61 Flavors of Daylight

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ABSTRACT

A field study collected data on a range of 61 daylit spaces in six cities with a range of climate types around the United States. Occupants were surveyed about their visual comfort, and a team of daylighting experts visited each space to evaluate perceived daylighting quality. Annual simulations of each space were performed using a new annual simulation approach based on RADIANCE that produced a variety of metrics to describe the illuminance levels and daylighting characteristics of the spaces. The research team developed new reporting and visualization formats to better understand the analysis of complex annual simulation data across a large sample of spaces. These data were analyzed in conjunction with expert and occupant qualitative assessments to determine which metrics and specific criteria best explained the variability in subjective responses to a suite of daylight sufficiency and quality categories.

This paper reports on the annual simulation visualization methods innovated and applied across all study spaces, focusing primarily on the daylight sufficiency metric. Findings from the annual illumination analysis are presented for all 61 spaces, with an emphasis on their ability to distinguish between alternative designs. Assumptions about the operation of window blinds proved to be a key variable in predicting annual illumination levels in the simulations. Differences in simulated illumination data are highlighted for three extremes of blinds operation—all open, operated and all closed—revealing the risks and resilience of different designs. A new method of ranking space designs by annual daylighting performance is discussed. Preliminary regression analysis of occupant and expert assessments and annual daylight illuminance calculations from simulation data are discussed.

Background

It is well understood that energy savings and electric demand reduction potential of daylighting is substantial. However, in order to prescribe a well-daylit building in building codes, voluntary ‘reach’ standards, or energy efficiency incentive programs, a fairly comprehensive set of daylighting performance metrics are required. Recognizing the need for new daylighting performance metrics, in 2006 the Illumination Engineering Society of North America (IES) created a Daylighting Metrics Sub-Committee (DMsC) to steer research on the topic and provide an important forum for a consensus based process. A consensus-based approach is critical to the success of this effort because historically there has been substantial disagreement about what constitutes a well-daylit building among experts. Therefore, internationally respected daylighting researchers and practitioners from both public and private sectors with backgrounds in architectural design, engineering, product manufacturing and academia were recruited to participate on the DMsC. Ultimately, the goal of the DMsC will be to answer the question: “What is good daylighting?” and to address the questions across multiple daylighting constructs including ‘sufficiency’, ‘excessiveness’, and ‘quality’. In the immediate term, it seeks to 1) define a suite of useful metrics and corresponding criteria, 2) describe a consistent methodology to generate these metrics based on currently available climate-based simulation tools, and 3) promote these findings to product developers, researchers, designers, organizations developing codes and standards, building ownership organizations and others. This will aid in the evaluation of the daylighting performance of alternative design strategies and products and promote the adoption of more successful daylighting practices, thus increasing energy savings and reducing electricity demand.

The ‘Daylight Metrics Project’ is described in this paper, and was developed to provide useful research to inform the work of the IES-DMsC. Funding from the California Energy Commission, Southern California Edison, Northwest Energy Efficiency Alliance and New York State Energy Research Development Authority supported the project. This research effort was lead by the Heschong Mahone Group, guided by the IES-DMsC, and supported by a team of national and international experts spanning a multitude of disciplines in the daylighting field, namely, researchers at the Integrated Design Lab (IDL) at the University of Idaho and University of Washington, National Research Council of Canada, Massachusetts Institute of Technology, and Loisos/Ubbelohde Design. The scope of the daylight metrics project included developing a suite of daylight performance metrics, which include daylight sufficiency and daylight quality, such as uniformity, contrast, glare etc. This paper focuses just on the results for the daylight sufficiency metric.

The need for daylighting performance metrics and criteria that are broadly accepted among researchers and practitioners and that can be universally referenced by multiple organizations has been well established [Mardaljevic, Heschong, & Lee 2009; Reinhart, Mardaljevic, & Rogers 2006]. In particular, organizations that develop and regulate building energy codes are each interested in the role of daylighting performance within their various programs. The lack of defensible, reliable, and universally recognized daylighting metrics and criteria has hampered the progress of these organizations, and therefore, they struggle to include daylighting meaningfully in their programs.

During the last decade there has been substantial progress in the conceptual design of daylighting metrics. A suite of alternative annual daylight metrics, often described as dynamic metrics, have been proposed [Mardaljevic 2000; Walkenhorst, Reinhart & Timmer 2002; Reinhart, Mardaljevic & Rogers 2006] but before this project there has been very little data available to determine which metric best described daylight quality, predicted good energy performance, or what appropriate thresholds and criteria are for a given space type. Furthermore, other important considerations such as the need for a consistent methodology to guide performance assessments (via prescriptive or simulation pathways) during design stages, guidelines for performance assessment at the space level instead of the building level, and the distinction between good daylight quality versus good energy performance has not been clearly articulated to organizations formulating codes, standards or incentive programs related to daylighting. This paper hopes to contribute to these discussions.

Research Design

This research analyzed two primary data types, data collected during site visits to each of the 61 spaces investigated, and data generated by the annual simulation, using a new approach called DYNAMIC RADIANCE [Saxena et al. 2010], built upon the RADIANCE software platform. During site visits to each of the 61 spaces, occupant and expert assessments of the daylighting quality in the space were recorded using a survey form. These qualitative assessments were later compared to output from the DYNAMIC RADIANCE simulations, using a nested regression model, in order to discern the success of candidate metrics to explain the variability of subjective assessments

Field Study

In conjunction with the IES-DMsC, the project team decided to focus its efforts on three key space types: classrooms, open offices, and library-type spaces. These three space types are commonly targeted for daylighting, provide important energy saving opportunities, and encompass a range of visual tasks and quality issues that need to be addressed. For purposes of this research, these space types were operationally defined by describing their use characteristics and therefore the findings can be generalized to any space with reasonably similar use characteristics.

For each study space, the limits of the physical area used during the subjective assessments and for simulation were determined based on two criteria; to define a coherent daylit area, and one large enough to include approximately 10 occupants who could be surveyed. For example, in the case of a classroom, the whole room was defined as the space, but in the case of a large open plan office, a representative area including 10 workstations was defined as the space. Typically these study spaces were approximately 1,000 SF. During the expert assessment, the electric lights were turned off whenever possible and the blinds were left as found, unless the spaces were unoccupied with blinds fully closed, in which case the blinds were set to reasonable operating positions

Sample frame. The team visited 77 candidate spaces over the course of five days in California (Sacramento, San Francisco, Truckee), two days in Washington (Seattle Metro area) and three days in New York (Albany, New York City). Spaces were intentionally selected with hopes of attaining a range of daylight strategies across all spaces with at least 20 spaces for each space type. From this initial group of 77 spaces, the study sample was reduced to 61 sites used in the analysis. A space was removed if 1) it was determined to be too irregular to represent the operational definitions of the three space types described above, 2) there was insufficient access to conduct the second site visit, 3) occupant assessments were not possible, or 4) it was too complex to be accurately simulated with current simulation tools within project limits.

The final study sample successfully captured a good range of daylit spaces with different daylighting strategies. The sample had 12 spaces with skylights, 7 with light shelves on windows, 9 with clerestories, 4 with rooftop monitors. Out of the 61 spaces, 28 had windows in more than one orientation, 32 had windows in a single orientation, and 3 had no windows, with daylighting from skylights or roof monitors.

Expert and occupant questionnaires. Early on in the project, the project team determined that two types of survey data would be needed to capture the variability of daylight over time and across the three space types. During the site visits, subjective data was collected using a questionnaire, from occupants and from experts. The occupant questionnaires were simple, only two pages in length, and included 26 items (7 demographic and space characteristic check box items, 15 Likert 9-point scale items, and 4 open-ended questions). Occupant questionnaires examined the following constructs: aesthetics, thermal comfort, acoustics, view quality, view quantity, satisfaction with blinds, electric lighting sufficiency, daylight sufficiency, daylight excessivenesses, and visual comfort (glare).The expert questionnaire was more in depth and included 54 items (49 Likert 9-point scale items and five open-ended questions). Expert questionnaires included the occupant questions, and others probing visual comfort (glare), daylight uniformity, visual interest, personal control, and visual and acoustic privacy in more detail. The survey questionnaires can be reviewed on the Daylight Metrics project website: http://www.h-m-g.com/DaylightPlus/Daylight_Metrics.htm

Simulation

The goal of the simulations was to use three dimensional computer models to predict annual daylighting conditions in the study spaces over the course of a full year. First we investigated the capabilities of available annual simulation tools and selected which programs to use in this project. ECOTECT Version 5.5 developed by Andrew Marsh of SquareOne was selected to generate the 3D geometry files for use with RADIANCE because at the time, it was the simplest mechanism to create detailed Radiance input files. A new approach to simulating annual daylighting called DYNAMIC RADIANCE was developed by Greg Ward of Anyhere Software. This allowed annual (8,760 hrs) simulations of daylighting using a TMY2 weather file for a location, and to report illuminance levels at sensor grids within the space models. Sensors were placed in continuous one foot grids at task level, eye level, and the ceiling (detailed further in 'Simulation Output' section). The reason for developing DYNAMIC RADIANCE and its innovations are discussed in separate publications [Saxena et al. 2010; Heschong, Saxena & Higa 2010].

Blinds assumptions. Assumptions about how blinds are treated within daylight simulation practices have been ill defined to date. Few studies are available about how people operate blinds and fewer are available about how daylight is transmitted through blinds. Moreover, standards and codes to date have not addressed the issue whatsoever, despite an intuitive understanding that blind use and blind type play a large role in daylight performance on an annual basis. Even annual daylight metrics such as Useful Daylight Illuminance (UDI) and Daylight Autonomy have not explicitly stated how blind use should be treated to generate consistent values. Therefore, a decision was undertaken with this project to develop a standardized method for simulating annual blinds operation. Our decisions were based upon the best available research [O'Neill et al. 2007; Reinhart & Voss 2003; Reinhart 2004; Leslie et al. 2005; Selkowitz personal correspondence 2008], and also chosen to be reasonably consistent with existing whole-building energy simulation protocols. These methods should be refined as additional research becomes available.

The blind operations and daylight transmission assumptions used in this project are as follows: 1) blinds are triggered by window groups; defined as groups of windows facing the same direction, in the same plane, having the same glass type and exterior shading geometry, and the same window attachment (blinds or shades), 2) blinds are either fully deployed or completely retracted, a deployed blind completely covers the window, while a retracted blind does not cover any portion of the window, 3) two types of products were modeled, opaque blinds or mesh fabric shades, 4) blinds are triggered to deploy when 2% of the horizontal 'eye level' sensors (described in a Section on Simulation Outputs) had an illuminance of 4,000 lux (roughly equivalent to 50

Watt/m2 of solar radiation) or greater when considering only sunlight as an illumination source from any given window group, 5) blinds were reopened when the condition had passed, based on checking in one hour increments.

The 'eye level' sensors that could see the disc of the sun was selected as a proxy for direct-sun glare from low angle sun. The result is a method that accounts for dynamic operation of an active blind operator, and is similar to the logic commonly used in whole-building energy analysis programs, such as eQuest, that operate the blinds according to a solar trigger, determined by radiation intensity on a window surface. In the future, when comparing outputs between illuminance and energy simulation programs one should be careful to verify that the blinds operating schedules are as similar as possible.

While the operation of the blinds was dynamic and carefully nuanced by orientation, the slat tilt angles relative to sun position were not accounted for, thus the photometrics were static. It was assumed that the blinds or shades produced a simple lambertian (diffused) distribution of daylight with a constant transmission whenever deployed. Blinds (horizontal or vertical) were assumed to transmit 20% of direct sunlight and 20% of diffuse skylight when deployed; mesh fabric shades were assumed to transmit 5% of each daylight source when deployed.

Simulation output. The research aimed to address three primary constructs of daylight within a space; 1) daylight sufficiency, 2) daylight excessiveness, and 3) daylight quality. To analyze the daylight illuminance in the space, three horizontal illuminance grids were specified in the simulations in order to provide output data to support a suite of daylight metrics. The illumination grid definitions are provided below.

1.) **Task level illumination grid:** A continuous gird of illuminance sensors with one foot spacing, looking upward, was located 32" above the finish floor (AFF).

2.) **Eye level sensor grid:** A second continuous grid was set at a seated eye level position (48" AFF). The sensor grid was then offset by 12" along the perimeter of the study space to simulate only those areas where a seated observer could occur.

3.) **Ceiling level illumination grid:** A continuous gird of illuminance sensors with one foot spacing, located at the highest continuous horizontal plane that could be located in the space. This grid was oriented to look downward.

Analysis Methodology

Illuminance Visualization Analysis

Simply making sense of all the output data from the simulations proved a daunting task. On average, there were 8,212,500 data points available for each of the 61 simulated spaces. The visualization method displayed in Figure 1 through Figure 3 (see 'Results' section) was used to compress the data further for a snapshot of annual performance. Data from all sensors and hours of each annual simulation run were plotted on a percentile curve that represents the percentile of all sensor readings that occur over a year below a given task-level illuminance shown on the x-axis. All of the curves have a similar 'S' shape, based on the natural annual fluctuation of daylight availability over the course of the seasons, but varying in magnitude and slope. Dim spaces have curves that rise quickly and reach 100% at low illumination levels. Bright spaces have more gradual curves that do not reach 100% until further to the right, at high illumination levels.

In Figure 1 through Figure 3, the three curves (magenta, green and blue) represent three separate simulations for the same space, specifically three blinds conditions – blinds always open, blinds operated (by a solar trigger), and blinds always closed respectively. The percentile curves provide a signature pattern, unique to the geometry, daylighting strategies, climate and orientation of each space.

Regression Analysis

We used regression as a tool to compare the results of the simulation output to the experts' and occupants' questionnaires. The metrics with the closest fit were judged to be the best. First, it was necessary to reduce the full range of possible regression models to just those meaningful for analysis. This was done through an iterative process that screened the data for co-linearities and other relationships, and then tested different formulations of field study variables in simple regressions for their predictive power.

Processing of simulation data in candidate metrics. The simulation output data was processed into a variety of candidate metrics. Each metric reduces the raw annual simulation data into a single value per space. For example, we calculated what we called 'inverse daylight autonomy q300' (DAq300) by first selecting only the data between 8:30 and 17:30 from the task level sensor grid, corrected for daylight saving time. Then we ordered all of the illuminance values for all remaining hours and all sensors in the space by illuminance. The DAq300 value was then the percentage of sensor-hours where the illuminance was below 300 lux. We calculated this value and values for other candidate metrics, derived from the all the sensor grids, for all spaces.

The other candidate metrics calculated for daylight sufficiency were Inverse Daylight Autonomy with eight different illuminance threshold values (ranging from 200 lux to 5000 lux), Continuous Daylight Autonomy (three threshold values from 200 lux to 500 lux), Useful Daylight Illuminance (between 100 and 2500 lux), and Daylight Saturation Percentage (between 400 and 4000 lux). These represent the range of alternative annual daylight metrics that have been proposed by various researchers [Mardaljevic 2000; Walkenhorst, Reinhart & Timmer 2002; Reinhart, Mardaljevic & Rogers 2006]. Along with these, three incumbent static daylight metrics of Daylight Factor (percent of space above 2% Daylight Factor under overcast skies), and percent of space above 25 footcandles at 9 am and 3 pm on sunny equinox day, were also calculated and considered in the analysis. Similarly, various versions of sun penetration, skyview, and uniformity were also considered.

Simple regressions. The simulation data and the questionnaire results were assembled into a master database for study using linear regressions. Then we formed a dataset by applying the candidate metrics to the simulation data, averaging the questionnaire results for each space, and including space characteristics such as number of window orientations and presence of skylights. This made a summary dataset with one row for each space. The candidate metrics were then set as the dependent variable in a simple linear regression, with the questionnaire items and space characteristics, (both singly and in groups) as the independent variables. The metrics with the strongest relationship to the qualitative assessments were chosen for further study using the nested regression method described below.

Nested regressions. The next step in the regression analysis was to create multilevel (nested) regressions that were structured to allow experts and occupants to have different relationships to the dependent variable being tested. These regressions were examined both for the whole data set of 61 spaces, and also separately by space type. The nested regressions gave more precision in our analysis, allowing us to see how a metric performs differently in different space types and according to both the expert and occupant assessments.

We used these regressions to evaluate all of the candidate metrics that were selected from the simple regressions, based on the direction and size of the relationship of the metric to the occupant and expert survey results and the R^2 goodness of fit statistic for the regression as a whole. For example, the DAq300 metric discussed above can range from 0 to 1, and the occupant and expert survey responses can range from 1 to 9. The regression model for all spaces shows a statistically significant positive relationship between both the occupant and expert responses to the combined "sufficiency" group and the DAq300 metric. In addition, the model has a relatively high R^2 compared to other candidate metrics of sufficiency, leading us to believe that this will be an effective metric for daylight sufficiency. We also observed that in the separate space models, the relationships remained stable and the predictive power strong.

Results

At this point in reporting, the analysis process is not complete, nor have the results been fully vetted by the IES-DMsC. Below we report on selected findings that show important trends, and suggest the general direction that daylight metrics are likely to head, especially those involving daylight sufficiency.

Expert and Occupant Assessments

A detailed discussion about the relationship amongst experts and between experts and occupants will be published separately, however a few highlights are provided here. Experts tended to agree with each other (high inter-rater reliability). This came as a surprise to some of the experts, given their historic disagreements. This result does lend confidence to the questionnaire instrument. Experts tended to be more judgmental with Likert Scores spanning the full 9-point scale, whereas occupants tended to be more tolerant in their assessment of spaces, staying closer to a neutral response. Occupants scored 'quality of view' similarly to 'how much they liked being in the space'; whereas experts scored daylight sufficiency similarly to 'how much they liked being in the space'.

Illumination Analysis Findings

There were interesting findings that came out of the illuminance analysis of all 61 spaces that clearly point out the effects of various daylighting strategies. Generating the percentile of sensor-hour plots for all 61 spaces provided a unique look at key aspects of daylighting performance and pointed to areas for further research required to better simulate, and prescribe good daylighting in buildings.

Daylight percentile plots. Figure 1 shows plots of two sister classrooms near Sacramento, CA, with identical geometry and orientation, the only difference being that the classroom on the right in Figure 1 has tubular skylights, the one on the left does not. The plots show that the classroom with skylights clearly receives more daylight across greater floor area throughout the year. The magenta (blinds always open) and blue (blinds always closed) lines are relatively close to each other, showing that the effect of window blinds in both these classrooms is minor. The plot without skylights has about 85% of sensor-hours below 300 lux, while the one with tubular skylights has about 20% below 300 lux, a substantial difference in this measure of daylight sufficiency.

Figure 1: Percentile of Sensor-Hours Plot for Classroom in Sacramento with No Skylights (Left) and With Skylights (Right)

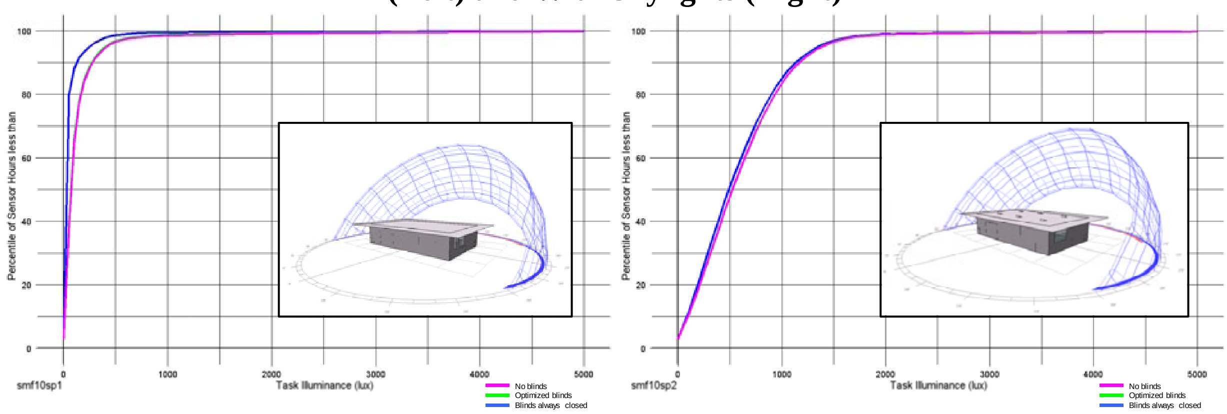
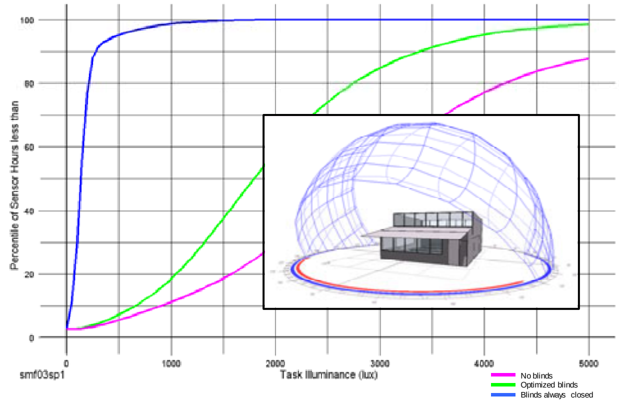


Figure 2 provides the percentile of sensor-hour plots for a 1960's era finger-style classroom in Sacramento. The classroom has North and South exposure, with three large, high windows. The windows are fitted with curtains that can be drawn by the teacher as needed on all three windows (the original clerestory solar shading louvers were removed at some point).

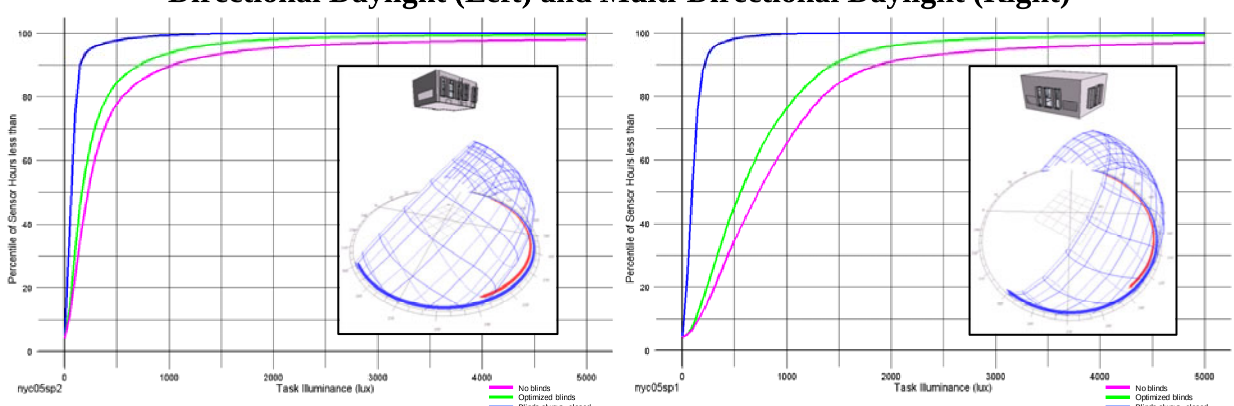
Figure 2: Percentile of Sensor-Hours Plot for Classroom in Sacramento with Large North-South Exposures



Our plots for this space revealed just how substantially the annual daylighting quantity in the space changes with blind use. The difference in the percentiles at any illuminance level between the magenta (blinds always open) and green (blinds operated) reveals a large number of hours when blinds need to be closed to prevent sun penetration. The difference between the magenta (blinds always open) and blue (blinds always closed) lines suggests that the daylighting design is easily defeated if blinds are not properly operated, which would be the worst outcome for a space designed for the inclusion of daylight since the heat gain and losses from windows would still exist but the benefits of daylighting would not. This points to the need for better shading, effective and accessible control for blinds, or an automated blinds solution, in spaces with excessive sun penetration.

Figure 3 shows the percentile of sensor-hour plots for two classrooms in New York, that point out the effectiveness of uni-directional versus multi-directional daylight exposures. The figure on the left in Figure 3 is a plot of a classroom with windows on only one façade, facing southwest. The figure on the right shows a plot of another classroom in the same building, but with windows in three orientations, facing south-west, north-west and north-east.

Figure 3: Percentile of Sensor-Hours Plot for NY South-West Facing Classroom with Uni-Directional Daylight (Left) and Multi-Directional Daylight (Right)



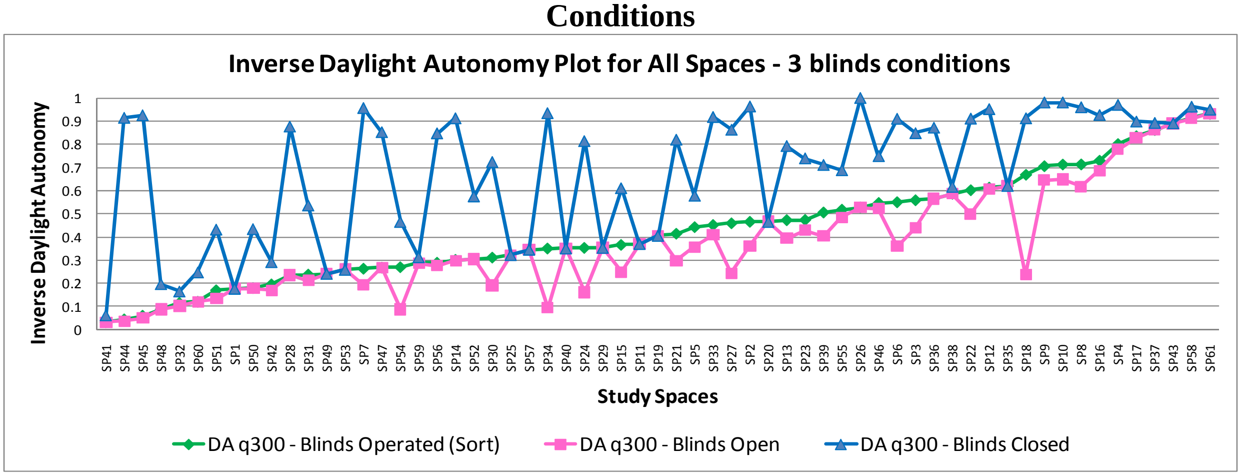
The room with uni-directional daylight has about 60% of sensor-hours below 300 lux, while the room with multi-directional daylight has only 20% below 300 lux, a reduction of about 40% in this measure of daylight sufficiency. By bringing daylight into the space from more than one orientation, the likelihood that blinds in one window group will be open when the others are closed is higher, thus ensuring better daylighting for throughout the day and year.

Analysis at 300 lux. To examine the findings from the entire dataset, we plotted the percentile of sensor-hours below 300 lux (DAq300) for all three blinds cases of all the 61 spaces. This percentile of sensor-hours can also be termed as 'inverse daylight autonomy' (a lower value means more daylight, higher means less daylight). The plot in Figure 4 shows the 61 spaces with their identifiers on the x-axis, and their respective 'inverse daylight autonomy' (DAq300) on the y-axis. The plot is sorted from left to right by the value of the 'blinds operated' (green line) case.

The graph shows a large range in magnitude between the three blinds cases in many of the 61 spaces. There were a few spaces where 'blinds open' (magenta) and 'blinds operated' (green) values were identical or very close to each other. These spaces were either only skylit, north facing, or heavily shaded from direct sun with exterior overhangs or adjacent buildings such that the blinds were only required a few times in the year. In most spaces the 'blinds closed' (blue) case reduced the available daylight in the space substantially as compared to the 'blinds operated' (green) case.

This analysis showed that in most of the study spaces, blinds operation plays an extremely important role in determining sufficiency of daylight. These results also point to the value of further scrutiny on assumptions used in this study for the blinds light transmission and blinds operation. Given that blinds will be used by occupants for a variety of reasons, and indeed were found to be operated in 83% of our study spaces, their contribution to improving or defeating daylighting conditions is a critical area for further research and refinement.

Figure 4: Plot of All 61 Spaces Inverse Daylight Autonomy - 300 Lux at Three Blinds Conditions



Results from Regression Analysis

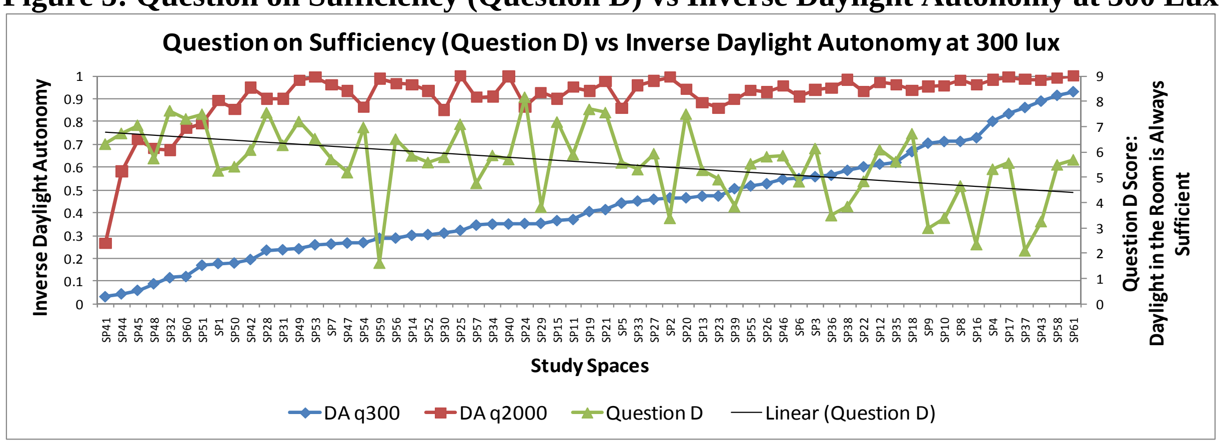
At the time of writing, the project team is continuing to analyze results from the regression analysis, with only preliminary findings that have not been fully reviewed by the IES-DMsC. The goal of the regression analysis was to test a set of equations for different daylighting performance metrics and determine which ones have the best correlation with the occupants' and experts' assessments of the spaces. Some highlights of our preliminary findings are provided below.

The analysis for daylighting sufficiency shows that the inverse daylight autonomy metric at 200 lux or 300 lux are both plausible candidates, providing enough variance within the dataset to differentiate between different daylit spaces and different daylighting strategies. Among our three space types, occupants had the strongest preference for brighter classrooms, and thus the metrics with the higher threshold, DAq300, had the most predictive power for classrooms. Given that a 300-lux threshold is also consistent with IES recommended minimum electric illumination levels for many space types, the project team is currently favoring this criterion for adoption.

The regression analysis shows that occupants have a consistent preference for brighter spaces, as judged by annual illuminance, regardless of threshold. We have not been able to identify any upper "limits" where too bright becomes objectionable. Figure 5 shows a plot of the 61 spaces sorted from left to right by DAq300 (from brightest on the left to dimmest on the right). The averaged response from experts and occupants for each space to the compiled question 'D' for daylighting sufficiency is plotted in green, with a trend-line indicating brighter spaces are preferred. This simplified analysis clearly shows that people tend to rate brighter spaces as having greater daylight sufficiency. The nested regression for the same variables returned the same basic finding, but with more precision.

We expected to find that the brightest spaces would have more frequent reports of glare problems. However our regression analysis indicated that occupants in brighter spaces, regardless of the threshold considered, tended to report less problems with glare or "troublesome reflections". Also the response to the item "this space is never too bright" was positively associated with increasingly brighter spaces. So far, only 'hours of sun penetration' (before blinds operation) has been found to predict responses to any items associated with glare or excessive brightness. These findings deserve further scrutiny.

Figure 5: Question on Sufficiency (Question D) vs Inverse Daylight Autonomy at 300 Lux



With further regression analysis, the project team aims to recommend a set of metrics that when used together help to describe overall daylight quality and resulting occupant comfort. These metrics will then be submitted to the DMsC for discussion, refinement and eventual approval from the IES.

Discussion

Once completed, the analysis from the Daylight Metrics Project will provide a highly sought, consensus-based set of daylight metrics. Once the proposed metrics are agreed upon, the relevant regression equations can be employed to help suggest criteria thresholds that could be adopted by codes, standards, design specification and energy efficiency programs to identify a well-daylit space. We hope that the next round of updates to various energy codes and standards will utilize these metrics to prescribe well daylight spaces for energy savings and occupant satisfaction with indoor environmental quality. The data collected through this project and the regression models developed can be used to justify the criteria selected. Furthermore, the simulation methods outlined in this paper can help define the methodology to be used in performance pathways in codes and standards. Finally, appropriate guidance for prescriptive or single-point-in-time performance criteria can also be 'backed out' of this data set by correlating the annual simulation results from simplified version of the models.

Previous blind use research summarized by Reinhart and Voss [Reinhart & Voss 2003] suggests that most people are not likely to adjust manual blinds actively over the course of a day to maximize daylighting. Instead, they are likely to leave blinds down after the first instance of discomfort from glare and not change the position for the rest of the day, quite often for weeks at a time. This project shows the substantial difference in annual daylight values between the two limiting assumptions of blinds all open or blinds all closed. The importance of accurate blind operation assumptions and the current lack of knowledge in this cannot be overstated. Results also demonstrate the importance of assumptions about blinds light transmittance and blinds trigger, which can have a considerable effect on the calculation output from various metrics. With the development of DYNAMIC RADIANCE as part of this project, it is now possible to simulate various complex blinds and shade configurations and their operation with automated systems that use motorized controls. Other complex optical glazing products, light redirecting blinds, and tubular skylights can now also be efficiently modeled to get accurate annual daylighting simulations, which makes it possible to determine their value for building energy efficiency.

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