California Daylighting plus

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HMG

March 12, 2008

PIER DAYLIGHTING PLUS – DAYLIGHT METRICS

To: Program Advisory Committee (PAC) Members

From: Heschong Mahone Group, Inc.

Re: Daylight Metrics Project Description

1. PROJECT OBJECTIVE

The objectives of this project are to develop a set of daylight performance metrics and criteria, in cooperation with national and international leaders in the field, which can be used in programs, codes and standards to promote successfully daylit buildings, and thus greater energy savings and demand reduction. This project will address both energy performance and illumination standards for daylit buildings.

The Daylight Metrics project is a necessary step toward achieving widespread promotion and use of daylighting in buildings. The energy savings and demand reduction potential of daylighting are enormous, but since acceptable performance is poorly defined, current programs, codes and standards are hesitant to require daylighting.

Once daylight metrics and criteria have been developed and recognized by national stakeholder groups, they will be available to product developers, researchers, designers, program managers, building owners, etc., to evaluate performance and promote the adoption of better daylighting strategies. Without improved metrics, the market will remain confused and advancement of this field will be delayed.

2. PROJECT APPROACH

A range of daylit spaces will be identified for study. Each study space will be evaluated for the “goodness” of its daylighting conditions by both experts and occupants. Three dimensional computer models will also be created in order to run annual simulations of the daylight illumination and resulting building energy use impacts for each space. The occupant qualitative assessments will be compared to output from the simulations in order to develop quantitative metrics that capture the most useful descriptors of annual daylight performance in the spaces. Ultimately, we hope these newly defined simulation outputs will provide more useful insight into the annual quantity and quality of daylit spaces than the current common practice of calculating a static daylight factor or daylight illuminance levels for only a few selected sky conditions.

3. PROJECT TEAM

This work is being done in concert with the work of the Daylighting Metrics Subcommittee of the Illuminating Engineering Society of North America, and with input from many stakeholders to ensure that the analysis methods and output are widely applicable.

This project is funded by the California Energy Commission PIER Program, the Northwest Energy Efficiency Alliance (NEEA). It is being run in parallel with a similar project funded by the New York Energy Efficiency Authority (NYSERDA). Principal Investigator for both projects is Lisa Heschong, of the Heschong Mahone Group: Mudit Saxena is Project Manager. PIER team members include Professor Joel Loveland and members of the Integrated Design Lab at the University of Washington in Seattle, Washington State; Christoph Reinhart, PhD, of National Research Council of Canada, in Ottawa Canada (and starting a new teaching appointment at Harvard University); Professor Marilyne Andersen of Massachusetts Institute of Technology Department of Architecture; and George Loisos, of Loisos/ Ubbelohde Design. The NYSERDA Project team includes Energy Resources Group of New York City, in addition to Christoph Reinhart and Marilyne Andersen.

4. PROJECT TASKS – PROGRESS TO DATE

4.1 Selection of Study Space Types

In conjunction with the IESNA subcommittee, 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, have key visual quality issues that need to be addressed, and represent three rather different visual challenges. Key characteristics of these three space types were further defined as:

Classroom type – occupants engage in a wide variety of visual tasks, including: individual reading and working at desks on both computers and paper tasks; studying material presented on whiteboards, TV screens, projector screens, and material posted on walls; engaging in both focused group and informal one-on-one conversations. Occupants have limited ability to reposition themselves in order to improve their visual comfort. Classroom type spaces range from small conference rooms to large lecture halls. They are the most uniform geometries of the three space types, most commonly a rectangular space with medium ceiling height.

Open office type – occupants engage in a wide variety of visual tasks, including: individual reading and working at desks on both computers and paper tasks; use of vertical surfaces is more limited than in classrooms; conversations are mostly informal, one-on-one. Occupants have almost no ability to reposition themselves in order to improve their visual comfort. Open office type spaces range from small offices with a few workstations, to large cubical floor plates of high rise buildings. They generally have the most constrained geometry of the three space types, frequently with lower ceilings.

Library type – occupants engage in a wide variety of visual tasks, including: individual reading and working at desks on both computers and paper tasks; use of vertical surfaces is for display, navigation, and decoration; conversations occur most importantly at a service counter or in sitting areas. Most occupants, with the exception of library staff, can reposition themselves freely in order to improve their visual comfort. Library type spaces include library reading rooms, lobbies, customer service areas, and multi-purpose function rooms. They are generally the largest volume spaces of the three types, with the highest ceilings.

4.2 Sample Frame

Given project resources, the project team set a goal of finding a range of daylit spaces, with a sample of 20 spaces per space type. The sample should include a range of space geometries, including sidelit and toplit, large and small daylight apertures, a variety of orientations, simple and sophisticated design approaches, and a range of good and bad visual conditions. To ensure diversity, we agreed that we would target about two spaces per building site, and no more than four per site; that we should avoid visiting more than one building per architect; and that there should be a variety of space conditions visited in each of the three states.

Type:	California	Washington	New York	Total
Classroom	12	6	2	**20**
Office	12	6	2	**20**
Library	12	6	2	**20**
Total	**36**	**18**	**6**	**60**

Figure 1: Proposed Study Space Sample Frame

The team identified a range of candidate spaces and logistical constraints that would allow a team of experts to visit the spaces together during the summer of 2008. The team visited 77 candidate spaces over the course of five days in California, two in Seattle and three in New York. From this group, the study sample was reduce to the 61 sites described in Figure 2 below, determined to be the best match for the overall study purposes.

Type:	California	Washington	New York	Total
Classroom	13	4	5	**22**
Office	11	7	5	**23**
Library	9	6	1	**16**
Total	**33**	**17**	**11**	**61**

Figure 2: Achieved Study Space Sample

4.3 Definition of the Study Space

Another key issue was the definition of the study space. Simple rooms, such as classrooms, were easy to define, however about half of our candidate spaces were sub-areas of much larger spaces, such as daylit zones in a high-rise office building, or daylit areas in a large library that also included non-daylit stacks and counters. Thus, when a daylight space was much larger and/or more complex, we needed a consistent rule-set for defining the sub-area to study. The definition of the study space determined where the experts located themselves during their evaluations, and where we recruited occupants for the occupant assessment.

Upon each site visit, a 'study space' was defined that ideally, defined a space less than 40 feet square, and a work area for about 10 people, who could answer our occupant survey. In addition, if it was part of a larger area, it captured all the significant daylit area of the larger space, or a representative "slice" of the larger space, isolating the influences from various daylight apertures. Wherever possible, we used the major geometrical elements of the larger space, such as columns or balcony walls to define the edges of the smaller study space. During the summer site visits, extensive photos and high dynamic range (HDR) images were taken of each space, along with a grid of handheld illuminance readings at task level, and along the walls or edges of the define space.

In addition to the boundaries of the study area, we also needed to collect information about the boundaries of the "contextual space" that would be included in the three dimensional models to capture the interactions between the study area and the surrounding area, both interior and exterior. Thus, for study spaces that were a sub-area within a larger space, a rule set was described that basically included any additional interior area within two ceiling heights of the defined study space as part of the "contextual space" for the simulation models. All major exterior obstructions within view of the study space were also modeled. In some city locations, we were even able to obtain three dimensional models of the surrounding neighborhood.

4.4 Expert Assessment

Expert assessments were done during the site visits in July and August of 2008. Daylighting experts were recruited from the project team and the IESNA subcommittee to evaluate each study space. A four page evaluation form was developed, which included one page closely imitating the occupant assessment form. Four to eight experts visited each study space together, so that they were evaluating the space under the same daylighting conditions. The questions on the evaluation form were reviewed for consistent interpretation with each expert before beginning the assessment, but discussion was discouraged during the site visit to avoid developing a premature consensus. An average of 4.5 experts reviewed each study space. Based on an informal review, we believe that there was a reasonable consensus among the experts on the evaluation of the spaces, varying only in intensity not the general direction of the opinions.

Some simple hand-held illumination measurements and a series of hemispherical high dynamic range (HDR) photographic images were taken at the time of the experts' visit in order to document lighting conditions in the space at that point in time. The HDR images will support quantitative evaluation of the luminous conditions at the time of the expert assessment.

4.5 Occupant Assessment

The occupant assessment provides us with a layman's view of the lighting quality in our daylit study spaces, and importantly, provides an assessment over an extended period of time, rather than the short, one-time visit by the experts. As part of the survey occupants reported how long they had been working in the study space, and for about how many hours per day.

The occupant assessment form was distributed in one of four ways: 1.) during the first expert assessment visit if enough occupants were present at that time. 2.) during the second pass survey 3.) distributed by a host at the site and collected later or 4.) in some elementary schools, a surveyor interviewed the children in the classroom, asking simplified versions of the questions, and recording a hand vote.

Our goal was to collect an average of ten occupant assessments per study space. We achieved an average of nine per space.

4.6 Simulation Methodology

The goal of the simulations was to use three dimensional computer models to predict 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. This decision process is described in an interim report called "Software Choice Memo." It was determined that the best opportunity for flexible analysis was presented with the use of Daysim for illuminance modeling and eQuest for energy impacts. ECOTECT was selected in order to create the three dimensional models. The capabilities and limitations of these available programs then helped to determine the modeling methodology and output.

A key decision in the modeling methodology was to define three levels of analysis, that would satisfy a variety of needs for daylight metrics. These were defined as follows:

Level One: the simplest level of detail, appropriate for schematic design, to test the performance of alternative design strategies.

> This level uses default assumptions for most conditions that are not knowable during early design, and optimistic assumptions, to define the daylight potential for the space. Window conditions are defined with simplified two-dimensional openings, surface reflectance are standard defaults, and the operation schedule is all sunlit hours of the year.

Level Two: contains higher level of detail, as appropriate demonstrating compliance with codes or standards at the completion of construction documents.

> This level includes material properties determined by the building specifications, or proscribed defaults where appropriate for code compliance. It generally makes pessimistic assumptions about operating schedules to define a minimally acceptable condition. Window details are three dimensional, and operating schedules and window treatments are standardized defaults for the space type.

Level Three: contain the highest level of detail, appropriate for modeling existing buildings for research or verification purposes, where actual furniture layouts, window treatments, surface colors, and operating schedules are known.

> This level includes measured data where available, such as surface reflectance and operating schedules, or level two defaults when not available. Exterior details are fully modeled, including vegetation.

For the purposes of this study, three dimensional models were developed at Level Three, based on measurements taken during a “second pass” survey of each space. Measured drawings, building plans when available, photographs, illuminance measurements and interviews with building maintenance staff were used to provide as much detail as possible for the Level Three models. A second, Level One model, was then backed out from this information, to reconstruct what was likely knowable during the schematic design phase for each space. Level Two models were not part of this study, but may be useful in future efforts to develop code or standards compliance procedures.

4.7 Choice of Simulation Outputs

Once the simulation methodology had been determined, the next step was to specify their output which would provide the raw data from which the metrics of performance could be developed. We hoped to develop a multi-purpose dataset from which a variety of alternative metrics could be derived and tested against the qualitative assessments. Another goal was to identify output that could – in principal- be automatically generated by a variety of other daylight simulation programs such as SPOT, AGI, and 3d Studio Max.

We were directed by the IESNA subcommittee to generate metrics that could describe the visual quality in the space, in addition to illuminance sufficiency. Illuminance sufficiency was fairly easily described via the traditional metric of illuminance on the horizontal task. Thus, the analysis was directed to report hourly daylight lux at a horizontal grid of points on a one foot grid at task level throughout the space.

Visual Quality: Visual quality, however, is less easily defined. We considered two approaches to describing visual quality—using one of the many available glare calculations and/or analyzing luminosity, i.e. luminous patterns on the walls of the space. There were a number of problems however, that largely stem from the complexity of spatial geometries we found in our study spaces, and the shear computational intensity of climate-based calculations that consider every hour of the year. The following discusses some of the challenges we considered while developing the output list for our simulations:

1.) **Glare calculations**: While there are a number of alternative glare calculations, they all depend upon establishing a "point of view" for analysis. However, we were trying to describe the overall "goodness" of the entire space or room, rather than a single location within that room. We felt that a single point of view could not be universally selected for any space to be analyzed. In principal, a "critical task" might be described, where visual quality conditions must be satisfied, but even with the most uniform space type that we examined—classrooms—we could not define a rule set that always identified the best location for the "critical task" in each classroom. Furthermore, the shear data intensity required for hourly annual glare calculations promised to be overwhelming for this study.

2.) **Exterior sources of reflected glare**, such as reflectance off of buildings, windows, car windows, or even the ground, are often transient in nature, and very difficult to model accurately. Dirt accumulation, rain, snow, fog, deciduous vegetation, and changing locations (as in car windows) make exterior glare conditions rather unpredictable. In reality, most exterior glare is addressed with blinds, shades or curtains, or a change of position that allow the occupants to block out or filter exterior reflected glare when needed, adding another dynamic dimension. Given the current state of our simulation tools, we felt we could not adequately model these highly variable conditions.

3.) **Vertical surface luminance patterns:** Vertical grids of luminance readings might be usefully analyzed for uniformity, illuminance gradients, contrast ratios, or other metrics of visual comfort. However, given the wide variety of geometries that we found in our study spaces, it was not possible to easily create a rule set of how to generate a consistent vertical grid that would be universally significant. Rooms with re-entrant corners, splayed geometries, and vertical obstructions such as columns and stairs created reoccurring challenges. On the other hand, the generation of sensor grids in ECOTECT along horizontal plans is easy and reliable, largely due to existing programming capabilities. "Tiles" of horizontal grids can be programmed to fully fit any geometrical shape.

4.) **Luminance versus illuminance**: In Daysim, which uses Radiance as a preprocessor, luminance calculations are computationally intensive, whereas illuminance calculations are much more easily generated for grids of points. We weighed the pros and cons of generating luminance calculations, that might give us a better understanding of the visual environment as perceived by the occupants, versus the simpler illuminance calculations, that might serve as a proxy for luminance patterns. Our conclusion was that illuminance could capture most of the key information about uniformity and daylight distribution patterns. Given the complexities of defining points of view within the space, we abandoned the idea of generating luminance values.

Final Output: Given the considerations discussed above, we decided to specify three horizontal illuminance grids that would generate the following output for the simulation models:

> 1.) **Task Level Illumination Grid**: A continuous gird of illuminance sensors one foot on center, looking upward, 32" above the finish floor (AFF). This height avoided most furniture at table and chair level. Any of these points that were "captured" inside of furniture would report essentially no illuminance and could be mathematically eliminated from the analysis.
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> 2.) **Eye Level Sensor Grid**: A second continuous grid was set at eye level (48") through out the space, but asked to report on two outputs other than illumination.
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> a.) **Sky Glare**: The first output is the amount of sky that each upward looking hemisphere can "see" through any daylight aperture in the space. Given that we wanted to understand the worst case condition, this analysis would be done with no movable

obstructions to the fenestration, such as blinds or curtains. This value could then be compared between spaces to generate a “sky glare” potential for the space.

b.) **Sun Penetration**: The same grid of sensor points at eye level was used to report the number of hours of sun penetration per year at each point. This is a dynamic simulation, but again, was generated without obstructions in the windows, in order to assess a worst case condition for each space.

3.) **Ceiling Level Illumination Grid**: A third continuous grid of illuminance sensors was located at the highest horizontal plan in the space that did not intersect any ceiling structural elements. This grid was oriented to look downward, and was asked to report on illuminance arriving upward to the ceiling. We hoped that this grid of sensor points could contribute to an understanding of uniformity and daylight gradients in the space, and could serve as proxy for vertical illuminance uniformity.

5. NEXT STEPS

As of March 1, 2008, the three dimensional modeling is almost complete and Daysim simulations will begin soon. Likewise, the 3D ECOTECT models will be processed into eQuest models, which will be used to generate energy impacts of the daylighting designs. Some protocols for the eQuest simulations remain to be resolved before this can begin.

All occupant assessments for the study spaces have been collected and descriptive statistics of the expert and occupant assessments of the spaces will be presented at the Project Advisory Committee (PAC) meeting on March 18th 2008.

Once all of the Daysim and eQuest simulations have been completed, we will begin processing the output data from Level Three models into candidate metrics and test those metrics against the qualitative assessments. These very large data sets will be processed in SAS (Statistical Analysis Software) using various statistical techniques. Input will be sought from the IESNA Subcommittee and other stakeholders on the format of the metrics to test.

Findings form the analysis will be reviewed with the Subcommittee, the project team and other stakeholders in preparation for writing the analysis report and making recommendations on which metrics are the most promising. Selected metrics will be evaluated for ease of use by the Integrated Design Lab at the University of Washington and other interested stakeholders. Once approved by the Subcommittee, the team will be able to evaluate the three space types for appropriate threshold criteria from Level One output for qualifying as a ‘daylit space”, with the goal of making these criteria available for adoption into various codes, programs and/or voluntary design standards.