II

RESEARCH ARTICLES

RESEARCH

EFFECTS OF SEMI-TRANSPARENT GLAZING ON THE EMOTIONS OF OFFICE WORKERS

Keith Everette Sylvester, Ph.D.[1] and Jennifer Lynn Bowler, Ph.D.[2]

ABSTRACT
The use of sunlight has always been a major goal of architects and building owners in the design and operation of commercial buildings to minimize electrical consumption when using artificial lighting. However, glazing systems that are designed to allow optimal visible light transmission also allow significant unwanted direct solar gain. Conversely, glazing systems that are designed to reflect unwanted direct solar heat gain significantly reduce the transmittance of visible light through windows. Semi-transparent window glazing reduces light transmission through windows resulting in unknown effects of the natural illumination of spaces on emotional perceptions of office workers. A survey was administered to assess the emotional effect of office spaces that use semi-transparent glazing as compared to clear glazing during daylight hours. Computer visualization software was used to create animated recordings of an office environment, and a modified lighting approach was used to compute accurate solar irradiance levels for various geographic locations. While an analysis of variance revealed significant differences in satisfaction between groups, the differences did not create negative emotional responses to glazing with lower transmittances.

KEYWORDS
daylighting, computer simulation, human appraisal

INTRODUCTION
A primary goal in the design and operation of commercial buildings is the use of sunlight to minimize electrical consumption in artificial lighting environments (Riisberg & Boutrup, 2010). Glazing systems that are designed to reflect unwanted direct solar heat gain significantly reduce the transmittance of visible light through windows. Conversely, it is believed that the comfort of buildings depends upon lighting, view, and privacy (Schuster, 2006). As a result, glazing systems are designed to allow optimal visible light transmission which results in significant direct solar gain in the near infrared region of the light spectrum. Still, according the 2003 Commercial Building Energy Consumption Survey (CBECS), U.S. commercial buildings alone accounted for 6.5 quadrillion BTUs of energy in the form of heating

[1]Architectural and Manufacturing Sciences, 1906 College Heights Blvd., Western Kentucky University, Bowling Green, KY 42101-1066, 270.745.4021 Office, keith.sylvester@wku.edu.
[2]Department of Psychology, 104 Rawl Building, East Carolina University, Greenville, NC 27858, 252-328-6474, bowlerj@ecu.edu.

and cooling loads, incurring $108 billion in costs (Office of Energy Markets and End Use, 2006). While compromises between daylight transmittance and thermal performance are necessary when using traditional glazing systems, this research seeks to eliminate such compromises by significantly optimizing the thermal performance of glazing with maintained or improved light transmittance to interior spaces. Glazing systems thus fulfill important roles in buildings in the 21st century (Gustavsen, Jelle, Arasteh, & Kohler, 2007). According to Selkowitz (1999), the major energy performance challenges for glazings are 1) to control heat loss, 2) to admit daylight with minimal solar heat gain, 3) to dynamically control solar heat gain and glare, and 4) to redirect incident daylight for more effective use in buildings. While compromises between daylight transmittance and thermal performance are necessary when using traditional glazing systems, this research seeks to understand the relationship between reduced daylighting and visibility created by semi-transparent coatings that are applied to window glazing.

Within the building community, many unanswered questions abound with regard to the design and use of semi-transparent glazed windows in commercial buildings. Although these concerns are primarily quantitative in nature, qualitative issues continually arise. The National Renewable Energy Laboratory (NREL) has stated that the greatest environmental concern surrounding reduced light transmission of windows is its aesthetic effect on relevant occupants (Anson, Sinclair, & Swezey, 1993).

Prior research has garnered convincing support for individual preference for windows in their indoor work spaces (Biner & Butler, 1989). Most people clearly favor the visual presence of daylight or sunshine to artificial light in offices (Collins, 1975) (Keighly, 1973) (Markus, 1967) (Wotton & Barkow, 1983). These studies indicate a positive relationship between the size of the windows and people's penchant for them. In short, larger windows that allow more daylight and sunshine into work spaces are generally preferred over smaller ones that do not.

However, additional research suggests that subjective responses to window preference are primarily influenced by previous standards in building construction rather than by personal preferences (Biner & Butler, 1989). Moreover, this line of research evidenced greater variability in window preferences and factors than prior studies had indicated. Hence, the effect of reduced light transmission and visibility of semi-transparent glazing on individual preference is unclear. However, Cuttle's (1983) research suggests that a positive linear relationship exists between transparency (visibility) of semi-transparent windows and individual aesthetic preferences. Accordingly, the current study investigates whether semi-transparent windows can produce a view that is equally acceptable to office occupants as the view produced by clear glass.

Assessment Measures

Previous research indicates that three dimensions—arousal, pleasure, and dominance—are required to assess the affective attributes that an individual assigns to his or her environment. Measurement of these three dimensions was suggested by semantic differential evidence of Osgood (1996). In addition, other multidimensional scaling studies of such influencing parameters indicate that, in addition to dominance, several secondary dimensions beyond arousal and pleasure exist that are cognitive in nature. When describing individual emotional states, however, Russell and Pratt (1980) assert that only two orthogonal and bipolar dimensions—pleasure and arousal—are required. On these grounds, the Affect Grid was developed in an effort to assess pleasure and arousal simultaneously as independent dimensions, where pleasure is the polar opposite of displeasure and arousal is the polar opposite of sleepiness. The reliability of the Affect Grid was established using a comparative analysis of scales within four experiments: a) group ratings of emotion-related words, b) group ratings of facial expressions of emotion, c) individual ratings of facial expressions, and d) mood (Russell & Pratt, 1980). The scales compared in their study were: a) direct circular scaling, b) multidimensional scaling, c) unidimensional scaling, d) semantic differential scales of pleasure and arousal, and e) Positive and Negative Affect Schedule (PANAS) (Watson, Clark, & Tellegen, 1988). The Affect Grid displays strong evidence of convergent validity with other measures of pleasure and arousal, and thus was chosen for use in the current study to assess the emotional effects of the transmittance of various window glazing on occupants of a typical office space during daylight hours.

Optical Properties of Window Glazing

Semi-transparent glazing has been proven effective in reducing energy use and offsetting high-energy consumption in commercial buildings,. In primarily cold climate regions, infrared heat is reradiated back into the space, thus minimizing heat loss. In primarily hot climate regions, the location of the semi-transparent coating is reversed, causing infrared heat to be reflected to the outside, minimizing heat gain. Measured optical properties of such advanced glazing are necessary inputs for computer simulation programs. These measurements are used to determine the energy performance of window glazing and its effects on a building's energy use. These data also determine numeric measurements to quantify the transmitted light and its spatial distribution. Such quantitative assessments are necessary for the successful implementation of advanced glazing concepts by architects, engineers and constructors. In the current study, transmittance calculations (Ishikawa, 1994) were used to calculate the transmittance of the semi-transparent window glazing (Sylvester & Haberl, 2000).

Measurement

When assessing simulated environments, the validity of the appraisal is contingent upon the presentation method (Danford & Williams, 1975). These methods include the use of a) the actual environment, b) scale models, c) slides, d) photographs, and e) a video recording of an actual environment. In the interest of time, cost, efficiency, and ease of analysis, studies of human responses to environmental stimuli by Danford and Williams (1975) used simulations such as scale models rather than the actual environment. They discovered that the reproduction of pertinent environmental properties and the selection of a reliable means of simulating those properties elicited responses that concurred with those elicited by the actual environment (Bechtel, Marans, & Michelson, 1987). However, the comprehensive perception of solar and related shadow motions for daylight hours cannot rely on these techniques alone and require computer-generated techniques to efficiently assess changing real-world conditions (Proffitt & Kaiser, 1986). Consequently, time-lapse animated sequences of a computer-generated office environment were employed in this study.

State-of-the-art computer programs use radiosity algorithms to define global illumination within virtual environments. Specifically, radiosity algorithms simulate the behavior of light including the light transfer between three-dimensional objects (Nielsen & Christensen, 2002). To increase the realism of the environment, three-dimensional objects interact with light using physical attributes of texture, reflectance, color, specularity (shininess), and opacity, in addition to rendering quality. Significant technological advancements in rendering algorithms and the subsequent quality of recorded virtual events have been made. Conversely, the use of radiosity software still requires considerable time investment for the setup and rendering of computer animated sequences within three-dimensional environments. While radiosity algorithms allow for accurate definition of general global illumination, they do not make complex lighting calculations that allow the interactions of varying solar irradiance levels by location, time of day (solar angle), and window transmittance to be assessed. In order to account for these conditions, a modified lighting approach was developed using solar engineering computations.

The current study employed animation software that allows expedient and controlled animation of lighting variables such as solar irradiance levels and the position of the sun. In order to obtain a numerically accurate simulation with reference to lighting, the solar irradiance levels were calculated using Fresnel equations (F-Chart Software, Inc., 2008) and scaled for input into the visualization software.

METHOD

In order to examine the psychological effects of visible light transmittance and visibility of windows on office occupants, this study targeted high-rise buildings within densely populated urban centers in the United States. A representative city with a human population greater than one million was selected within each U.S. census region (Northeast, Midwest, South, and West). For those census regions in which more than one city met the selection criterion, the city with the largest population was used. In this study, solar irradiance levels for New York (Northeast), Detroit (Midwest), Houston (South) and Los Angeles (West) were used. Overall, the contribution of daylight will be greater for the window view as compared to the non-window view (Aries, Begemann, S., Zonneveldt, & Tenner, 2002). While such high light levels resulting from the window view are favorable, this research quantifies the emotional effects of varying visible light transmittance on office workers.

Sample

Data were collected from 188 undergraduate students. The average age of the participants was 20 years old, and 67% of the sample was male. Because computers were used to simulate a real-world environment, the mode of analysis is discussed in relation to material and light properties within the office environment. Using the Affect Grid to measure arousal and pleasure as independent variables, the participants anonymously responded to window stimuli by selecting the squares that corresponded to their feelings. The mean score for each window treatment response was computed. These data were averaged across subjects for all trials: $2 \times 4 \times 2$ (transmittance/visibility × solar condition for each census region × transmittance levels –100% and 40%). An analysis of variance was then used to test for significantly different treatment means (Figure 1). "A" represents the view (Window or Non-Window), "B" represents the solar characteristics of the site (Houston, Detroit, Los Angeles, or New York), and "C" represents the window treatment (100% vs. 40% transmittance).

Response Format

As shown in Figure 2, the Affect Grid is a square grid abstraction of the "circular ordering of eight descriptors" (Russell, Weiss, & Mendesohn, 1989). The center of the square represents a neutral, average, everyday feeling. In this study, the participants used the Affect Grid to denote arousal and pleasure as independent variables, one along each axis. The pleasure/displeasure score is taken as the number of the square checked, with squares numbered along

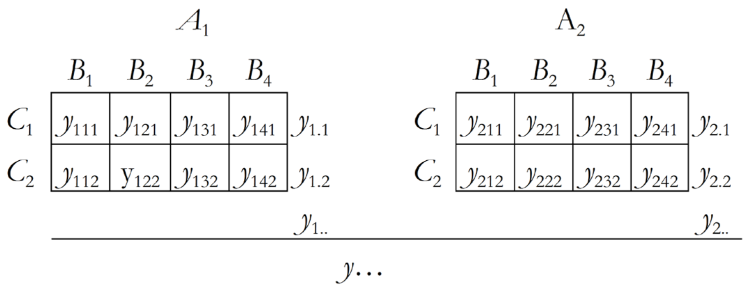


FIGURE 1. Humans Assessment Model.

the horizontal dimension, counting one to nine, starting from the left. The arousal/sleepiness score is taken as the number of the square checked, with squares numbered along the vertical dimension, counting one to nine, starting from the bottom. To put these data in perspective, a score of five represents a normal, everyday feeling. A score of six or more indicates that the subjects experienced higher degrees of arousal or pleasure, and a lower score indicates that the subjects experienced higher degrees of sleepiness or displeasure. These measurements are based on a scale from one to nine.

Abstraction of the Affect Grid

Due to the size of the study population, a general-purpose answer sheet was used to solicit responses and automate the evaluation process. The answer sheet used in this study was a general purpose answer sheet and was scanned by the Measurement and Research Service to increase accuracy and to economize time.

Figure 2 has been recreated using figures created by Russell and Pratt (1980). The horizontal dimension represents pleasure in which the right half of the grid represents pleasant feelings and the left half represents unpleasant feelings. The vertical dimension of the map represents the degree of arousal, which denotes how wide-awake, alert or active a person feels, independent of whether this sensation is positive or negative. Russell and Pratt also state that the top half denotes feelings that are above average in arousal and the bottom half indicates feelings that are below average, including sleepiness.

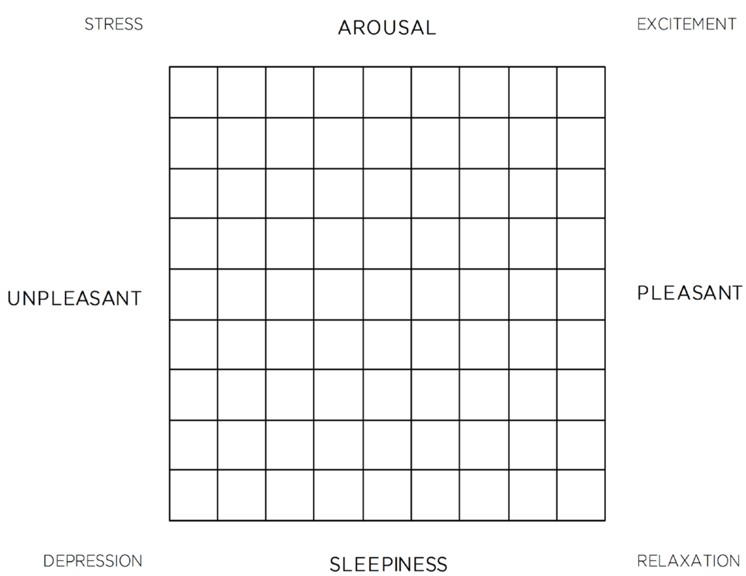
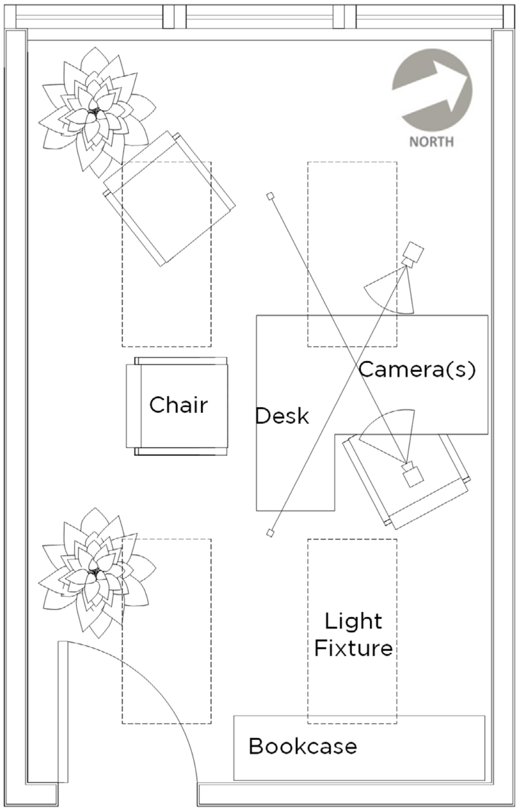
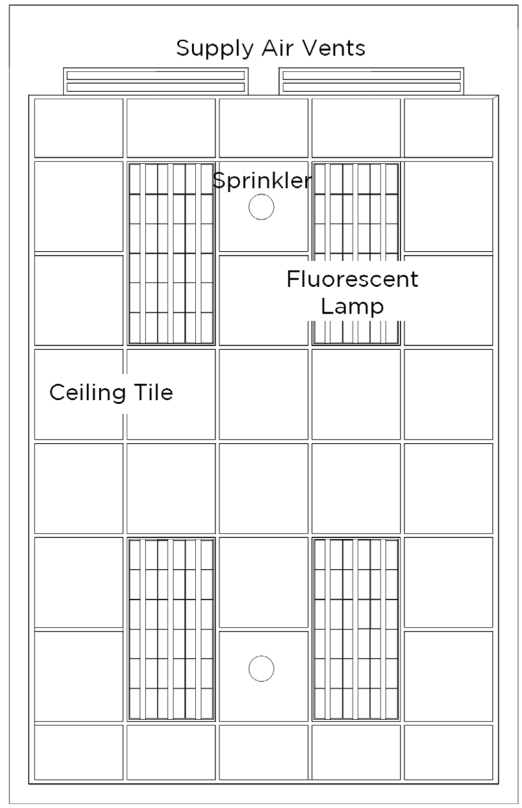


FIGURE 2. Affect Grid.

FIGURE 3. Floor Plan and Reflected Ceiling Plan of a Typical Office Space.





The Simulated Environment: Typical Office Space

As shown in Figure 3, the dimensions of the simulated office space were 10 feet by 15 feet and has windows with a westward orientation. The floor space contained two plants, three chairs, a desk, and a bookcase. The ceiling contained fluorescent light fixtures with three 32-watt lamps each, two sprinkler heads, a 2′ × 2′ ceiling tile layout, and supply air vents. Return air vents were incorporated in a 1/4 inch gap on the periphery of each light fixture. Major materials consisted of carpet on the floor, a painted metal door, eggshell-painted walls, gray base molding, textured ceiling tile with a white grid support, and glazing material of the window. The major surfaces (the floor, the walls, the roof and the desktop) have been assigned recommended reflectances (International Energy Agency, 2000). In adherence with daylight monitoring protocols for private office spaces (Atif, Love, & Littlefair, 1997), two observation points were selected representing the brightest and darkest locations and camera positions for window and non-window views.

Mode of Simulation

While full scale in situ testing would provide the actual behavior of the office space (Wolf & Gall, 2006), the physical behavior of light in this research is defined within computer simulation. This research identifies a relative effect when reducing visible light transmission in glazing. To account for the complex physical properties of materials in the office environment,

TABLE 1. Window Glazing Properties.

Type	U-factor (W/m^2K)	SC	SHGC	RHG (W/m^2)	Tvis	Keff (W/m^2K)
Clear	2.730	0.877	0.763	576	0.8140	0.0669
Semi	2.158	0.568	0.494	376	0.5200	0.0466

U-factor is the amount of heat gain or loss through a substrate as a result of indoor and outdoor temperatures.

SHGC is known as the solar heat gain coefficient and is the amount of solar energy that is absorbed or transmitted to interior spaces.

SC is the shading coefficient and is the ratio of heat gain comparing standard 1/8″ clear glass to a material under similar conditions.

RHG is the relative heat gained from passing through the glass.

Tvis is the visible transmittance percentage.

Keff is the total effective conductivity of all components of the glazing system except the inner and outer glazing layers.

The values above were calculated using Window 6 Glazing Simulation Software.

material and light properties were defined using real-world properties and translated within the visualization software. Thus, it is important to examine the extent to which the simulation approximates real-world conditions using known quantifiable variables. For the purpose of this study the specularity and shininess of simulated objects were matched to average surface reflectance values (Rea, 2000) and color and texture variables were adjusted subjectively.

To determine the visible transmittance of the two window conditions, Window 6 glazing simulation software was used. For the semi-transparent glazing layer, a circular laser cutting method (Ishikawa, 1994) was assumed to define the effects of a solar coating with 40% visible transmittance through the back of the front layer, typical of conditions in hot and humid climates (Sylvester & Haberl, 2000) (Table 1). Each double glazed system was simulated in the glazing simulation software (Lawrence Berkley National Laboratory, 2010). An approximate 30% difference in visible transmittance was noted. With regard to lighting, light fixtures were recessed and contained three T8, 32-watt fluorescent lamps, which translated into 96 watts (6720 lumens) per fixture. Because the lights remained on throughout the simulation, effects of the artificial lights were primarily inspected for visual correctness. The summer solstice (June 21) with clear sky conditions was fixed for each site, while the period of daylight hours, from sunrise to sunset, varied according to the solar calculations. The hourly solar irradiance levels striking the windows were determined using time series plots from solar engineering software (F-Chart Software, Inc., 2008) and the path of the sun for each selected site was determined using the internal programming of the visualization software (Table 2 and Table 3).

Specifically, solar irradiance levels were scaled to light levels of the visualization software ranging from zero (lowest) to 255 (highest). All sites were grouped, and the highest solar irradiance level was assigned the highest lighting level of the software. All light was considered white in color. In addition, sunlight levels were calibrated and magnified to account for the increased light intensity of the sun as compared to artificial light sources.

Likewise, the interior reflected light of the sun was calculated by offsetting the scaled time series plots with the total average surface reflectance (47%) of the interior objects. However, only one interaction of reflection was considered to approximate all reflected light of the sun and artificial sources. When necessary, the calculated reflected light was again adjusted to account for decreased light entering the space for solar controlled window conditions (as shown in Tables 2 and 3).

TABLE 2. Solar Irradiance Values for Clear Glazing.

Time	Houston		Los Angeles		Detroit		New York	
	Sim. Sun	Refl. Light	Sim. Sun	Refl. Light	Sim. Sun	Refl. Light	Sim. Sun	Refl. Light
5-6	6.06	1.82	8.47	2.54	12.70	3.81	11.59	3.48
6-7	24.02	7.21	28.20	8.46	35.13	10.54	32.26	9.68
7-8	63.88	19.16	81.12	24.34	77.32	23.20	70.41	21.12
8-9	107.51	32.25	137.98	41.39	121.96	36.59	110.85	33.26
9-10	148.37	44.51	191.08	57.32	163.28	48.98	148.33	44.50
10-11	180.12	54.04	232.38	69.71	195.18	58.55	177.29	53.19
11-12	197.49	59.25	255.00	76.50	212.58	63.77	193.10	57.93
12-13	197.49	59.25	255.00	76.50	212.58	63.77	193.10	57.93
13-14	180.12	54.04	232.38	69.71	195.18	58.55	177.29	53.19
14-15	148.37	44.51	191.08	57.32	163.28	48.98	148.33	44.50
15-16	107.51	32.25	137.98	41.39	121.96	36.59	110.85	33.26
16-17	63.88	19.16	81.12	24.34	77.32	23.19	70.41	21.12
17-18	24.02	7.21	28.20	8.46	35.13	10.54	32.26	9.68
18-19	6.06	1.82	8.47	2.54	12.70	3.81	11.59	3.48

Source: (Sylvester & Haberl, 2000)

TABLE 3. Solar Irradiance Values for Semi-transparent Glazing.

Time	Houston		Los Angeles		Detroit		New York	
	Sim. Sun	Refl. Light	Sim. Sun	Refl. Light	Sim. Sun	Refl. Light	Sim. Sun	Refl. Light
5-6	2.42	0.73	3.39	1.02	5.08	1.52	4.64	1.39
6-7	9.61	2.88	11.28	3.38	14.05	4.22	12.90	3.87
7-8	25.55	7.67	32.45	9.73	30.93	9.28	28.17	8.45
8-9	43.00	12.90	55.19	16.56	48.78	14.64	44.34	13.30
9-10	59.35	17.80	76.43	22.93	65.31	19.59	59.33	17.80
10-11	72.05	21.61	92.95	27.89	78.07	23.42	70.92	21.27
11-12	79.00	23.70	102.00	30.60	85.03	25.51	77.24	23.17
12-13	79.00	23.70	102.00	30.60	85.03	25.51	77.24	23.17
13-14	72.05	21.61	92.95	27.89	78.07	23.42	70.92	21.27
14-15	59.35	17.80	76.43	22.93	65.31	19.59	59.33	17.80
15-16	43.00	12.90	55.19	16.56	48.78	14.64	44.34	13.30
16-17	25.55	7.67	32.45	9.73	30.93	9.28	28.17	8.45
17-18	9.61	2.88	11.28	3.38	14.05	4.22	12.90	3.87
18-19	2.42	0.73	3.39	1.02	5.08	1.52	4.64	1.39

Source: (Sylvester & Haberl, 2000)

Environmental conditions such as solar angle, irradiation, and luminance were defined within the simulated environment. Due to dynamic conditions of daylighting and the controlled transmittance of the glazing, numerical calibration of the simulated environment with real-world conditions were not required.

FIGURE 4. Typical Window and Non-Window View at 5 pm CST.

Procedure

Time-lapse animated segments representing a single day were used to measure the arousal and pleasure effects for window and non-window views in each location using clear and semi-transparent glazed windows. Following standard instructions, participants viewed a videotape of 16 randomly-ordered animated sequences

Each animated segment was shown twice, and participants were only allowed to respond during the second viewing. For five seconds, the video displayed a preparatory segment and notification that the sequence was about to begin. Following this, a digital image sequence appeared as a time lapse representation of one day from sunrise to sunset. For the initial screening the segment lasted for 15 seconds and for the final screening the segment lasted for 10 seconds. Finally, text stating "Please record your response" was displayed on a blank screen for 10 seconds. In total, 16 sequences were shown. Figure 4 represents a sample animated sequence created for Houston on the summer solstice (June 21st) from sunrise to sunset. The windows in this sequence feature 100% transmittance.

Using the Affect Grid to measure arousal and pleasure, each participant anonymously responded by marking the square that best represented his or her feelings. The mean for each treatment response was computed and averaged across subjects for all trials. Analysis of variance (ANOVA) procedures are commonly used to assess whether the means of several groups differ significantly. Thus, a 2 × 4 × 2 (view for window and non-window positions × solar conditions for each census region × transmittance/visibility levels for clear and semi-transparent glazing – 100% and 40%) ANOVA was conducted to assess the variance in the mean scores for each group. In addition, general comments were solicited to establish the validity of the simulated environments with regard to real-world conditions.

RESULTS

The mean scores for arousal and pleasure displayed in Figure 5 indicate that participants experienced moderate levels of both of these affective states across all conditions. With regard to arousal, results of the ANOVA (displayed in Table 4) indicate significant main effects for view (window vs. non-window), location, and glazing (clear vs. semi-transparent). In addition, three out of four interactions (view × location, location × transmittance, and view × location × transmittance) were also significant. Thus, variations in the test stimuli were detected at various levels of the glazing type. With regard to pleasure, significant main effects were noted for

FIGURE 5. Mean Responses for Arousal and Pleasure.

AROUSAL

Window View

	Houston	Detroit	Los Angeles	New York	Mean
Clear	5.05	6.72	5.78	6.77	6.08
Semi	2.58	4.79	5.41	5.00	4.45
					5.26

Non Window View

	Houston	Detroit	Los Angeles	New York	Mean
Clear	6.13	4.98	6.35	5.47	5.73
Semi	3.17	4.41	4.10	3.22	3.73
					4.73

Overall Mean for Arousal: 5.00

PLEASURE

Window View

	Houston	Detroit	Los Angeles	New York	Mean
Clear	6.19	6.51	5.64	5.97	6.08
Semi	4.6	6.14	6.15	6.09	5.74
					5.91

Non Window View

	Houston	Detroit	Los Angeles	New York	Mean
Clear	5.49	5.63	4.9	5.7	5.43
Semi	4.27	5.1	5.18	4.36	4.73
					5.08

Overall Mean for Pleasure: 5.5

view and for glazing, but not for location. Again, three out of four interactions (view × transmittance, location × transmittance, and view × location × transmittance) were also significant.

Overall, the results of the ANOVA (displayed in Table 4) indicate that individuals experienced a higher state of both arousal ($F = 64.59$, $p < .001$) and pleasure ($F = 191.36$, $p < .001$) when occupying a seated position facing the window compared to facing the door. In addition, participants preferred the spaces that featured clear glazed windows to the spaces using windows with 40% transmittance, as indicated by the results for both arousal ($F = 309.76$, $p < .001$) and pleasure ($F = 76.08$, $p < .01$).

Moreover, although people distinctly prefer clear windows to those with reduced visibility, the latter alternative does not appear to engender stressful or unpleasant feelings at visibility differences of up to 40%. Thus, semi-transparent windows with up to 40% transmittance are not perceived to create aversive effects in office occupants.

CONCLUSION

With regard to the design and operation of commercial buildings, the use of energy efficient glazing to minimize electrical consumption and to reflect unwanted direct solar gain continues to constitute a major priority. However, current dogma assumes that compromises must be made between human satisfaction (daylighting) and thermal performance of build-

TABLE 4. ANOVA for Arousal and Pleasure.

Source: Arousal	DF	ANOVA SS	Mean Square	F Value	Pr > F
View	1	221.01	221.01	64.59	0.0001
Location	3	267.11	89.04	35.46	0.0001
Glazing	1	1127.31	1127.31	309.76	0.0001
View *Location	3	130.90	43.63	14.84	0.0001
View* Transmittance	1	4.38	4.38	1.59	0.2110
Location* Transmittance	3	133.47	44.49	15.35	0.0001
View*Location*Transmittance	3	177.90	59.30	20.72	0.0001

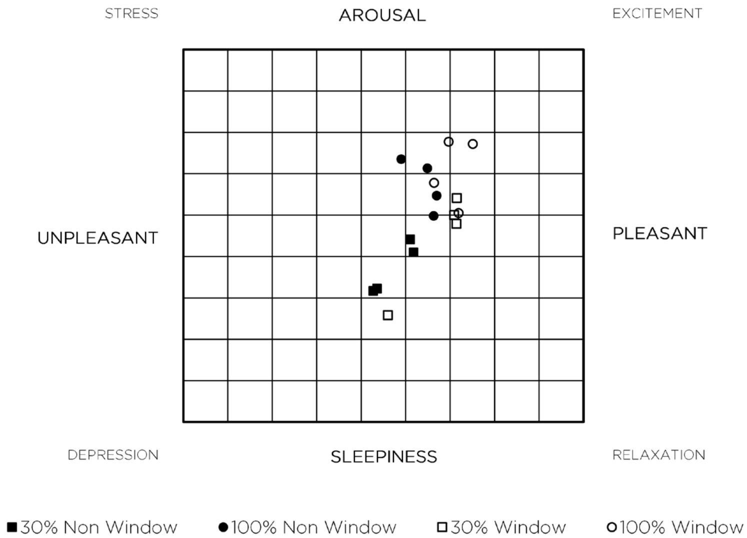
Source: Pleasure	DF	ANOVA SS	Mean Square	F Value	Pr > F
View	1	191.36	191.36	56.64	0.0001
Location	3	35.83	11.94	3.07	0.0287
Glazing	1	76.08	76.08	7.39	0.0082
View *Location	3	9.57	3.19	0.91	0.4384
View* Transmittance	1	77.05	77.05	26.61	0.0001
Location* Transmittance	3	126.23	42.08	10.68	0.0001
View*Location*Transmittance	3	128.48	42.83	15.43	0.0001

ings that use semi-transparent glazing. Considering that so many buildings are located in hot and humid climates in which ambient temperatures are inhospitable, energy reduction efforts become paramount. Likewise, buildings can become immediately energy efficient and sustainable using existing glazing technologies despite reductions in visible light transmittance.

Despite the known benefits of semi-transparent glazing, architects, builders, and developers have limited themselves to traditional glazing systems due to the lack of data about the effect of glazing transmission on office workers. In addition, decisions regarding the design and construction of buildings must balance financial consequences of material cost and energy consumption of window glazing with their effects on employee productivity (Boyce, Hunter, & Howlett, 2003). While employee performance is influenced by physiological perceptions and motivations, including ability, technical skill, values, and personality (Marchant, 2001), psychological preferences do not correspond equally to employee productivity. Human preference for daylighting is primarily based on one's prior experiences and their related environmental conditions.

The results of this study indicate that existing glazing technology can further offset the existing drain on non-renewable energy using semi-transparent glazing without negatively

FIGURE 6. Emotional Response by Location for Varying Window Condition.



affecting the emotional state of office workers. This research further purports that daylight transmittance can vary significantly while continuing to facilitate an emotionally healthy work environment (Figure 6). Thus, with respect to the affective states of arousal and pleasure, variations in transmittance and visibility levels of 40% do not create unpleasant work environments. Future research should investigate windows with broader variances in visible light transmittance to develop baselines for office environments.

ACKNOWLEDGEMENTS

The authors would like to thank the American Architectural Foundation and the American Institute of Architects for their partial financial support which made it possible to conduct the studies discussed in this paper.

REFERENCES

Anson, S., Sinclair, K., & Swezey, B. (1993). *Profiles in renewable energy: Case studies of successful utility-sector projects.* Golden: National Renewable Energy Laboratory.

Aries, M. B., Begemann, S., Zonneveldt, L., & Tenner, A. (2002). Retinal illuminance from vertical daylight openings in office spaces. *Right Light , 5*, 75-80.

Atif, M. R., Love, J. A., & Littlefair, P. (1997). *Daylighting monitoring protocols & procedures for buildings*. Retrieved August 25, 2011, from National Research Council of Canada: http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc41369/nrcc41369.pdf

Bechtel, R., Marans, R., & Michelson, W. (1987). *Methods in environmental and behavioral research.* New York: Van Nostrand Reinhold Company, Inc.

Biner, P. M., & Butler, D. L. (1989). Effects of setting on window preferences and factors associated with those preferences. *Environment & Behavior , 21*, 17-31.

Boyce, P., Hunter, C., & Howlett, O. (2003). *The benefits of daylight through windows.* Washington, DC: U.S. Department of Energy.

Collins, B. L. (1975). *Windows and people: Psychological reaction to environments with and without window.* Washington, DC: Department of Commerce and the National Bureau of Standards.

Cuttle, C. (1983). People and windows in workplaces. *Proceedings of the People and Physical Environment Research Conference*, (pp. 203–212). Wellington.

Danford, S., & Williams, P. (1975). Subjective responses to architectural displays: A question of validity. *Environment and Behavior , 7*, 486-516.

F-Chart Software, Inc. (2008). *PV F-Chart user's manual.* Madison: F-Chart Software, Inc.

Gustavsen, A., Jelle, B., Arasteh, D., & Kohler, C. (2007). *State-of-the-art highly insulating window frames: Research and market review.* Oslo: SINTEF Building and Infrastructure.

International Energy Agency. (2000). *Daylight in Buildings: A Sourcebook on Daylighting Systems and Components.* International Energy Agency, Solar Heating and Cooling Programme. Berkley: Lawrence Berkeley National Laboratory.

Ishikawa, N. (1994). Building integrated PV mounting technologies in Japan. *Proceeding of the Third International Workshop on Photovoltaics in Buildings.* Cambridge.

Keighly, E. C. (1973). Visual requirements and reduced fenestration in office: A study of multiple apertures and window area. *Building Science , 8*, 321-331.

Lawrence Berkley National Laboratory. (2010, 12 13). WINDOW 6.3.9. *Window and daylighting software*. Lawrence Berkley National Laboratory.

Marchant, T. (2001). Strategies for improving individual performance and job satisfaction at meadowvale health. *Journal of Management Practice , 2* (3), 63-70.

Markus, T. A. (1967). The function of windows: A reappraisal. *Building Science , 2*, 97-121.

Nielsen, K. N., & Christensen, N. J. (2002). Fast texture based form factor calculations for radiosity using graphics hardware. *Journal of Graphics Tools , 6* (4).

Office of Energy Markets and End Use. (2006). *Commercial buildings energy consumption and expenditures 1989.* Washington, DC: Energy Information Administration.

Osgood, C. (1996). Dimensionality of the semantic space for communication via facial expression. *Scandinavian Journal of Psychology , 7*, 1-30.

Proffitt, D. R., & Kaiser, M. K. (1986). The use of computer graphics animation in motion perception research. *Behavior Research Methods, Instruments, & Computers , 18* (6), 487-492.

Rea, S. (2000). *The IESNA lighting handbook: reference & application.* New York: Illuminating Engineering Society of North America.

Riisberg, V., & Boutrup, J. (2010). Adjusting daylight and solar heating in offices. *The Nordic Textile Journal , 2*, 6-13.

Russell, J. A., & Pratt, G. (1980). A description of the affective quality attributed to environments. *Journal of Personality and Social Psychology , 38*, 311-32.

Russell, J. A., Weiss, A., & Mendesohn, G. A. (1989). Affect grid: A single-item scale of pleasure and arousal. *Journal of Personality and Social Psychology , 57*, 493-502.

Selkowitz, S. E. (1999). High performance glazing Systems: Architectural opportunities for the 21st century. *Proceedings from Glass Processing Days Conference.* Tampere.

Sylvester, K., & Haberl, J. (2000). Semi-transparent photovoltaic glazing: Development of window properties for input within the DOE-2 window library. *Solar 2000 Conference Proceedings.* Madison: American Solar Energy Society.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology , 54*, 1063-1070.

Wolf, S., & Gall, D. (2006). *Luminance analyzers - what they are and how do they work*. Retrieved 8 25, 2011, from Digitale Bibliothek Thuringen: http://www.tu-ilmenau.de/fileadmin/public/lichttechnik/Publikationen/2003/cie2003.pdf

Wotton, E., & Barkow, B. (1983). An investigation of the effects of windows and lighting in offices. In T. Vonier (Ed.), *International Daylighting Conference.* Phoenix.