Missing Factors in Daylighting Standards: A Study of Desired Activities and Task Performance in a Sunlit Room

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Abstract

Current quantitative daylighting standards are insufficient to guarantee a high-quality daylighting experience because they fail to consider occupants' behavior. This research investigates occupants' behavioral responses to a sunlit room. Investigations of subjects' declared sitting preference and their task performance indicated that subjects were generally attracted to sunlight and outdoor views, but they did not necessarily perform best in these areas. Instead, privacy and a sense of control were two hidden factors that greatly affected subjects' decision and performance. The perceived problem of visual glare caused by sunlight penetration did not affect performance as much as subjects believed it would.

Keywords: daylighting, sunlight, glare, declared preference, cognition

Behavioral Studies in Daylighting Research and Design

Empirical research on daylighting and building occupants has revealed that daylight is related to improved productivity in schools and offices (Charles & Veitch, 2002; Küller & Lindsten, 1992; Ne'eman, Sweitzer, & Vine, 1984), higher sales (Heschong Mahone Group, 1999), shorter recovery time in hospitals (Beauchemin & Hays, 1996; Benedetti et al., 2001; Ulrich, 1984), and increased job satisfaction and well-being (Butler & Biner, 1989; Leather et al., 1998). However, available daylighting standards mainly emphasize the quantity of daylight and visual comfort (Boubekri, Hulliv, & Boyer, 1991). They either recommend minimum illuminance levels for different tasks, control over daylight factors (British Standards Institution, 1992), or specify sizes of window (Illuminating Engineering Society of North America, 1999). These measures do not necessarily ensure a good daylighting design because they fail to consider the complexity of interaction between natural light and human beings beyond mere visual performance. Especially, the case of sunlight penetration has not been fully understood yet. For instance, room occupants seldom reopen window blinds once they close them to block out direct sunlight in office (Linsay & Littlefair, 1993; Rea, 1984). In such cases, all energy benefits of the window are cancelled while the disadvantages of the window's poor thermal performance are still present. The way that occupants use a room vis-à-vis daylight remains to be explored and explained.

Refereed Full-Papers

The gap between daylighting research and design practice is deepened by (i) complexity of daylighting scenarios, (ii) unreliability of some lighting and behavior studies (Veitch & Newsham, 1998), and (iii) difficulty of converting research results to feasible design guidelines. The gap between what people think and how they behave is also a barrier to research. Common beliefs may mislead our judgment (Butler & Biner, 1990; Gifford, 1994).

People, in general, are not sensitive to their visual environment unless it is bad (Hopkinson & Bradley, 1965).

While much has been written about the virtues of daylighting, little discussion has taken place about how architects can design accordingly. The valuable information from research has not been effectively translated into an architectural language. This would require illustrating how occupants use a daylit room and specifying how they react to their luminous environment and adjust their activities accordingly. In this study, we aim to obtain a comprehensive understanding of the relationships between room occupants and their immediate sunlit environment. We used subjective measurement, but did not limit data collection to self-reported opinion. We attempt to explore ways of improving daylight quality by studying several interrelated factors.

Methods

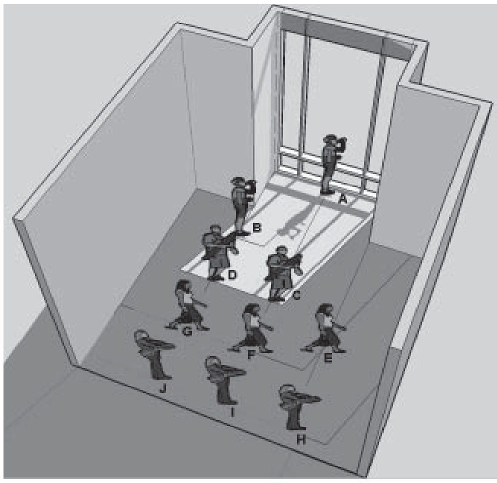
In this paper, we examine subjects' daylighting condition through their distance to a sun patch on the floor of a room. The presence of sunlight in relation to room occupants' wellbeing, satisfaction, and performance has been investigated in terms of the duration of sunlight penetration (Ne'eman, Craddock, & Hopkinson, 1976) and the size of sun patches (Boubekri et al., 1991). However, the distance between room occupants and sun patches has never been discussed in any precedent lighting study. We believe that the distance is an effective indicator of subjects' relationship to their environment because, besides lighting levels and thermal conditions related to a sun patch, the distance also gives information of subjects' position to a window, which consequently changes the percentage of outdoor view. We can thus make a comprehensive evaluation of a sunlit environment.

We set up a controlled experiment in a work setting to investigate behavioral responses at different spots in a sunlit room. Subjects' behavioral responses were dependent variables and were measured in two ways: a) furniture arrangement within the room and vis-à-vis the sun patch and b) cognitive performance. The former reflected occupants' preferences and their desired ways to use a room; the latter helped us locate optimal zones for improved cognitive performance and analyze their features. We hypothesized that the preferred sitting areas would not totally overlap the optimal performance zones and we expected to illustrate an existing gap between what people think and how they behave in a sunlit room.

Procedure

We conducted the experiment in a multifunctional seminar room with a floor-to-ceiling window facing east. Participants were 100 university students, which included 62% undergraduates, 26% graduates, and 12% doctoral students. About half were female (51%) and half were male (49%). We collected the data in the spring when temperature would not affect people's preference for sun as much as it might during a hot or a cold season. A condition of 30 percent sunlight penetration, measured in terms of the percentage of the size of the sun patch on the floor to the total floor area, was maintained by the full-height window blind. Ten sitting spots were examined (Figure 1). All the subjects were oriented with the window at their side—an optimal sitting position in a daylit room (Boubekri et al., 1991).

Subjects were not fully informed about the research. They were firstly given two articles to read and then were asked to answer related questions within a restricted amount of time. After the reading comprehension, subjects were asked to complete an analogy task called "People-Pieces" (Sternberg, 1977, Viskontas et. al. 2004). The third task was furniture arrangement. Subjects were given three room plans with similar sun patch of the experiment room. They were required to arrange a meeting table, relaxing armchairs, and a workstation in three independent rooms and to explain why the room was used in that way. This task was to study their preferred sitting area and environmental factors that affect their preference and decision.



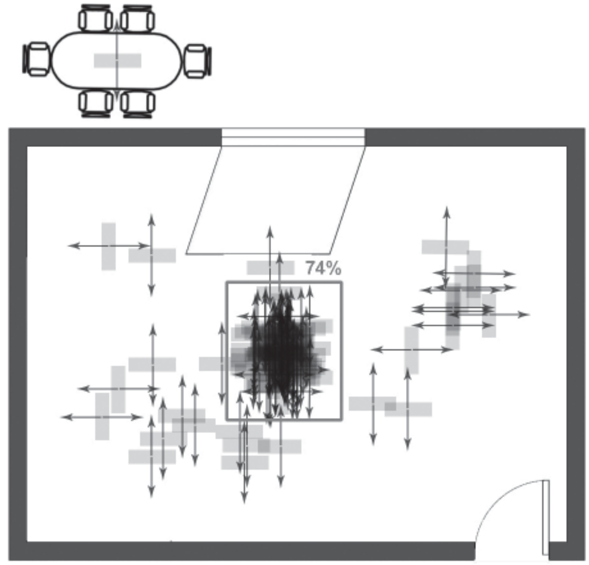
A and B were in the sun patch; C and D were on the boundary of the sun patch; E, F and G were four feet from the sun patch; and H, I and J were eight feet from the sun patch.

Figure 1: Ten study groups in a room with a floor to ceiling window facing east.

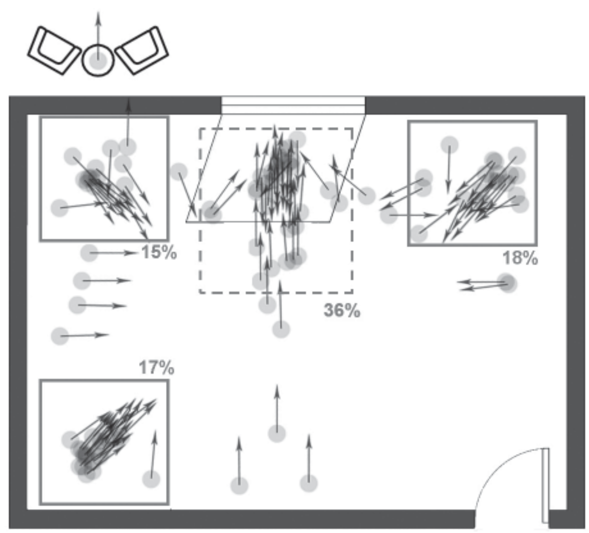
Analysis of Furniture Arrangement

Factors influencing preferred sitting area

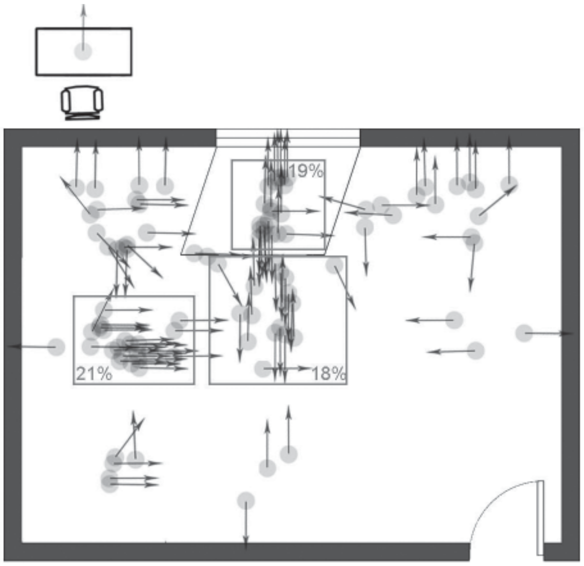
We firstly analyze main environmental factors that influenced subjects' furniture arrangement. Seventy-four percent of subjects arranged the meeting table in the center of the room (Figure 2a). The top two reasons given by subjects were centralization (61%) and room circulation (24%). Subjects found it important to have equal space around the table and to create a feeling of gathering together. Obviously, the function of the room played a dominating role over all environmental factors. Activities that might take place in the room seemed to be the first consideration.



(a) 74% put the meeting table in the center of the room.



(b) Totally 50% put the relaxing armchairs in the corners of the room, while 36% was in the middle of the room and close to the window.



(c) 19% arranged the working desk in the sun patch, 18% were close to the sun and in the middle of the room, and 21% were side to the window and away from the door.

Figure 2a-c. Preferred sitting area in a room with sunlight penetration

Fifty percent of subjects preferred to have the relaxing armchair in the corners of the room. Figure 2b shows that half of the total arrangements were fairly evenly distributed among the three corners away from the door (15%, 18%, and 17%). Among the other half, 36% chose to stay in the middle of the room and close to the window. Sunlight (29%) and privacy (27%) were important factors. However, not all subjects who chose to sit in the corner noticed that privacy was a factor influencing their decision: with 50% of subjects placing their armchairs in a corner and only 27 of those 50 subjects specifically citing privacy—a desire to not be seen or interrupted by others—as a reason for the corner placement.

Figure 2c shows that 19% of subjects placed the work desk in the sun patch, 18% preferred to be close to the sun and in the middle of the room, and 21% chose a position sideways to the window and away from the door. The top three reasons given were visual comfort (42%), control over the room (40%), and view (39%). "Control" here does not refer to control systems such as light switches or window blinds but rather accentuates a psychological level, as many subjects mentioned that they wanted to be aware of what was going on in the room and to see the doorway to be able to respond quickly when others were close by or came in. A higher percentage mentioned environmental factors suggested that subjects were more aware of their office environment, compared with their meeting or relaxing environments.

Sitting orientations

In this section, we analyze the popular orientations that they chose to face to in relation to the window and the door. Figure 3a shows that 86% of subjects oriented the length of the meeting table along the length of the room. Almost one third of the respondents gave a reason that it was the most common room layout they had seen in meeting rooms. For relaxing armchairs, 45% of subjects chose to view the entire room, 23% preferred to face the outdoors through the window, and 30% had a view of both the room and the exterior (Figure 3b). Half of the subjects (50%) listed outdoor view as a reason for their armchair arrangement, indicating that the view factor was fully recognized. However, among the 75 subjects who chose a position with full control over the room, only 17 reported that control was significant. Figure 3c shows that 32% of subjects chose to face the entire room, 18% preferred to face the outdoors through the window, and 30% wanted a view of both. Outdoor view (39%) and a sense of control (40%) were the top two reported factors related to such an arrangement. Both factors were well recognized by subjects.

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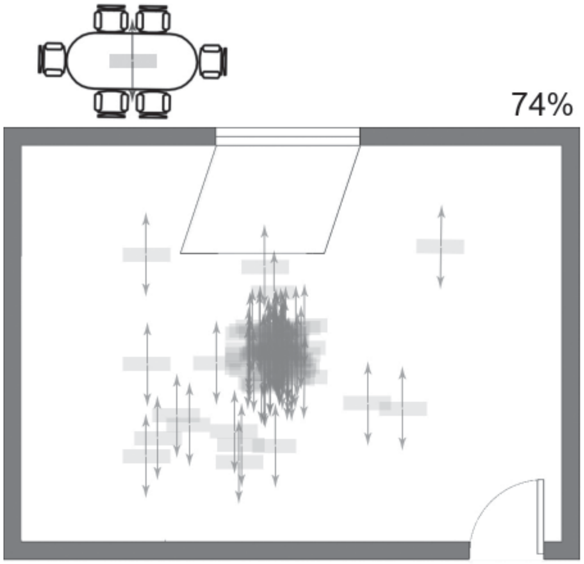
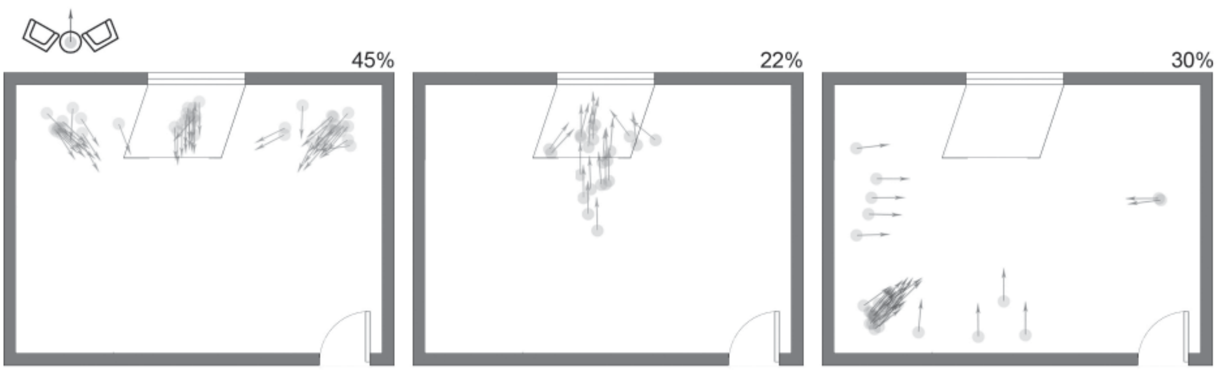
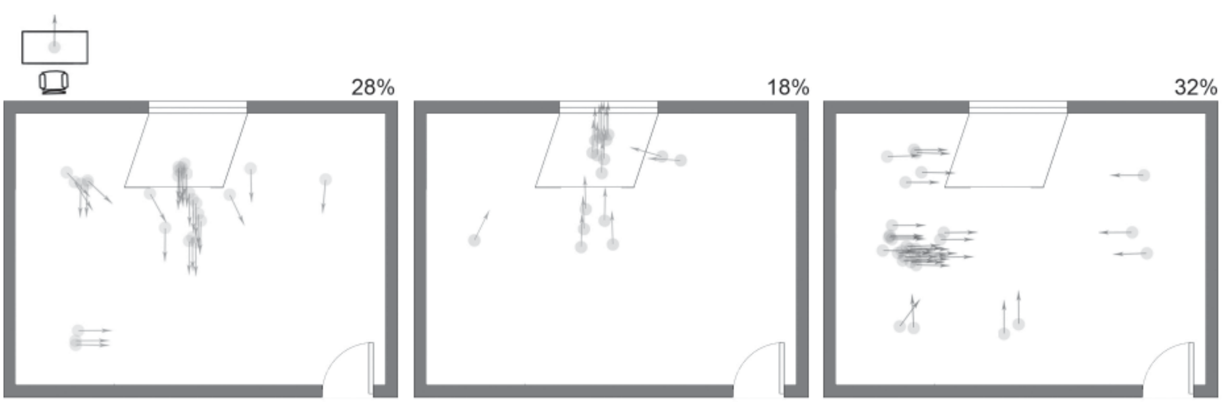


(a) 86% orientated the length of the meeting table along the length of the room.



(b) 45% chose to view the entire room; 22% preferred to face outdoor through the window; and 30% had a view of both.



(c) 28% chose to face the entire room; 18% preferred to face outdoor through the window; and 32% had a view of both.

Figure 3. Preferred sitting orientations in a room with sunlight penetration

Analysis of Cognitive Performance

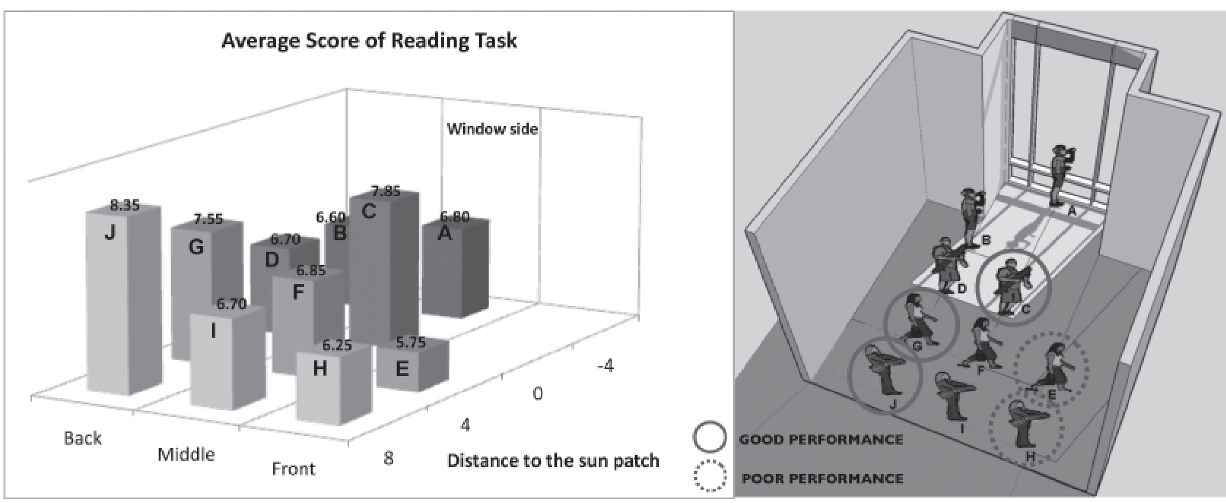
Reading task

Reading comprehension contained two articles and twenty questions. Each question was scored one point. We performed an analysis of variance and found a significant interaction between reading performance and sitting location for both readings (for Reading 1, $F [9, 90] = 3.218$, $p < 0.002$, and for Reading 2, $F [9, 90] = 2.360$, $p < 0.019$). A comparison of average reading scores among the ten seating positions shows that reading performance in Group J (as shown in Figure 4) was 26% higher than Group H. This result was significant ($F [9, 90] = 3.542$, $p < 0.001$). Groups C, G, and J had above-average performance, while groups E and H had poor reading performance. However, we found no simple linear relationship between reading scores and the subject's distance to the sun patch.

Analogy task

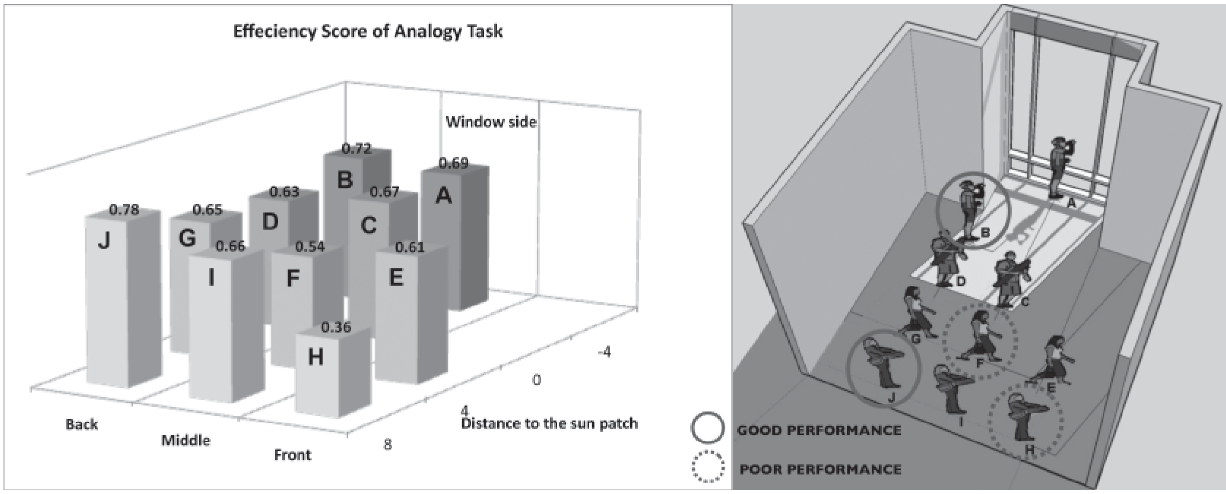
Analogy task contained 60 questions and each had one point. Subjects' performance was evaluated based on their speed score (ratio of completed questions to total questions), accuracy score (ratio of correct answers to completed questions), and efficiency score (ratio of correct answers to total questions). An analysis of variance showed a significant interaction between speed and sitting location, ($F [9, 90] = 7.007$, $p < 0.000$) and between efficiency and sitting location, ($F [9, 90] = 5.863$, $p < 0.000$). Accuracy score was not found to significantly change with sitting position at $a=0.05$.

A comparison of speed and efficiency among the ten sitting position groups shows that the group with the highest scores, Group J, was 49% faster and 42% more efficient than the one with the lowest scores, Group H (Figure 5). With respect to total efficiency, Groups B and J were the top two with an average score higher than 7, while groups F and H were the bottom two with an average score lower than 5. However, no simple linear relationship was found between



	A	B	C	D	E	F	G	H	I	J	Ave.
Ave. score of reading task	6.80	6.60	7.85	6.70	5.75	6.85	7.55	5.25	6.70	8.35	**6.94**

Figure 4. Comparison of average reading scores among ten groups



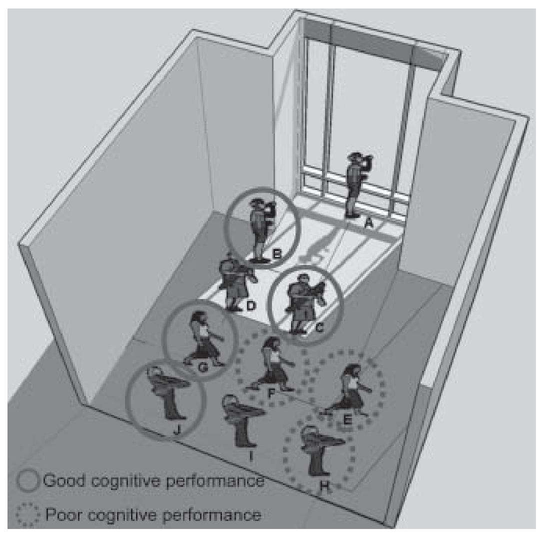
	A	B	C	D	E	F	G	H	I	J	Ave.
Ave. score of speed	0.74	0.77	0.72	0.69	0.68	0.61	0.71	0.39	0.78	0.88	**0.70**
Ave. score of efficiency	0.69	0.72	0.67	0.63	0.61	0.54	0.65	0.36	0.66	0.78	**0.63**

Figure 5. Comparison of speed and accuracy among ten groups

performance on the analogical task and the distance to the sun patch.

Optimal performance zones

Optimal performance zones for each task were illustrated in Figure 6. Even though a simple linear relationship between cognitive performance and distance to the sun patch on the floor was not found, results supported the hypothesis that measured performance is significantly affected by sitting location in a sunlit room. Performance was affected by several factors including outdoor view, privacy, sense of control, and sunlight penetration. Due to space limitation, the combined effects are discussed in detail elsewhere (forthcoming Wang 2009).



Group C, G, and J had better performance in reading task; and Group E and H had poorer performance. Group B and J had better performance in analogy task; and Group F and H had poorer performance.

Figure 6. Comparison of performance on reading task and analogy task

Discussion

Furniture arrangement suggested that, for a group activity like a meeting, decision follows function while for individual activities, environmental factors play a more important role in decision making. Outdoor view, control, and privacy were important factors influencing sitting preferences. Compared with outdoor view, a sense of control and privacy had more powerful influences on seat selection, but were less recognized. Figure 7 shows preferred sitting areas and their corresponding sitting spots in the controlled experiment. A comparison of this map and optimal task performance zones (shown in Figure 6) indicated a gap between what people believe about daylighting environment and how they actually perform when in those environments.

Groups A and G, among the most preferred spots for workstations, were not within the optimal zones. Contrastingly, Groups B and J, which were chosen for relaxation, correlate with high task performance. It is worth mentioning that B and J had dramatically different lighting conditions: B was in the sunlight and had an average illuminance level of 1253 foot candle, while J had the lowest illuminance level among the ten groups at 35 foot candle. It suggested that lighting quantity was not the only factor influencing performance. Glare, a commonly discussed problem caused by sunlight, did not affect performance as much as people thought it would.

This study underscored why daylighting design guidelines need to change to reflect the reality that human activities are an important design criterion alongside physical variables. In order to improve office workers' cognitive performance, to gain the psychological and physiological benefits from daylight, and to achieve the expected energy savings, it is significant for architects to understand and consider multiple factors that influence occupants' behaviors and thus to provide maximum overlap of the preferred sitting area and the optimal performance area in their designs.

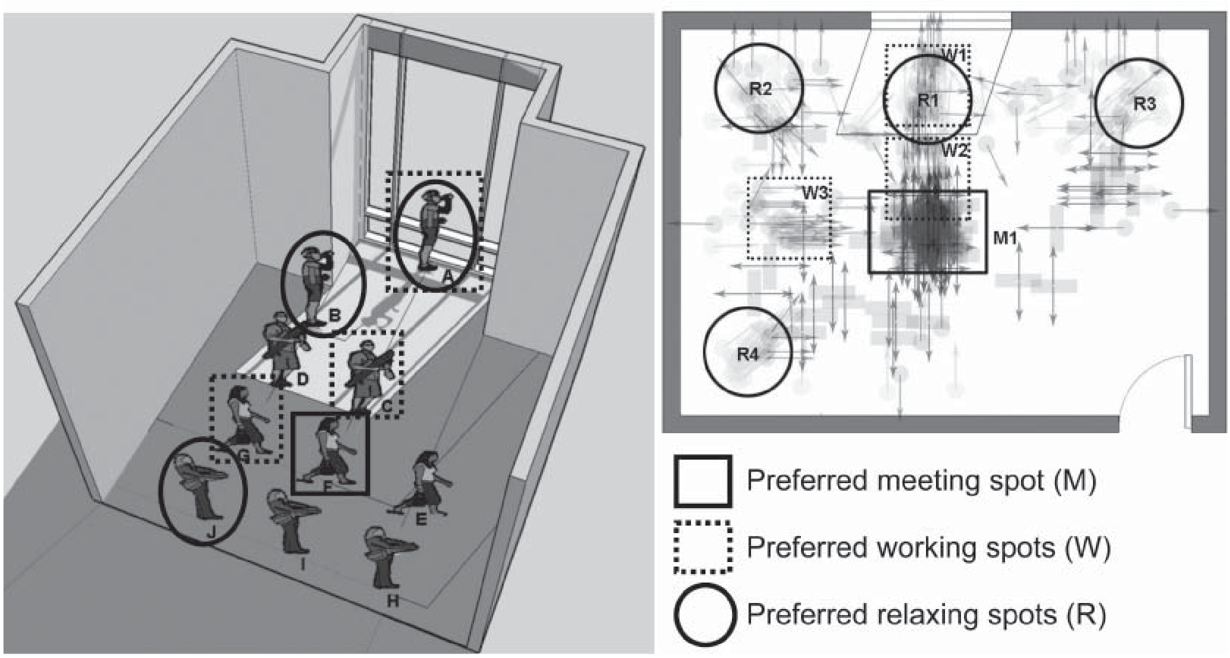


Figure 7. Preferred sitting area verse experimental groups

References

Beauchemin, K. M. & Hays, P. 1996. Sunny hospital rooms expedite recovery from severe and refractory depressions. Journal of Affective Disorders, 40, 49–51.

Benedetti, F., Colombo, C., Barbini, B., Campori, E. & Smeraldi, E. 2001. Morning sunlight reduces length of hospitalization in bipolar depression. Journal of Affective Disorders, 62, 221–223.

Boubekri, M., Hulliv, R. B. & Boyer, L. L. 1991. Impact of window size and sunlight penetration on office workers' mood and satisfaction: A novel way of assessing sunlight. Environment and Behavior, 23, 474–493.

British Standards Institution. 1992. Lighting for buildings—Part 2: Code of practice for daylighting. London, British Standards Institution.

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

Butler, D. L. & Biner, P. M. 1990. A preliminary study of skylight preferences Environment and Behavior, 22, 119–140.

Charles, K. E. & Veitch, J. A. 2002. Environmental Satisfaction in Open-Plan Environments: 2. Effects of Workstation Size, Partition Height and Windows. Ottawa, Ontario, Institute for Research in Construction, National Research Council Canada.

Gifford, R. 1994 Scientific evidence for claims about full spectrum lamps: Past and future. IN Veitch, J. A. (Ed.) Full-spectrum lighting effects on performance, mood, and health (IRC Internal Report No. 659). Ottawa: ON, National Research Council of Canada, Institute for Research in Construction.

Heschong Mahone Group. 1999. Skylight and retail sales: An investigation into the relationship between daylighting and human performance. Pacific Gas and Electric Company.

Hopkinson, R. G. & Bradley, R. C. 1965 Glare from very large sources. Journal of the Illuminating Engineering Society, 55, 288–297.

Illuminating Engineering Society Of North America. 1999. Recommended Practice of Daylighting. Illuminating Engineering Society of North America.

Küller, R. & Lindsten, C. 1992. Health and behavior of children in classrooms with and without windows. Journal of Environmental Psychology, 12, 305–317.

Leather, P., Pyrgas, M., Beale, D. & Lawrence, C. 1998. Windows in the workplace: sunlight, view, and occupational stress. Environment and Behavior, 30, 739.

Linsay, C. R. T. & Littlefair, P. J. 1993. Occupant use of venetian blinds in offices. Watford, Building Research Establishment.

Ne'eman, E., Craddock, J. & Hopkinson, R. G. 1976. Sunlight requirements in buildings I - Social survey. Building and Environment, 11, 103–130

Ne'eman, E., Sweitzer, G. & Vine, E. 1984. Office worker response to lighting and daylighting issues in workspace environments: A pilot survey. Energy And Buildings, 6, 159–171.

Rea, M. S. (1984) Window Blind Occlusion: A Pilot Study. Building And Environment, 19, 133–137.

Sternberg, R. J. 1977. Intelligence, Information Processing and Analogical Reasoning: the Componential Analysis of Human Abilities. Hillsdale, NJ: Erlbaum.

Ulrich, R. S. 1984. View through a window may influence recovery from surgery. Science, 224, 420–421.

Veitch, J. A. & Newsham, G. R. 1998. Determinants of lighting quality I: State of the science. Journal of the Illuminating Engineering Society, 27, 92–106.

Viskontas, I. V., Morrison, R. G., Holyoak, K. J., Hummel, J. E. & Knowlton, B. J. 2004. Relational integration, inhibition, and analogical reasoning in older adults. Psychology And Aging, 19, 581–91.

Wang, N. 2009. In Broad Daylight: An investigation of the multiple environmental factors influencing mood, preference, and performance in a sunlit workplace. Ph.D. Dissertation. University Of Illinois at Urbana-Champaign.