 2002, 21-26). In this case glass does not symbolize an idea but actually becomes an image of that building, its owner or its function and has the ability to act as a medium for carrying messages to the public at large.

3.0 DAYLIGHT AND VIEWS

> *"…we have a deep hereditary affinity for the natural world and modern life and the built environment increasingly isolates us from it." (Nick Baker, 2000)*

As a key material in architectural design and building construction today, glass enables a number of beneficial characteristics that can positively impact the occupants and owners of buildings. As part of the façade of a building, glass provides transparency to let sunlight in and

to let people see out. These two primary benefits of glass – daylight and views – are studied extensively as part of research on the productivity and health of building occupants, topics covered in the following sections of this report.

In a recent article in the journal *Lighting Research & Technology*, Drs. Wang and Boubekri cite a much earlier survey completed by Ne'eman et al in 1976 who reported that "sunlight was found desirable in interiors by 93% of the interviewed households, 91% of hospital patients and 73% of office workers" (Wang and Boubekri 2011, 57). In addition to daylight as a long considered benefit of glass, Ne'eman's early research also pointed to problems with glare, heat gain and heat loss. Since the 1980's, technologies like automated louvers and specialized coatings have been rapidly improving to help to control glare and reduce solar heat gain, and sealed double- and triple-glazed units are helping to reduce heat gain and loss to mitigate the problems associated with glass while continuing to improve the quality of daylight introduced into buildings.

Nick Baker, in his article "We are all Outdoor Animals," cites a study completed in 1999 for which people using library spaces were surveyed on their preferences for both daylight and views. The study reported that uniformly lit environments were scored badly by occupants of three Cambridge libraries who favored abundant, changing daylight even to the extent that too much direct sunlight caused discomfort and glare, as long as two conditions were also met: a landscape view was present and the occupant was free to adjust or move in order to improve visual comfort (Baker 2000). In line with discussions on connections to local climate and changing to adapt to one's environment presented by Lisa Heschong in her 1979 book *Thermal Delight in Architecture*, Nick Baker relates personal adaptation, views to the outdoors and changing daylight conditions to the need and desire for stimulation. With regard to our attraction to nature, he states: "One of the characteristics of the natural world is its variety (in space) and variability (in time), and the opportunity and the need to make adaptive responses (Baker 2000, 4).

In the significant 1975 literature review by Belinda Collins, cited numerous times throughout this literature review as a specific historical reference point to contrast the more recent research, we read that preferences for views to the exterior are proven over and over again – the preferred scene being one in which there is a greater variety of distant objects as well as both ground and sky (Collins 1975). Thirty years later, in a study on the economic value of views written by Drs. Kim and Wineman at the University of Michigan, the value of and therefore desire for a view is quantified for high-rise hotels, office buildings and residential towers in Chicago, New York and Los Angeles: 16 of the 22 office buildings contacted indicated that price and views are interrelated (Kim and Wineman 2005).

While views were found to be considered into the pricing structure for all three building types, the authors conclude that views are most important in residential towers because of the amount of time people spend at home as opposed to work and hotels, in addition to the different type of values and expectations people have for their living spaces versus working space. In terms of glass, daylight and views in offices, specifically, the authors add that "…by having an open, spacious, flowing floor plan with plenty of windows and quality views, a corporation communicates to its employees that its business practices and interpersonal philosophies are also open and inviting, ultimately leading to the generation of positive feelings among these employees (Kim and Wineman 2005, 1).

4.0 PRODUCTIVITY

> *"There is a clear suggestion from this work that windows and views are important for sustained human performance." (Heschong-Mahone Group, 2003)*

Productivity is defined as "the ability of people to enhance their work output through increases in the quantity and/or quality of the product or service they deliver" (Leaman and Bordass 1999, 6). Productivity related to the physical attributes of one's space is typically quantified in ways specific to the building and/or occupancy type. For instance, studies on productivity in retail stores might consider data such as increases in sales and transactions, while studies in educational facilities consider data such as absenteeism rates and test scores. In both cases, the analyses included in this literature review combine the quantifiable data related to an activity specific to each building type with relatively detailed descriptions of the spaces in which those activities take place.

Offices, retail buildings and schools have been identified as three particular building types for which a number of productivity studies are available that include the key physical components related to glass: views and daylight. Healthcare is included in the next section as patient health is not only a measure of productivity, in a certain sense, but perhaps more importantly applicable to broader questions of health and well-being. In the three building types, the literature reviewed attempts to identify and isolate the key physical attributes of spaces for working, shopping and learning that have the most proven effect on measures of productivity. While studies on productivity related to natural daylight date back to the 1920s with research conducted on silk weavers (Edwards and Torcellini 2002), the collection of literature referenced in this section attempts to present newer work that simultaneously builds on the successful research completed by many others.

4.1 OFFICES

Quantifiable data presented in studies on productivity in offices include: rates of absenteeism, performance on cognitive tests, rates of employee turnover, time spent on primary tasks and additional work hours gained. The physical attributes of a workspace related to glass presented in the studies below include access to views, access to daylight, proximity to windows, glare and partition height.

In a recent study published in the journal *Lighting Research and Technology*, Drs. Wang and Boubekri tested single-occupancy office spaces and the preference of desk position within that space in order to propose design guidelines for human preference in relationship to sunpatch location. Cognitive test scores were found to improve up to 20% above the average for those participants seated within the “preferred zone” with access to views and/or daylight. For those seated outside the preferred zone, cognitive test scores dropped as low as 24% below the average. Predicting a consistent decrease in participant mood upon administration of the cognitive tests, it was also found that the mood of the participants seated in the preferred zone decreased less than those positioned further from daylight and without direct views to the outdoors (Wang and Boubekri 2011).

The authors of another recent study by researchers at Michigan State University, published in the *American Journal of Public Health*, surveyed a total of 263 people for two case studies in Lansing, Michigan as participants moved into new workplaces that had achieved either Gold or Platinum levels of LEED certification. Daylight and views were described in connection to concerns of lighting, acoustics and ergonomic design and safety, and therefore linked to well-being issues of depression, stress and productivity. The benefits of the new “green” workplace were considered resultant from the combined physical attributes of the space, and therefore the specific contributions of daylight and views cannot be isolated. Nevertheless, the benefits reported include: (a) an additional 2.02 work hours per occupant having previously reported stress or depression; and (b) an additional 38.98 work hours per occupant due to an improvement in productivity of 2.6% for all occupants (Singh, et al. 2010).

As a follow-up to their original 1999 study on office worker productivity, Heschong-Mahone Group administered a series of five cognitive tests to 201 employees of the Sacramento Municipal Utility District working in three different buildings. Of the physical characteristics affecting their performance on the visual memory tests taken at participants’ desktop computers, the best primary views produced a 16% improvement in performance, and the best general view a 9% improvement. Glare from windows surpassed the positive or negative effects of any of the physical characteristics: the worst glare decreased performance by 17%. The authors also found that SMUD Call Center employees with the best available views performed 6-7% better

than their peers. In addition, those with the highest partitions performed 11-18% worse than their peers. In isolation, these percentages are significant. However, each physical attribute included in the model for these studies is only responsible for approximately 0.5-1.0% of total performance. Together, then, variation in the physical space could only be linked to about 2-5% of worker performance, which the authors maintain is nonetheless a significant impact (Heschong-Mahone Group 2003 Offices). In a similar study by Mariana Figueiro et al., presented at a conference on “Light and Human Health” sponsored by the Lighting Research Office at the Electric Power Research Institute, we read that people seated near windows spent 15% more time working on their primary tasks on the computer; their peers without access to a window were observed spending that same time talking on the phone or to each other (Figueiro, et al. 2004).

In a literature review on natural light sponsored by the National Renewable Energy Laboratory in 2002, Edwards and Torcellini present additional statistics from numerous studies relevant to the effect of daylight and views on office employees. These statistics include: (a) a 15% decrease in absenteeism at Lockheed Martin after they moved into a daylit building; (b) 6.8 hours per person increase in attendance at VeriFone Worldwide Distribution Center after moving into a new daylit building; (c) a 15% decrease in absenteeism at the International Netherlands Group Bank building constructed in 1987 in which no employee sits further than 23 feet from a window; and (d) a 200% decrease in employee turnover for one group at the Story County Human Services in Iowa after the employees moved into a daylit building (Edwards and Torcellini 2002).

4.2 RETAIL

Quantifiable data presented in studies on productivity in retail include: monthly sales and monthly transactions. The physical attributes of a retail space related to glass presented in the studies below include daylight hours: the number of hours of daylight that exceed a certain illumination threshold, measured from sources other than entrance façade glass.

As a follow-up to their original 1999 study on retail sales in stores both with and without daylight, Heschong-Mahone Group isolate monthly sales and monthly transactions to test the prediction that daylight increases sales by 40%. The model developed for the 2003 follow-up study includes many additional variables from data collected over 24 months from 73 stores of a single retail chain, as well as a higher percentage of visits by researchers to the stores to confirm the spatial qualities under investigation. The results of the second study showed that the initial 40% sales increase is the upper bounds of a range of improved sales performance that averages 0-6%, depending on co-linear variables like parking, and various modeling techniques. The authors note that while many retailers introduce daylight in order to save on energy costs,

the potential for additional sales could have a much greater positive impact on their budget. In addition to sales performance and energy cost, employee morale and productivity will affect the operations of a retailer's business: HMG found more positive feedback from employees in locations with daylight when surveying workplace satisfaction (Heschong-Mahone Group 2003 Retail).

4.3 SCHOOLS

Quantifiable data presented in studies on productivity in schools include test scores, attendance records and individual surveys. The physical attributes of a learning space related to glass presented in the studies below include the presence or absence of windows, access to and amount of daylight, access to views, acoustic performance, thermal comfort and glare.

In the third study completed by Heschong-Mahone Group on the topic of windows and productivity, the authors analyze the extent to which the physical environment of a classroom may or may not have an impact on a student's learning as related to the test score performance of over 8000 students in grades 3-6 in the Fresno Unified School District. It is noted that elementary-age students were chosen as they spend the majority of their time in a single, assigned classroom. HMG report a 21% improvement in test scores from fall to spring in fully daylit classrooms as opposed to non-daylit classrooms, with results controlled for numerous other variables like teacher ability. In addition to daylight and views, the model includes many other physical attributes including acoustics, air movement and thermal comfort; the authors find that there are consistently trade-offs between all the physical attributes studied. For example, operable windows are preferable in terms of personal control and to help relieve uncomfortable indoor conditions, but typically reduce acoustic performance by letting in extra noise. Likewise, large areas of windows introduce problems with heat gain, heat loss, glare, and poor acoustic performance, but are desirable in order to provide better light quality and views to the outdoors – qualities that are associated with better student performance (Heschong-Mahone Group 2003 Classrooms).

In a much earlier report for the National Bureau of Standards in 1975, Belinda Collins compares results of studies on classrooms with and without windows altogether and cites the same types of concerns regarding the benefits of daylight and views against the problems of distraction, acoustics and glare. She reports that the studies find little to no difference in learning opportunity and performance between the two settings despite a definite preference for windows based on attitude and perception. From her review and analysis of numerous studies at the time, Collins also presents a hypothesis that as the age of the student increases, the desire for windows is less urgent (Collins 1975). Unfortunately, no single study yet exists that includes a

range of students from kindergarten through college in order to specifically study the relationship of daylight and a student's age.

Heschong-Mahone Group report that each isolated physical characteristic tends to influence about 0.3 to 0.1% of the outcome of overall performance for the elementary students in their study. The authors admit: these are very small numbers. However, HMG further contend that even this amount of improvement is notable given the lifespan of the building and sheer quantity of students that will be affected by a single school building (Heschong-Mahone Group 2003 Classrooms).

5.0 HEALTH

> *"Larger windows should be provided to permit more exposure to daylight and restorative nature views in patient rooms and other spaces where depression, pain and stress are problems." (Roger Ulrich, 2008)*

A popularly cited statistic alongside green building campaigns is that people spend nearly 90% of their time indoors; this is one of many statistics included in a document produced by the US EPA called "Buildings and their Impact on the Environment." This fact is consistently presented within the context of "healthy" interior spaces, therefore underlining its importance. In the LEED green building rating tool created by the United States Green Building Council and administered by the Green Building Certification Institute, the effort toward improving the quality of the interior environment is covered with both requirements and credits that account for off-gassing from installed materials, air filtration to reduce particulates and improve air quality, air quality testing, protection of HVAC equipment during construction, and design guidelines toward providing daylight and views for all regularly occupied spaces.

A majority of the studies included here are related to the impact of daylight and views on health are typically situated within a healthcare setting and/or linked directly into conversations on improving productivity. The literature either addresses health from a general perspective or from a healthcare setting, with the exception of a portion of Heschong-Mahone Group's research in offices. It is worth noting that some of the earlier work on human health related to indoor environments came from growing concern over sick building syndrome symptoms due to sealed buildings and lack of adequate ventilation and fresh air, though these studies are not included as part of this review.

5.1 GENERAL HEALTH

The most recent research on daylight and health focuses on the effect of light in maintaining human circadian cycles, or “body clock,” though the long list of health concerns linked to daylight and views also includes: rickets, osteomalacia, safety, eyestrain, migraine, autism, sleep disorders, seasonal affective disorder (SAD), depression, Vitamin D deficiency, Alzheimer’s disease, stress, and more.

In their 2001 report on “Lighting and Human Performance” for the National Electrical Manufacturers Association, described as an update to an earlier 1989 literature review on the same topic, Peter Boyce and Mark Rea identify daylight as “the main source of circadian entrainment” (Boyce and Rea 2001, 5-9). They describe circadian photobiology as a significant aspect of the health and productivity of building occupants, particularly as it can impact fatigue and stress (Boyce and Rea 2001).

In a short article titled “We are all Outdoor Animals,” presented at the Millennium Conference on Passive and Low Energy Architecture (PLEA) in 2000, Nick Baker cites circadian rhythm as a crucial component to reducing the effects of seasonal affective disorder (SAD). Baker cites a 1994 study at the University of Cambridge in which illumination measurements in daylit and artificially lit spaces revealed a significant discrepancy in the amount of light received from each source – daylight provided up to 2000 lux while artificial light rarely reaches 100 lux – and that this increase in illumination, particularly its intensity in the morning, is directly linked to the circadian synchronization. Baker states that SAD is suffered due to shifts in the natural circadian rhythm where people are deprived of daylight and its synchronizing effect. The consequences of this type of research can be seen in the marketplace where numerous products are being developed to offer “full-spectrum” or “virtual daylight” to sufferers of SAD and depression (Baker 2000).

5.2 OFFICES

In the 1975 literature review by Belinda Collins, we read that surveys of office workers identified problems like feelings of being cooped-up, isolation and claustrophobia, depression and tension as reasons for not liking offices without windows (Collins 1975). Similarly, access to an interesting view, as opposed to a “boring” one or none at all, is identified by Heschong-Mahone Group in their 2003 report as reducing the likelihood of reports of fatigue, headache, difficulty concentrating, and eye strain. The authors state: “The fewer complaints employees had about their physical environment, the fewer negative health symptoms they also reported” (Heschong-Mahone Group 2003 Offices, 127).

HMG further identify fatigue as a health indicator of particular interest and note which spatial characteristics have the most impact on either increasing or reducing the amount of fatigue reported by participants. The comfort conditions most likely to induce fatigue, in order, include: a drafty window, allergies, electric light reflections, lack of sunlight, and dull lighting in general. The comfort conditions most likely to reduce the occurrence of reported fatigue, in order, include the best views, comfortable humidity, no noise distractions and no lighting problems. The presence and quality of view is cited as the most consistent predictor of fatigue (Heschong-Mahone Group 2003 Offices).

5.3 HEALTHCARE

In a recently published book called *Biophilic Design* edited by Yale Professor Stephen Kellert, Dr. Roger Ulrich uses a discussion of health outcomes and stress, in particular, as a method for understanding the effect daylight and views might have in a healthcare setting (Ulrich 2008). Biophilia is a term first used by social psychologist Erich Fromm to describe an attraction to all things alive and vital and was then used by E.O. Wilson, a popular figure in environmental sustainability, as a title for his book and to describe a connection subconsciously sought by humans with the rest of life. This relationship between humans and the natural world is further developed by Stephen Kellert et al. in *Biophilic Design* as the basis for a paradigm shift in the way in which we conceive of, design and construct buildings. Of 70 design attributes identified in the book as part of a biophilic design approach, 14 are directly related to issues of daylight and view.

Ulrich states that there are more than 50 rigorous studies on the topic of daylight and views and the influences these qualities have in healthcare settings on patients, visitors and staff. Ulrich has authored a number of these studies, which are frequently cited by many others including both Baker and Boubekri, authors of works included in this literature review. He continues: “This growing literature indicated that evidence-based biophilic design can have a positive impact by reducing stress, improving emotional well-being, alleviating pain, and fostering improvements in other outcomes” (Ulrich 2008, 87). This literature dates back to at least 1972 when a study cited by Belinda Collins in her 1975 review concluded that 40% of patients in a windowless intensive care unit developed “post-operative delirium” as opposed to 18% of patients in a space with windows (Collins 1975).

Numerous healthcare-related studies either authored or cited by Ulrich show that: (a) patients with a view of nature were found to consistently suffer less pain indicated by far fewer doses of narcotic pain medication; (b) incidents of jaundice increase when windows in maternity units are covered or shaded; (c) Alzheimer’s patients exhibit lower agitation levels with higher light exposure; (d) nurses exposed to daylight for three or more hours per day reported less work

stress; (e) adult patients in a Canadian hospital had substantially shorter stays, a 2.6 day reduction in length, if they were assigned to sunny rooms; and (f) post-spinal surgery patients in sunny rooms, exposed to 46% higher sunlight intensities than those in the shaded side of the ward, "reported less pain and stress, took 22% less analgesic medication and had 21% percent lower medication costs" (Ulrich 2008, 100).

6.0 FURTHER RESEARCH OPPORTUNITIES

> *"In spite of the wealth of research and occupier evidence that high perceptions of personal control bring benefits like better productivity and improved health, designers, developers, and sometimes even clients seem remarkably reluctant to act on it." (Leaman and Bordass, 1999)*

Several further research opportunities exist when considering the positive benefits glass can have on the occupants of a building, as well as the larger built environment. In addition to more extensive work on the topics addressed above, questions of personal control, better technology, thermal comfort, various climate conditions and the effect that glass has on the urban population in general are briefly introduced here as research needs identified throughout the literature review.

6.1 PERSONAL CONTROL

More than a decade after Adrian Leaman and Bill Bordass asserted a wealth of research on productivity and health, there are still many areas of opportunity for additional research in order to offer design professionals and building owners specific evidence of the qualitative and quantitative benefits of glass in buildings. The question of personal control over position relative to windows, light and glare levels is relevant not only to daylight and views but also to thermal comfort, general lighting and other indoor environmental controls. In the LEED rating tool, for example, credits are available to projects that design and install a certain level of individual control over temperature and lighting into the regularly occupied spaces of a building. Research specific to the benefits and challenges of personal control over daylight and views would help to advance the collective body of work that proves increases in productivity and performance due to higher satisfaction with one's space.

6.2 TECHNOLOGY

In the focus groups conducted by Spectrum Associates Market Research, the primary perceived barriers to the use of glass in terms of daylighting are found to be additional capital costs or

problems with technology, particularly with regard to the controls that drive the operability of technologies like automated shading systems and daylight dimming. Participants suggested the development of better, proven, and less expensive technologies to aid in daylight design while also improving the education of both professionals and end-users to share success stories and new technology options. A ranked list of nine possible strategies was created within the focus group to prioritize perceived barriers to daylighting in all types of buildings; in order of importance, as ranked by the participants. Of the nine, seven were consistently prioritized in discussions: (a) proof of increased productivity; (b) daylighting design tools for architects and engineers; (c) better communication of benefits to owners/developers; (d) better windows to reduce glare; (e) better controls; (f) proof of increase in retail sales; and (g) proof of health benefits. Items d and e are particularly relevant to the overarching importance of technology identified within the focus groups (Spectrum 2003).

6.3 THERMAL COMFORT

In their 2003 study on windows and offices by Heschong-Mahone Group, the authors decided to abandon questions of radiant temperature readings as an additional model variable due to what they called “modest” ranges observed in the difference between ambient room temperature and radiant temperatures at windows. However, in their preliminary work they found that the window surfaces were 2-10 °F warmer on the South and 1-2 °F cooler on the North than the reported uniform temperatures recorded elsewhere throughout the space. These temperature differentials are significant enough to merit additional study in order to gather information on the complete indoor environment near windows where it has been shown people prefer to locate themselves for access to daylight and views (Heschong-Mahone Group 2003 Offices, Wang and Boubekri 2011).

6.4 VARIOUS CLIMATES AND SEASONS

In the same 2003 study, Heschong-Mahone Group state that they did not observe any changes in the data related to a change in seasons. It is worth noting, however, that their studies were conducted exclusively in California where the climate is relatively temperate (Heschong-Mahone Group 2003 Offices). Noted as early as 1975 in Belinda Collins' literature review, there are few studies that address extreme hot or cold climates nor is there sufficient research on the effect of changing seasons in climates with distinct seasonal shifts (Collins 1975). A 2006 article on the use of glass in the United Arab Emirates by Mohsen Aboulnaga reinforces a lack of research in hot climates. Further, Aboulnaga contends that “daylighting is most challenging in hot and sunny climates due to the immense amount of illumination received and the lengthy sunshine hours” (Aboulnaga 2006, 635). A line of inquiry on the impact of seasonal change and type of climate could be seen as directly parallel to the comparison between Fanger’s predicted mean vote

(PMV) in which a universal level of thermal comfort is assumed no matter the climate and Brager and de Dear's adaptive model for which thermal comfort levels are adjusted with respect to local conditions – both models currently being in use by mechanical engineers. A seasonal desire for daylight and views could be important to the perceived benefits of daylight and views, especially in colder climates when daylight hours are significantly reduced and SAD is more prevalent. The climate in Michigan is potentially useful as a location with distinct seasonal shifts where ongoing research might be undertaken.

6.5 COMMUNITY CONNECTION

In her chapter for the book *Biophilic Design*, Vivian Loftness states that "While a direct connection from the indoors to the natural diversity of outdoor places may be critical for human health and inspiration, the direct connection from outdoors to inside is equally critical" (Loftness 2008, 129). This connection may in fact become increasingly important as we become more and more urban in our living conditions. Loftness, through an example of transparent and opaque coffee shops, implies that glass and its transparency support the ongoing growth of a community, ensure safety for those on the street, provide a sense of belonging and inclusion as opposed to isolation and depression, and allow access to the richness of the activities inside (Loftness 2008). In short, Loftness is making an argument for transparency as a means of supporting urban connectivity and sustainable communities.

The use of expansive glass at street level for retail is almost so ubiquitous in most cities, that it has likely never been studied relative to its positive impact on both urban street life, as well as retail sales. Following Loftness' suggestion, a further study might also investigate the desire, use and positive urban and community impact of large street-level areas of glass for public and community buildings in cities.

THE BENEFITS OF GLASS
Annotated Bibliography of Resources

Aboulnaga, Mohsen M. "Towards Green Buildings: Glass as a Building Element – the Use and Misuse in the Gulf Region." ***Renewable Energy*** **31 (2006): 631-653.**
Mohsen Aboulnaga holds a PhD from the University of Leeds and is currently teaching at The University of Dubai and The American University in Dubai. Aboulnaga has held a number of government appointments in the United Arab Emirates and has over twenty-five years of experience teaching and consulting on various topics related to sustainability. The study focuses on the recent trend of nearly all-glass buildings in the hot climate of the Gulf Region. Fifteen buildings, divided evenly into high-, medium- and low-performance, were studied. The author cites research on how the misuse of glazing can cause the same problems typically solved with the use of glass, like fatigue due to glare and loss of productivity due to excessive heat gain. The author notes a general agreement on the many positive effects of daylight and views, with specific reference to the studies completed by Heschong Mahone Group, and identifies the lack of similar data in the Gulf Region and hot climates in general as the specific impetus for his paper.

Baker, Nick. "We are all Outdoor Animals." Paper presented at the Millennium Conference on Passive and Low Energy Architecture (PLEA), Cambridge, England, July 2-5, 2000.
Nick Baker is affiliated with the Martin Center for Architectural and Urban Studies at the University of Cambridge and noted as an expert in energy efficiency and daylighting as a consultant, teacher and researcher. The PLEA conferences, where this paper was presented, are attended by professionals, academics and students working within the fields of architecture and the built environment. In close parallel to the arguments presented by Lisa Heschong in her book *Thermal Delight in Architecture*, published in 1979, Baker makes a case for adaptive environments in which we introduce more nature or nature-related design characteristics. Specific topics discussed, albeit very briefly, include adaptation and survival, daylight and health and nature in buildings, all in support of the human need to respond to natural stimuli.

Boubekri, Mohamed. ***Daylighting, Architecture and Health*****. New York: Architectural Press, 2008.**
Dr. Mohamed Boubekri is currently an Associate Professor of Practice & Technology in the College of Fine and Applied Arts at the University of Illinois at Urbana-Champagne. He received his PhD in Architecture from Texas A&M University and currently serves as the Chair of the Practice & Technology Faculty in the School of Architecture at UIUC and as a Member of the

Daylighting Committee for the Illuminating Engineering Society of North America (IESNA).The aim of the book is to discuss how much daylight is necessary in our lives, and why. Following a brief summary of the history of daylight and architecture, Boubekri discusses the need for daylighting legislation. The next three sections in the book discuss Seasonal Affective Disorder, additional health concerns mainly related to Vitamin D, and psychological effects one mood and behavior. Boubekri's substantial compendium of references reflects extensive research on the topic of daylight and health.

Boyce, Peter. "Reviews of Technical Reports on Daylight and Productivity." ***The Daylight Dividends Program.*** **Troy, NY: Lighting Research Center at Rensselaer Polytechnic Institute, 2004.**
Dr. Peter R. Boyce is currently Professor Emeritus of Architecture at Rensselaer Polytechnic Institute and Head of the Human Factors Program for the Lighting Research Center at RPI. Prior to his work at RPI, Dr. Boyce researched the interaction of lighting and people in the UK for the electrical industry. The Daylight Dividends Program, began in 2003, is run by the Lighting Research Center at Rensselaer Polytechnic Institute in Troy, NY, and produces research and resources to building professionals to promote daylighting in buildings. This paper reviews the three 2003 reports authored by the Heschong Mahone Group on the topic of productivity and daylight in offices, retail stores and schools. The 2003 reports are included in this bibliography and attempt to replicate previous findings in similar studies published in 1999. Dr. Boyce reports that the studies in retail stores and schools fail to successfully replicate significant positive effects on productivity related to the presence of daylight and views in a space, and further insists that "whether daylight has a positive or negative effect on the outcomes studies depends on how it is delivered."

Boyce, Peter and Mark Rea. "Lighting and Human Performance II: Beyond Visibility Models Toward a Unified Human Factors Approach to Performance." (1006415) Palo Alto, CA: EPRI, VA: National Electrical Manufacturers Association and Washington, DC: U. S. Environmental Protection Agency Office of Air and Radiation, 2001.
Boyce describes this report as an update to the earlier 1989 version published by the National Electrical Manufacturers Association and the Lighting Research Institute, with three objectives: first, summarize research on the relationship between human performance and lighting, second, summarize progress found since the 1989 publication, and third, develop a research agenda for a more clearly understood and demonstrated relationship between lighting and human performance. The report, though clear in its intent and organization, is less directed to studies related to daylight and more broadly concerned with lighting in general.

Boyce, Peter, Claudia Hunter and Owen Howlett. "The Benefits of Daylight through Windows." ***Capturing the Daylight Dividend Program.*** **Troy, NY: Lighting Research Center at Rensselaer Polytechnic Center, 2003.**

The Daylight Dividends Program, began in 2003, is run by the Lighting Research Center at Rensselaer Polytechnic Institute in Troy, NY, and produces research and resources to building professionals to promote daylighting in buildings. This report comprises a literature review of articles on "the impact of daylight on human performance and workplace productivity; human health; and financial return on investment." The aim of this report is to first identify and summarize these topics in order to develop a research agenda for further work that includes "exploring the impact of daylight operating through the human circadian system on task performance," and "testing the biophilia hypothesis." Biophilia is further addressed by Loftness and Ulrich, below.

Collins, Belinda. "Windows and People: A Literature Survey: Psychological Reaction to Environments with and Without Windows." ***National Bureau of Standards Building Science Series 70*****. Washington, D.C.: GPO, 1975.**

Dr. Belinda Collins received her Ph.D. in experimental psychology (vision studies) from the University of Virginia and currently serves as the director of the Technology Services unit at the National Institute of Standards and Technology (NIST) having previously served as a research psychologist. The NBS states that the Building Science Series publications, including this literature review, are "directed toward the manufacturing, design, construction, and research segments of the building industry, standards organizations, and officials responsible for building codes." Collins' literature review cites 88 articles from 1959-1974, organized into subtopics supporting evidence for and against both windowed and windowless spaces of a variety of use-types. Benefits and psychological functions of windows discussed include: view, illumination, photobiology, post-surgical recovery time, absenteeism and perceived spaciousness.

Edwards, L. and P. Torcellini. "A Literature Review of the Effects of Natural Light on Building Occupants." (NREL/TP-550-30769) Golden, Colorado: National Renewable Energy Laboratory, 2002.

Dr. Paul Torcellini is the Team Leader of Commercial Buildings Research at the National Renewable Energy Laboratory (NREL) and has work with NREL for 14 years. Dr. Torcellini earned his PhD at Purdue University and is now called an expert in the energy performance of commercial buildings. NREL is described as "the only federal laboratory dedicated to the research, development, commercialization and deployment of renewable energy and energy efficiency technologies, and serves as the principal research laboratory for the Office of Energy Efficiency and Renewable Energy of the US Department of Energy. This literature review presents a summary of literature "commonly cited for showing the impacts of daylighting in

buildings," organized into light and building type. The first two sections introduce light in physical and biological terms, while the remaining sections summarize research available on the impact of daylighting in the office, schools, retail, healthcare facilities and industrial environments. The authors conclude that daylight leads to improved occupant health which benefits building owners and others due to an increase in productivity.

Figueiro, Mariana G., Mark Rea, Richard G. Stevens and Anne C. Rea. "Daylight and Productivity – A Possible Link to Circadian Regulation." In *Light and Human Health: EPRI/LRO 5th International Lighting Research Symposium,* edited by Terry McGowan and John Kesselring. (1009370) Palo Alto, CA: EPRI, and Danvers, MA: Osram Sylvaia, 2004.
Dr. Mariana Figueiro is currently a Program Director and Associate Professor at the Lighting Research Center at Rensselaer Polytechnic Institute in Troy, NY. Her research interests include photobiology research, energy efficient lighting and human factors in lighting. The Symposium is sponsored by the Lighting Research Office (LRO) at the Electric Power Research Institute (EPRI) who state as their goal: to organize, manage, review, publish and disseminate "significant lighting research worldwide." This study was conducted at a software development company in upstate New York with a total 120 desk spaces monitored throughout 81 offices; private offices were excluded. The findings do not directly link circadian regulation and productivity together, and instead suggest a likely relationship between the two based on higher productivity related to access to windows – and therefore daylight and views.

Heschong-Mahone Group. "Daylight and Retail Sales." *Integrated Energy Systems: Productivity and Building Science Program*. (P500-03-082-A-5) Sacramento: California Energy Commission, 2003.
Lisa Heschong is a licensed architect, Managing Principal of the Heschong Mahone Group, and Principal Investigator for the series of 2003 Integrated Energy Systems reports for the California Energy Commission. Her 30 years of experience includes building design and energy research and writing, including the well-known book *Thermal Delight in Architecture*, published in 1979. Produced under the CEC's Public Interest Energy Research Program (PIER) as part of the State's larger goals for energy research and development, the reports aim to "bring to market energy technologies that provide environmental and economic benefits to California's ratepayers." This report documents follow-up to an earlier study by the same authors on the topic of skylights and their influence on retail sales, and studies 73 stores over 24 months between 1999 and 2001. The authors present the study as evidence that a "major retailer is experiencing higher sales in daylit stores than in similar non-daylit stores," with an average effect of 0-6% and a direct connection to the amount of parking provided as well.

Heschong-Mahone Group. "Windows and Classrooms: A Study of Student Performance and the Indoor Environment." ***Integrated Energy Systems: Productivity and Building Science Program*****. (P500-03-082-A-7) Sacramento: California Energy Commission, 2003.**

This study, also follow-up to earlier work on the same topic in 1999, uses measured improvement on standardized math and reading tests over the course of an academic year as a method for analyzing what effect daylight and other characteristics of indoor environments have on student learning. Over 8000 students in grades 3-6 in the Fresno Unified School District were compared using regression analysis to isolate the effect of particular variables on desired outcomes of improved learning. General conclusions outlined by the authors include the positive effects of evenly distributed light, extensive views. The authors also note the potential negative side effects of glare, thermal heat gain and, most importantly in schools, poor acoustics.

Heschong-Mahone Group. "Windows and Offices: A Study of Office Worker Performance and the Indoor Environment." ***Integrated Energy Systems: Productivity and Building Science Program*****. (P500-03-082-A-9) Sacramento: California Energy Commission, 2003.**
This study, also follow-up to earlier work on the same topic in 1999, is based on a series of five cognitive tests delivered to 201 employees of the Sacramento Municipal Utility District working in three different buildings. The tests were administered via each participant's desktop computer over five weeks from mid-October to November on successive Thursdays, and tested productivity through numerous variables like visual acuity and short-term memory. Access to the best views out of a window, "gauged primarily by the size of the view and secondarily by greater vegetation content," is reported as the most significant environmental influence on worker performance with an average increased call processing time of 6-12% and improvements of 10-25% on the mental function and memory recall portions of the cognitive tests. Conversely, the greatest glare potential from primary view windows had a negative effect, decreasing performance by 15-21%.

Kim, Jong-Jin and Jean Wineman. "Are Windows and View Really Better? A Quantitative Analysis of the Economic and Psychological Value of Views." ***The Daylight Dividends Program.*** **Troy, NY: Lighting Research Center at Rensselaer Polytechnic Institute, 2005.**
Dr. Jong-Jin Kim is currently an Associate Professor of Architecture and Dr. Jean Wineman an Associate Dean at the Taubman College of Architecture and Urban Planning at the University of Michigan. Dr. Kim specializes in research on daylighting, airflow modeling and sustainable design, Dr. Wineman in environmental programming, design and evaluation. The Daylight Dividends Program, began in 2003, is run by the Lighting Research Center at Rensselaer Polytechnic Institute in Troy, NY, and produces research and resources to building professionals to promote daylighting in buildings. In order to quantify the types of value frequently assumed on views to the exterior, Kim and Wineman construct two specific sets of

data. The first part of the analysis is based on a cost-height ratio determined with data from the 2002 BOMA Experience Exchange Report as well as a simple survey conducted via telephone to a total of 21 hotels, 15 residential buildings and 22 office buildings in Chicago, New York and Los Angeles. The second part of their analysis is based on seating preference observations collected over 3-4 days (each) at a cafeteria and library on the University of Michigan campus in Ann Arbor, Michigan. The authors conclude that views are consistently factored into the cost of the buildings they studied. They also observed preferences for seating available with the best views as opposed to those seats available further away from the windows. This remains true until the spaces become more fully occupied at which point seating is more often chosen in line with patterns of even distribution throughout the entire space.

Lawrence Berkeley National Laboratory. "Indoor Air Quality Scientific Findings Resource Bank: Impacts of Indoor Environments on Human Performance and Productivity." http://www.iaqscience.lbl.gov/performance-summary.html (Accessed December 23, 2011).

The Lawrence Berkeley National Laboratory is supported by the US Department of Energy (Office of Science) and managed by the University of California as part of a national system of laboratories. The lab had a 2011 budget of $836 million and is located near the UC Berkeley campus; the lab was founded in 1931 by Ernest Orlando Lawrence, a Nobel prize-winning physicist at UC Berkeley. The Indoor Health and Productivity project is referenced by Heschong Mahone Group in their 2003 report on Office Workers, and at that time was noted as a project sponsored by the National Science and Technology Council of the White House. The project is currently located within the LBNL with funding from the US Environmental Protection Agency (EPA) as part of its Indoor Air Quality Scientific Findings Resource Bank (IAQ-SFRB), published online in April 2008. The LBNL state an aim for the IAQ-SFRB to serve as an open resource for public health and building professionals as well as any others "who seek scientific information about the effects of IAQ on people's health or work performance." It is not clear how often the website resource is updated though the last "substantial update" is noted as March 2009.

Leaman, Adrian and Bill Bordass. "Productivity in Buildings: The 'Killer' Variables." *Building Research & Information* 27.1 (1999): 4-19.

Adrian Leaman and Bill Bordass, together, direct the Usable Buildings Trust, a non-profit research organization in the UK, and are credited as having more than thirty years' experience, each, assessing the performance of buildings based on both occupant satisfaction and technical performance. The UBT was born out of their work on the Probe Team, having published a series of twenty building case studies in the CIBSE Journal between 1995 and 2002. Subtitled "Feedback and strategy for better buildings," the UBT states that recent projects aim to make feedback and knowledge management, including building evaluation techniques, more

accessible and routine for building designers and clients alike. This paper specifically addresses "killer" variables – within the design, management and use of indoor environments – identified by the authors by which losses or gains of up to 15% in employee turnover/retention might be attributed. The "killer" variables are organized into four clusters: personal control, responsiveness, building depth and workgroups. The discussion in terms of building depth is most relevant to the benefits of glass as daylight and views are noted as corollaries to the preference for limiting building depth to 15 meters, wall to wall.

Loftness, Vivian and Megan Snyder. "Where Windows Become Doors." In *Biophilic Design*, edited by Stephen Kellert, Judith Heerwagen, and Martin Mador, 175-187. New York: Wiley, 2008.

Vivian Loftness is currently a Professor of Architecture in the School of Architecture at Carnegie Mellon University, having previously served as the Head of the Architecture School from 1994-2004. Loftness has over thirty years of experience in work and research on the topics of environmental design and sustainability, advanced building systems and systems integration; she earned her Masters of Architecture degree from MIT. The book Biophilic Design is edited by Stephen Kellert and others, and presents biophilic design methodologies as part of a paradigm shift in how we design and construct buildings. Biophilia is a term first used by social psychologist Erich Fromm to describe an attraction to all things alive and vital and was then used by E.O. Wilson, a popular figure in environmental sustainability, as a title for his book and to describe a connection subconsciously sought by humans with the rest of life. Dr. Stephen Kellert is currently a Professor Emeritus of Social Ecology and a Senior Research Scholar at the Yale University School of Forestry and Environmental Studies. The publisher notes that the book is written for building professionals (architects, landscape architecture, planners, etc) as well as building owners. The chapter written by Loftness and Snyder conceptualizes the window as a door that "ensures access" to a number of important, rich qualities like daylight, views, fresh air and climate. The authors refer to numerous studies as a means of supporting the importance of windows and the access they provide to building occupants, and conclude the article by identifying an area of further needed work: transparency in an urban setting as a means of connecting people to people as much as we are concerned with connecting people to nature.

Schittich, Christian, Gerald Staib, Dieter Balkow, Matthias Schuler, and Werner Sobek. *Glass Construction Manual*. Basel: Birkhäuser, 1999.

Christian Schittich is currently the editor-in-chief of the German magazine DETAIL since 1998, having been on staff since 1992. Schittich completed a degree in architecture at the Technical University of Munich and worked in an architectural firm for seven years. *Glass Construction Manual* is an addition to a series of books authored by Edition DETAIL and published by

Birkhauser – "Publishers for Architecture," meant as construction manuals for architects and engineers. The book is organized into four parts: (1) "Glass in architecture" presents a number of short essays around historic architectural periods of design and topics like 'Baroque' and "The dream of the glass house;' (2) "Principles" describes glass and its material properties relative to architecture, including different types of glass, its structural capacity and its relationship to energy. Parts 3 and 4 present "Construction details" and "Built examples," respectively, and include detailed drawings along with project information to illustrate particular applications and uses of glass.

Schittich, Christian, Werner Lang and Roland Krippner. *In Detail: Building Skins*. Basel: Birkhäuser, 2002.
Building Skins is an addition to a series of *In Detail* books authored by Edition DETAIL and published by Birkhäuser – "Publishers for Architecture," meant as references for architects and engineers. The book begins with three essays on the topic of the building façade before presenting a series of 28 case studies with project descriptions, photographs and detailed design drawings. Glass is one material among many considered in both the essays and case studies, though it is recognized one of the most important for contemporary design because of the aesthetic and creative opportunities it offers to building designers, occupants and owners.

Seppanen, Olli, William J. Fisk and David Faulkner. "Control of Temperature for Health and Productivity in Offices." *ASHRAE Transactions* 111 (2005): 680-686.
Together the authors represent the Helsinki University of Technology's Institute of Heating, Ventilation and Air Conditioning and the Lawrence Berkeley National Laboratory's Indoor Environment Department. This article was published in the journal of the American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and funded by both the Finnish and U.S. governments. The purpose of the article is to provide an economic model for quantifying the cost implication of thermal comfort related directly to human performance, which is approximated to be a 2% productivity loss for every degree Celsius rise above 25 ºC. Low temperature data is not as readily available. This study focuses very specifically on the issue of air temperature and does not cite specifically the role of glazing and its effect on internal temperature, nor on radiant temperature sensations that many have an impact on occupant productivity.

Singh, Amanjeet, Matt Syal, Sue C. Grady and Sinem Korkmaz. "Effects of Green Buildings on Employee Health and Productivity." *American Journal of Public Health 100:*9 (2010): 1665-1668.
At the time of the study, Singh, Syal and Korkmaz were associated with the School of Planning, Design and Construction at Michigan State University in East Lansing, Michigan. Sue Grady is

with the Geography Department at the same University. The study was funded in part by the Environmental Research Initiative of the Environmental Science and Policy Program at Michigan State University. The study included survey results from 263 people divided into two case studies; the participants were surveyed pre- and post-move as they moved into new workspaces that were LEED certified. Significant health and productivity benefits were recorded as part of the self-reported survey results, though the authors note that the pre-move surveys were administered a number of weeks after the actual move and therefore realize the potential for bias as well as the Hawthorne effect in which results may be skewed due to satisfaction simply with the newness of the place.

Spectrum Associates Market Research Incorporated. *Daylight Dividends: Focus Group Research Project Final Report*. Farmington, CT: Spectrum, May 2003.
Led by Dr. Eliot Hartstone, founder of Spectrum Associates in 1986, Spectrum Associates Market Research Inc. advertises "extensive experience with qualitative and quantitative research methodologies." Dr. Hartstone received his PhD in Sociology from New York University and has a varied list of clients and industries for whom he has completed and published research studies; they include education, energy, federal government agencies, health care, manufacturing and retail. The Daylight Dividends Program, began in 2003, is run by the Lighting Research Center at Rensselaer Polytechnic Institute in Troy, NY, and produces research and resources to building professionals to promote daylighting in buildings. This report presents key findings from five focus group sessions of 48 participants that were either building designers (architects, engineers, lighting designers) or building end-users (owners, developers, managers). The sessions were held in New York City, Portland, Oregon, Charlotte, North Carolina, and Des Moines, Iowa and focused on recording and discussing perceptions the participants held toward daylight and its benefits and barriers. The perception was found to be in favor of, by an overwhelming majority of 94%, "widespread use of natural light."

Ulrich, Roger S. "Biophilic Theory and Research for Healthcare Design." In *Biophilic Design*, edited by Stephen Kellert, Judith Heerwagen, and Martin Mador, 87-105. New York: Wiley, 2008.
Dr. Roger S. Ulrich is currently a Professor in the Department of Architecture at Texas A&M University, and holder of the Endowed Professorship in Health Facilities Design. Dr. Ulrich earned his PhD from the University of Michigan in Human/Behavioral Geography and his research work focuses on healthcare design at the building, landscape and urban scale where evidence-based design knowledge has been applied; his research on the effects of daylight and views in healthcare settings is frequently cited by others. The book Biophilic Design is edited by Stephen Kellert and others, and presents biophilic design methodologies as part of a paradigm shift in how we design and construct buildings. Biophilia is a term first used by social

psychologist Erich Fromm to describe an attraction to all things alive and vital and was then used by E.O. Wilson, a popular figure in environmental sustainability, as a title for his book and to describe a connection subconsciously sought by humans with the rest of life. Dr. Stephen Kellert is currently a Professor Emeritus of Social Ecology and a Senior Research Scholar at the Yale University School of Forestry and Environmental Studies. The publisher notes that the book is written for building professionals (architects, landscape architecture, planners, etc) as well as building owners. The chapter written by Dr. Ulrich draws on decades of his research and is organized around health outcomes and stress as the two primary methods by which one might understand the effect daylight and views have in a healthcare setting: daylight and views are consistently found to reduce stress, pain and depression in patients, reducing recovery time and thereby improving the hospitals ability to care for more patients.

Wang, Nora and Mohamed Boubekri. "Design Recommendations Based on Cognitive, Mood and Preference Assessments in a Sunlit Workspace." ***Lighting Research & Technology*** **43:55 (2011): 55-72.**

Dr. Nora Wang completed a Masters degree in Architecture in Singapore prior to earning her PhD at the University of Illinois at Urbana-Champagne. She specializes in daylighting design, behavioral study, and building performance analysis as a researcher at the Pacific Northwest National Laboratory in Richland, Washington. Dr. Mohamed Boubekri is currently an Associate Professor of Practice & Technology in the College of Fine and Applied Arts at the University of Illinois at Urbana-Champagne. He received his PhD in Architecture from Texas A&M University and currently serves as the Chair of the Practice & Technology Faculty in the School of Architecture at UIUC and as a Member of the Daylighting Committee for the Illuminating Engineering Society of North America (IESNA). The journal *Lighting Research and Technology* was first published in March 1969 and aims to publish "original research on all aspects of light and lighting." The authors of this article present design recommendations for daylighting following a study of cognitive performance, mood impact and observed seating preference within a single-occupancy office space. Wang and Boubekri contend that daylighting design guidelines continue to focus on daylight factors and windows sizes instead of a more human-oriented design approach that considers specific behaviors related to mood, preference and cognition.

Wigginton, Michael and Jude Harris. ***Intelligent Skins*****. Oxford: Butterworth-Heinemann, 2002.**

Michael Wigginton is an architect and author, known for his 1996 book *Glass in Architecture*, a history of and handbook for designers of glass buildings. Wigginton served as Head of the School of Architecture in 1996 and as a member of the Management Committee for a European Union research program on glass and interactive building envelopes. The book is the result of a

10-stage research program proposed by Wigginton in 1995 and named the Intelligent Façade Programme; the first task of the program was a case study review. The book is organized into 8 chapters and 22 case studies. The chapters present the terms by which the “intelligent skin” is meant to be understood, and the case studies work as evidence in further support. While little of the text in the chapters are specific to glazing, each case study includes a section describing the material properties and intended performance of the glass. One case study also states “The glazing gives the GSW tower its character.” (51) It may also be surmised that an intelligent skin has a substantial amount of glazing – this assumption is supported by the high façade transparency figures (typically 45-100%) recorded for each of the 22 case studies.