Daylighting-Bias and Biophilia: Quantifying the Impact of Daylighting on Occupants Health

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ABSTRACT: This paper reports on a state-of-the-art study quantifying the health and human impacts of daylighting strategies and views quality from windows on employees health in offices. The study attempts to quantify an important yet not scientifically proven assumption concerning the biophilic relationship between views of nature and daylighting in the workplace and their impacts on sick leave of office workers. The specific hypothesis tested is; that employees with a view of nature will take fewer sick days, have fewer Sick Building Syndrome (SBS) symptoms than those with a view of urban structures, or with no views out at all. A corollary hypothesis is whether daylight availability and dynamic lighting quality in offices could also play a role in reducing the number of sick leave hours and SBS symptoms related to poor circadian rhythms and hypersensitivity. This is an objective to answer and quantify a long debated hypothesis regarding the importance non-residential building occupants place on the need to be in contact with nature/the outdoors while working within a building. This paper reports on a three-phase long-term study. In phase I, employees' preferences and ratings towards natural and urban human-made views were investigated. For this phase of the study a qualitative sorting task technique was employed, followed by in-depth interviews on a cross-sectional sample of office employees (n=98). In phase II of the study, physical office conditions, lighting qualities, and quantities inside120 office spaces and cubicles in an office building were systematically evaluated covering 175 employees participating in this study. This included daylighting availability (window shape, properties, glazing properties, area, and its distance from employees' desks); Daylighting quality (luminance, glare analysis, room materials, reflections, orientation, brightness patterns, etc.), and quality of outside views (type of view, pleasantness rating, and preference rank) according to the view metric developed earlier in phase I of the study. In phase III of the study, employees' health conditions were surveyed using an on-line questionnaire and physical health screening forms. In addition, we compiled employees' actual sick leave days from their payroll records as well as in aggregate format based on their office locations, views, floor level, and area of the building they occupy. A multi regression and Pearson correlation statistical analyses tests were performed on the data set. Standard bivariate regression and correlation were used to examine the relationship between sick leave hours and ratings of lighting quality and views. In both cases, the relationships are in the predicted direction and statistically significant supporting positively our hypothesis. Workers in offices with poor ratings of light quality and in offices with poorer views used significantly more sick leave hours. Taken together, the two variables explained 6.5% of the variation in sick leave use, which was statistically significant. The implications of these findings are huge when one considers productivity and health insurance costs these sick leave hours can affect to an organization.

Keywords: Office Building, Daylighting, Views, Employee Sick Leave

INTRODUCTION

The biophilia hypothesis suggests that there is an instinctive bond between human beings and other living systems [1]. Following on Edward Wilson's (1984) seminal text "Biophilia" many building designers adopted these ideas to green buildings. Despite the popularity of the concept, the biophilia hypothesis in buildings remains largely contested due to lack of empirical body of knowledge that supports it [2;3]. This study investigated the relationship between dynamic lighting quality, views from windows, and health of office workers. It also attempts to place a value on windows and daylighting in the workplace by linking their degree of availability to sick leave of office workers and Sick Building Syndrome (SBS) symptoms. In addition, the study investigated the meditational effects, such as, stress levels, and hypersensitivities between the availability of biophilic features in the environment and their impact on sick leave and health of office workers.

Specifically, the research attempts to provide answers to whether windows rather than just more light levels are better appreciated by occupants [4]. It also attempts to place a value on windows, view quality, and lighting quality in the workplace by investigating the relationship between these constructs and actual sick leave and absenteeism hours of office workers based on official payroll records. The research investigators employed a multi-method approach to assess views quality outside offices, daylighting availability inside offices, lighting quality, daylight aperture, glare index, and window properties, as well as other parameters of the physical environment and the relationship of these factors to employees' sick leave and absenteeism hours.

Most studies of indoor environmental quality and health concentrate on the relationship of building environments either to common non-specific symptoms or to asthma and rare illnesses such as hypersensitivity pneumonitis [4]. Non-specific building related symptoms (BRS) have been associated with a variety of building features including very low levels of outdoor air supply per occupant in mechanically ventilated buildings (<10 to 20 cfm/person) and lack of windows [5]. However, studies going beyond self-reported symptoms to objective measures of the influence of building environments on health and productivity are few and non-conclusive [6].

Sick leave data represent outcomes that could be used to study the indoor environment. This outcome variable has been used for a variety of other purposes, such as indicators of respiratory disease among agricultural workers, to identify ergonomic issues in the workplace, and to evaluate industrial health promotion programs. In general, respiratory illness accounts for 60% to 70% of all sick leave and visual related illnesses and accidents account for another 20% to 30% [5]. Previous studies reported that occupants of an air-conditioned building were more likely to have multiple absences from work than were persons in a naturally ventilated building in northeastern France [7]. This study was limited, however, by the use of only two buildings, by lack of control for ventilation rates, and by individual and group factors that may have confounded the relationship between building and sick leave.

A substantial portion of the U.S. population spends a minimum of 40 hours weekly in their indoor office environments. A number of poorly designed offices with low ventilation rates, non-operable windows, and lack of potential for direct daylight and views has been associated with respiratory illnesses, allergies, and sick building syndrome symptoms [2]. Research evidence suggests that changes in building design, daylight availability to workers, connections to the outdoors, operation, and maintenance can significantly reduce these illnesses [8, 9]. However, since some of this evidence has been largely anecdotal and non-quantifiable, these changes are not yet prescribed in building or occupational codes. Decreasing the prevalence or severity of these health effects would lead to lower health care costs, reduced sick leave, and shorter periods of illness-impaired work performance, resulting in annual economic benefits for the U.S. in the tens of billions of dollars [8].

Increasing the awareness of these potential health and economic gains, combined with other factors, could help bring about a shift in the way we design, construct, operate, and occupy buildings. The current goal of providing marginally adequate indoor environments could be replaced by the goal of providing indoor environments that maximize the health, satisfaction, and performance of building occupants [6, 9].

DAYLIGHT/BIOPHILIA HYPOTHESES

Based on the above, and previous literature reviews [10, 11], this study hypothesized that better lighting quality, view quality, and daylight availability will have a positive effect in reducing sick leave of employees in an office setting and will contribute to fewer building related health symptoms and complains by the occupants. The following specific hypotheses were investigated:

(1) Employees will prefer natural views of trees, shrubs, and soft landscapes over human-made urban views and hard landscape.

(2) Employees with a view of nature, seen from their desk, will take fewer sick days than those with a view of urban structures, or with no views out at all.

(3) Employees occupying offices with daylight availability and glare-controlled lighting would have fewer sick leave hours and fewer SBS symptoms, as compared to employees occupying offices with no daylight and poor lighting quality.

A UNIQUE RESEARCH SETTING

The study was conducted in Oregon hall, The University of Oregon in Eugene, Oregon. The building was built in 1973 and designed by the architecture firm of Zimmer, Gunsul, Frasca Partnership, to house the university's administrative and student service offices, It is home to the academic advising and student services, admissions, registrar, financial aid, veterans' affairs, international education, student life, multicultural affairs, and human resources offices.

The building represents an opportunity to study the hypotheses under investigation. The typical open-plan office building has 30% of offices overlooking a natural view to the north and part of the west, 31% of its offices are looking an urban view to the south and east, and the remaining 39% of the offices are internal open-plan offices with no outdoor views. Administrative University of Oregon staff with similar demographics and organizational culture occupies all the offices in Oregon Hall. The perimeter offices of the building facing north, east, south, and west are a mix of private and open-plan staff offices. The inward facing open-plan offices are shared offices separated by 4-6 ft high partitions with some fully enclosed offices for directors. In general, no significant hierarchy existed between departments and employees occupying the perimeter and open-plan offices. Entire departments occupied some of the inward facing offices with multiple ranges of staff classifications and organizational hierarchy. The following figures (1-8) below describe the building, its views, and floor plans.

Figure 1: North façade facing natural views

Figure 2: South façade facing urban views

Figure 3: Views to the north of landscaped natural elements

Figure 4: Views to the south of streets and human-made elements

Figure 5: The interior open-floor plan offices

Figure 6: Interior of partitioned offices

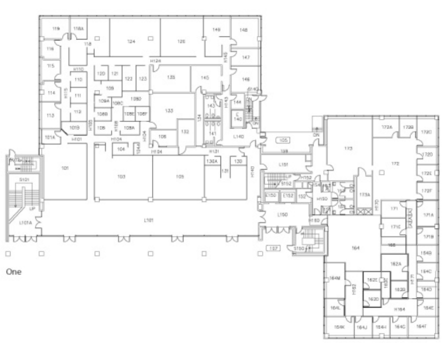


Figure 7: First Floor Plan - cubicle layout

Figure 8: Second Floor Plan – open office

DAYLIGHTING AND VIEW QUALITY METRICS

For this study, we have conducted a cross-sectional survey design on classified and unclassified employees. The study assessed the physical conditions of their work area, glare and lighting quality, views preference from a Q-sort metric, health, sick building syndrome symptoms, together with their payroll records regarding sick leave and health information via a standard health screening Simple Form (SF-12). We had a very high response rate of participation in our study. More than seventy percent (175 respondents) of the full-time staff employees participated in the study. The data collected included Hourly Sick Leave data from timecards and disability records for 24 months from the payroll department.

In addition, a physical screening and survey of employees' health conditions, SBS symptoms, and hyper sensitivity was collected. Physical environmental factors of each employee personal work station/office was assessed, coded, and analyzed. This included daylighting availability (window shape, properties, glazing, area, and its location from employee's desks); Daylighting quality and variability (such as luminance, illuminance, cubic illuminance, room materials, reflections, orientation, and brightness patterns) [11, 12, 13, 14]; Quality of outside views (such as type of view [urban-natural], pleasantness rating [from a sorting task survey], preference, and outdoor reflections). The study controlled for factors that may have influenced sick leave rates by inclusion of demographic and organizational variables in a statistical regression analyses test.

Findings from a standard bivariate regression and correlation were used to examine the relationship between the view content, luminance variability of the scene, and natural elements of the view, such as trees, shrubs, lawn area, and fauna. As a repeatable process, the Q-Sort methodology and view-metric developed has the potential to evolve into a reference for designers, researchers, and future green building owners.

VIEW QUALITY PREFERENCE ANALYSIS

In phase I, we investigated employees' preferences and ratings towards natural and urban human-made views. For this phase of the study we employed a qualitative multiple sorting task technique (Q-sort), followed by in-depth interviews on a cross-sectional sample of University employees. Ninety eight full-time employees representing both classified and unclassified employees voluntarily participated in the study to rank 8"x10" photographic images of 12 office-views surrounding the study setting and other various offices on campus that ranged from forest-like natural settings to urban-typical street scenes (Figure 9). Participants were asked to sort the images according to their degree of preference for views outside their working area. The multiple sorting tasks started by ranking the 12 images into three groups; Best, Average, and Worst. Following that, participants were asked to sort the top, medium, and low view within each group. After the completion of the multiple sorting task, participants were interviewed using a guide to solicit their reasons for ranking the twelve views and were prompt to identify elements in the sorted views that influenced their rankings.

Participants unanimously agreed to the importance of views in the workplace and perceived them important to diminish stress and combat the feeling of confinement inside offices. Results indicate an agreement of those surveyed to rank natural views at the top of their preference with wild forest like settings to be more preferred than manicured and structured landscaping. Urban views with streets and parking lots consistently ranked lowest and views with a mix of natural elements within urban settings to be consistently in the middle ranks (Figure 9). Employees with no views in internal facing offices were reportedly interested in any view over their windowless offices. Although they preferred natural views to urban ones, consistent with the rest of the participants, they were willing to accept any view over no views at all. Employees with no views and windows in their offices (39% of employees) had posters, postcards, and computer screensavers with images of natural scenes.

The findings corroborate previously reported preference for natural views. A metric and scale, however, was not previously developed [10]. Based on the findings we have developed a views preference metric and scale to rate employees preference for different types of views. This allowed us to quantitatively evaluate employee's preferences for outdoor views from windows for the setting under study. As a repeated scale it could be used to guide future views assessment ratings.

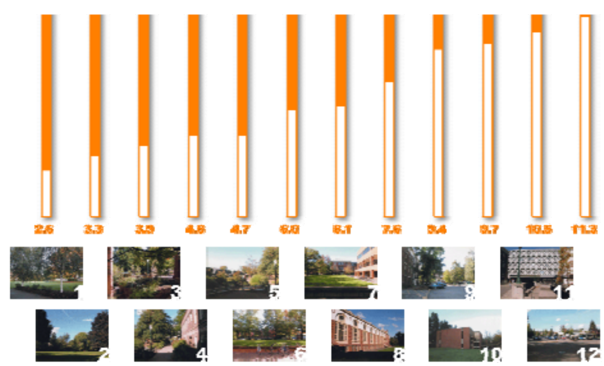


Figure 9: Ranking of views after q-sort task (Lower numbers indicated a better view preference).

LIGHTING AND VIEWS QUALITY IMPACTS

Seventy percent (175) of all employees (250) in the office building under study completed an on-line survey to rate their health, lighting, and satisfaction with their office conditions. The survey assessed sick leave absences, health symptoms perceived over the past two years, medical history, lighting satisfaction, lighting and environmental systems control, as well as other demographic variables. Figures 10-14 below provide a graphical representation of the findings of the survey.

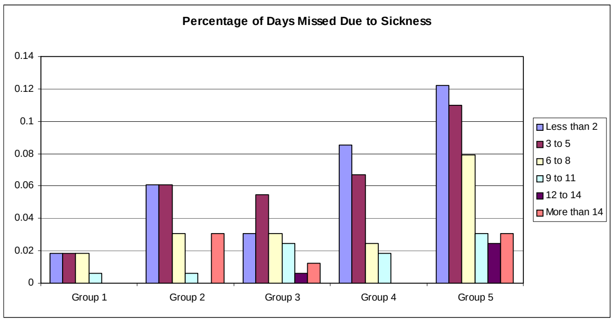


Figure 10: Percentage of days missed due to reported sickness analyzed by the different view groups of offices (Group 5=no view, Groups 1&2= best views)

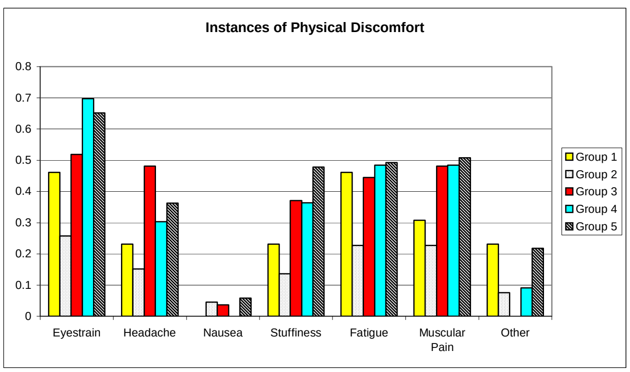


Figure 11: Percentage of reported incidents of physical discomfort analyzed by the different view groups of offices

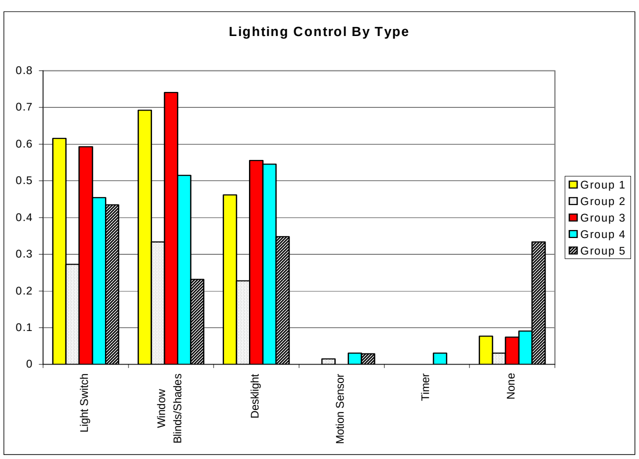


Figure 12: Availability of lighting control as it correlates to employee location in the different view groups of offices

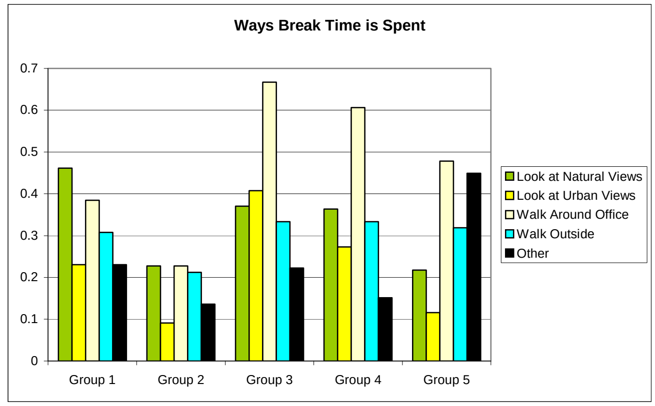


Figure 13: Percentage of ways employee spend their break time analyzed by the different view groups of

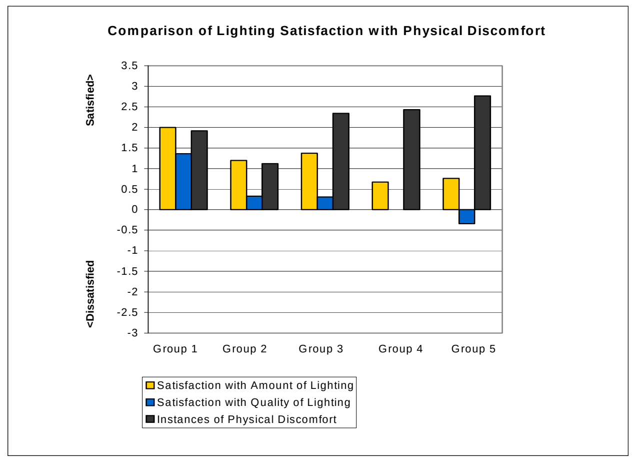


Figure 14: Comparison of lighting satisfaction and reports of physical discomfort analyzed by the different view groups of offices

The above figures all confirm a strong trend of increased sick leave days due to physical sickness of employees in group 5 (no views) and group 4(urban low rated views). In addition, offices with no views or low ranking views of urban structures were highly correlated with the perception of low lighting quality, reported physical discomfort, and lack of perceived control over lighting and the environment. It is interesting to note that the amount of lighting measured inside the offices was equal and was perceived to be adequate. However, qualitative aspects of lighting were correlated with better views. It is also interesting to note that the data suggests (figure 13) that employees with lowest ranking views or no views (groups 3, 4 & 5), have been consistently seeking better views by walking around their offices and visiting other office settings with better view ratings (group 5).

In addition to the on-line survey, on-site lighting analysis to assess the quality of lighting and glare in all spaces of the offices under study was simultaneously conducted by a team of site-surveyors following a detailed lighting quality assessment procedure (figure 15).

Table 1A, key

View Group	View Preference	View Orientation
I	1	Natural, west
II	1	Natural, north
III	2	Natural, east
IV	6	Urban, south
V	0	None, inward

Codes a01-a55 floor 1, b01-b40 floor 2, c01-c24 floor3.

RGB pixel map key

- 240-280
- 200-240
- 160-200
- 120-160
- 80-120
- 40-80
- 0-40

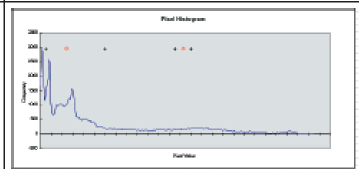
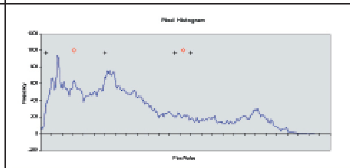
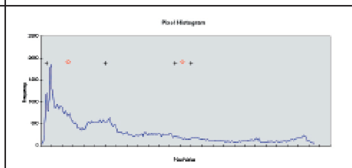
View group	Code	Field of vision inside office	Brightness analysis (RGB pixel map)	Pixel histogram	Glare ratio	Lighting quality rating
I, II	a31				1/3.91	1
II	a37				1/4.29	3
II	a41				1/5.28	5

Figure 15: A sample of the lighting analysis procedure for three workstation

The assessment included administering an image analysis and glare analysis procedures to determine the lighting quality of each office setting. Physical site-surveyors were trained to document the physical conditions of the work areas for the employees included in the study. This included measurements of employee's workstation, window position, window area, orientation, distance from window, type of view, glazing properties, rating of view, illuminance and luminance levels, daylighting aperture area and its properties, electric lighting system and its properties, temperature, relative humidity, and seating layout. Digital images of the office spaces representing the field of vision of each employee's viewing area from their workstation were analyzed using a High Dynamic Range Imagery (HDRI) luminous intensity scene analysis procedure. The pixel intensities were correlated to high and low levels of luminance in the space.

An excel macro was used to extrapolate for the different brightness patterns of the raster pixels in the image of the employee's work area and plot the results into a graph that represents the glare index for the office settings. In addition, an evaluation conducted by three lighting designers and lighting quality experts rated each lighting condition from 1 to 7 (with 7=poor). The experts' ratings of lighting quality ranged throughout the entire scale with an average of 4.1 (sad. = 1.7), almost exactly in the middle of the scale. Figure 15 above displays a sample analysis of three office settings.

WINDOW PROXIMITY IMPACTS

The researcher compiled a master data set that includes all data from the lighting quality analysis of each employee's office station combined with their survey answers and sick leave records. The data was tabulated and normalized for comparative and correlation analyses. Multiple regression analysis and Pearson's correlation tests were performed on the data set. A statistical regression model was employed to determine significance of the view variables, lighting quality, glazing area, and other physical parameters on the number of sick leave days as an outcome variable.

The subjects' average use of sick leave over a two-year period ranged from 9 to 148 hours, with a mean of 63 (sad. = 20.0). In other words, the average worker in Oregon Hall used approximately 8 days of sick leave per year in average. The experts' ratings of lighting quality ranged throughout the entire scale (1 to 7, with 7= poor), with an average of 4.1 (sad. = 1.7), almost exactly in the middle of the scale. The experts' ratings of the quality of view also ranged throughout the entire scale (1 to 10, with 10 = no view). The average value of the view ratings was 6.3 (sad. = 3.6). This value is toward the poorer end of the scale and reflects the fact that a substantial proportion of the subjects (39%) had no view at all.

Standard bivariate regression and correlation were used to examine the relationship between use of sick leave and the experts' ratings of lighting quality and views. Equation (1) below shows the relationship between sick leave hours used and the rating of poor lighting quality (PLQ). Equation (2) shows the relationship of sick leave usage with poor view ratings (PVR). In both cases, the relationships are in the predicted direction and statistically significant. Workers in offices with poor ratings of light quality and in offices with poorer views used significantly more sick leave.

Sick Leave = 52.6 + 2.6 (PLQ), $r = 0.22$, $p = 0.02$ (1)

Sick Leave = 55.6 + 1.2 (PVR), $r = 0.21$, $p = 0.02$ (2)

(PLQ = poor lighting quality, PVR = poor view rating)

The differences are not trivial, especially with respect to lighting quality. For instance, substituting values of the lighting quality measure in equation (1) indicates that a person in an office with the best lighting quality (PLQ = 1) would be expected to use an average of 55 hours of sick leave per year (a little less than 7 days), while someone in an office with the worst lighting quality (PLQ = 7) would be expected to use almost 71 hours (a difference of 16 hours or 2 days). Similarly, someone working in the office with the best view (PVR = 1) would be expected to use, on average, about 57 hours of sick leave (a little more than 7 days), but someone with no view at all (PVR = 10) would be expected to use almost 68 hours (11 hours or close to one and one-half days more per year).

As would be expected, the measures of lighting quality and view were related ($r = 0.43$, $p < 0.001$). Yet, multiple regression indicated that both independently influenced sick leave. When both variables were used simultaneously in a regression equation to predict sick leave they had almost equal influences; both variables had standardized regression coefficients of 0.15. Taken together, the two variables explained 6.5% of the variation in sick leave use, which was statistically significant.

The un-standardized multiple regression equation is shown in (3) below. Again, substituting values into the equation shows that the differences in sick leave in offices with different conditions are not trivial. A worker with the best lighting quality (PLQ = 1) and the best view (PVR = 1) would be expected to use about 53 hours of sick leave a year, while one with the worst conditions (PLQ = 7 and PVR = 10) would be expected to use 71 hours. This is a difference of 18 hours or over 2 days of work.

Sick Leave = 50.5 + 1.8 (PLQ) + 0.8 (PVR), R2 = 0.065, $p = 0.021$ (3)

Table 1 below gives the correlation coefficients and Table 2 below summarize the results of the regressions.

Table 1: Correlations between Official Reports of Sick Leave and Expert Ratings of Lighting and View

		(1)	(2)	(3)
Sick Leave Hours	r	1.00		
Poor Lighting Quality (PLQ)	r	0.217	1.00	
	p	0.018		
Poor View Rating (PVR)	r	0.212	0.426	1.00
	p	0.020	<.001	

Note: The sick leave measure is the average of hours used over 24-month (two years). The expert rating of poor lighting quality ranges from 1 to 7, with 7 as the poorest. The expert rating of view ranges from 1 to 10, with a value of 10 indicating no view. All measures are Pearson's product moment correlations. Significance tests are 2-tail. N= 119.

Table 2: Regression of Sick Leave Hours on Expert Rating of Poor Lighting Quality and Poor Views

Independent variable	Model 1	Model 2	Model 3		
	b	b	b	Beta	t
Intercept	52.6	55.6	50.49	----	10.33**
Poor Lighting Quality	2.55	----	1.81	0.15	1.48
Poor Views	-----	1.18	0.81	0.15	1.55
R squared	0.047	0.045	0.065		

Note: For Models 1 and 2, with only one predictor variable, the standardized regression coefficient, beta, is simply equal to the correlation coefficient given in Table 1. The R squared value is equal to the square of the correlation given in Table 1. The F ratio associated with the R square for Model 3 is 4.004, p = 0.021.

Upon further analysis and be adding glazing area (sq. ft.) to the model, the influence of view becomes smaller (beta drops to .11 from .15), but it is still in the predicted direction and significance. The effect of glazing area is as predicted; with fewer sick days used when glazing area is larger (negative coefficient). The R square value with the 3 variables in the prediction equation is 0.09. This says that almost 10% of the variation in the use of sick leave days is explained by these architectural and design elements; namely glazing area, lighting quality, and views quality.

CONCLUSION: QUANITFYING BIOPHILIA

This study investigated the relationship between views quality, daylighting, and sick leave of employees in administrative offices of a Northwest University Campus. It also places a value on views and daylighting in the workplace by linking their degree of availability to sick leave of office workers. The study investigated whether employees with a view of nature will take fewer sick days than those with a view of urban structures, or with no views out at all. A corollary hypothesis is whether daylight availability and better lighting quality in offices could also be a factor that reduces the number of sick leave hours an employee takes.

Following an extensive data collection and analysis procedures, the study's results positively supported the hypothesis investigated. Standard bivariate regression and correlation were used to examine the relationship between use of sick leave and the experts' ratings of lighting quality and view. In both cases, the relationships are in the predicted direction and statistically significant supporting positively our hypothesis. Workers in offices with poor ratings of light quality and in offices with poorer views used significantly more sick leave.

As would be expected, the measures of lighting quality and view were related ($r = 0.43$, $p < 0.001$). Yet, multiple regression indicated that both independently influenced sick leave. When both variables were used simultaneously in a regression equation to predict sick leave they had almost equal influences; both variables had standardized regression coefficients of 0.15. Taken together, the two variables explained 6.5% of the variation in sick leave use, which was statistically significant. The implications of the findings are huge when one considers productivity and health insurance costs sick leave hours can have on an organization.

Findings of this research create a base for a body of knowledge regarding the relationship between human health, view quality, and daylighting in offices. We hope that these results would influence office building designers and building owners. In addition, it establishes a base reference with respect to the effect of fenestration design and views on health and well being of office occupants.

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