Daylighting Metric Development Using Daylight Autonomy Calculations In the Sensor Placement Optimization Tool

Development Report and Case Studies

March 17, 2006

Prepared for
CHPS Daylighting Committee
Daylighting Forum
NWEEA

Prepared by

ARCHITECTURAL ENERGY CORPORATION
Integrated Engineered Solutions

Architectural Energy Corporation
2540 Frontier Avenue, Suite 201
Boulder, Colorado 80301

Daylighting Metric Development Using Daylight Autonomy Calculations in the Sensor Placement Optimization Tool

Development Report and Case Studies

Table of Contents

Table of Figures

Table of Tables

Preface

Architectural Energy Corporation (AEC), an energy and environmental research, development, and design consulting firm located in Boulder, Colorado, prepared this document for the Collaborative for High Performance Schools (CHPS) Daylighting Committee. The AEC Project Manager is Judie Porter and the authors of this report are Zack Rogers and David Goldman. AEC gratefully acknowledges the support of the Northwest Energy Efficiency Alliance for their financial support of this work and the CHPS Daylighting Committee for their technical support and expertise.

1.0 Introduction

The dynamic nature of daylight poses many challenges when considering metrics that define good and effective daylighting design. This report discusses the intricacies of what makes good daylighting design and discusses a broader methodology aimed at quantifying the many facets involved in good daylighting design to be implemented in the California Collaborative for High Performance Schools (CHPS) program.

In previous work funded by the California Energy Commission, Architectural Energy Corporation (AEC) developed a user friendly freeware program, the Sensor Placement Optimization Tool (SPOT™), to assist lighting designers to:

- quantify existing or intended electric lighting performance,
- evaluate annual daylighting characteristics, and
- help establish the optimal photosensor placement in a given space relative to annual performance and annual energy savings.

The software has been further enhanced, with funding from the Northwest Energy Efficiency Alliance, to provide the complex calculations discussed in this report for the CHPS program and was used to analyze a variety of daylight classroom scenarios.

2.0 Successful Daylighting Design

This section provides a general discussion on the reasons for introducing daylight into a building including discussion of strategies used in the design and analysis of daylighting systems and in their integration with other building systems to obtain optimal building performance and energy efficiency. This discussion provides a framework for what makes "good" daylighting with a concluding summary presented in Section 2.5.

2.1 Daylighting Benefits

There are two main benefits to daylighting a space: psychological and energy efficiency.

- Psychologically, the presence of controlled daylight has been shown in numerous studies to improve the overall attitude and well-being of the occupants. These studies have shown that daylight improves retail sales, worker productivity, student test scores, and patient recovery rates and results in reduced absenteeism. These benefits alone easily justify any added expense of introducing controlled daylight into a building. Poorly introduced daylight can negate some of these benefits by direct sunlight introducing disabling glare or distracting veiling reflections, or solar gains causing uncomfortable thermal conditions.

- From an energy efficiency standpoint, daylighting can offer great energy savings due to reduced electric lighting loads and in turn, reduced cooling loads. With proper fenestration solar control, solar gains during cooling load periods can be mitigated and solar gains during heating load periods can be beneficial, reducing both the overall cooling and heating requirements of a space.

2.2 Architectural Integration

The most effective daylight designs tend to be ones that are integrated well with the overall architecture. Daylighting design and solar control that are addressed as an afterthought and tacked on to an already designed building tend to be more costly to implement, less integrated with the building design and space layout, and in general more problematic. Hence, daylighting and solar control issues are ideally considered early in the design, and addressed in the programming of the various spaces. The following integration issues can be considered:

- **Daylighting Appropriateness** – For each space in a building, consider whether introducing daylight is appropriate. Spaces with very specific and inflexible lighting requirements, where too high of light levels could be problematic, should be a low daylighting priority. Spaces that are seldom used and/or used for short durations, such as storage rooms, restrooms, copier rooms, also should be a low daylighting priority. These types of spaces would ideally be located in the core of the building where there is limited access to daylight. Spaces that are continually occupied and where daylighting and views would benefit the tasks performed and the energy efficiency of the space should be a high daylighting priority. These spaces should be located towards the perimeter of a building where there is more plentiful daylight resources.

- **Direct Sunlight Tolerance** – For each space with a high daylighting priority, consider its tolerance to direct sunlight relative to glare and solar heat gains. In more public, transitory spaces, some direct sunlight, especially during the colder winter months or colder mornings, can be very pleasant adding sparkle and warmth to the space. These spaces are ideally located towards the south, east, and west sides of the building. If morning solar gains could be beneficial to space warmup on cold winter mornings, east-facing public spaces are recommended. Solar gain control is always important: designers must control the direct sunlight penetrating these spaces, shading the higher summer sun angles but allowing the lower winter sun angles to penetrate the spaces. Besides added horizontal overhangs, consider building layout and opportunities to shade these spaces from summer direct sunlight with other building elements. For example, lower floors could be recessed from upper floors resulting in higher summer sun shading. Stairwells or other less critical building components could be located to shade afternoon sunlight from more critical spaces. In spaces where controlling direct sunlight is critical, it is important to consider the direct sunlight control strategies early in the design process to avoid having to resort to more expensive solar control strategies, and less integrated to the rest of the design. These critical spaces could be located to the north, where incident sunlight is minimal. Space layout is important, since the location of interior walls can help in providing adequate direct sunlight shading and dictate the cut-off angles required.

- **Views and Connection to the Outdoors** – Even when the daylight resource is not adequate to provide the necessary lighting requirements, a view to the outdoors provides much of the psychological benefit of daylighting. For spaces that can be located close to a daylight resource, view lines are considered when determining the space layout. Consider the use of transom glass and other clear glass applications to maintain views for all building occupants.

- **Integrated Architecture and Daylight Harvesting** - When considering introducing daylight into a building, always consider synergistic strategies: ways to use other building elements, architectural, mechanical and structural, to serve dual functions by providing daylighting functionality as well.

2.3 Solar Control

In order for a daylighting design to be effective in improving the energy efficiency of a building, it is critical to consider both the electric lighting control and the solar heat gain control of the daylit spaces. With adequate control of electric lighting and solar heat gain, daylighting can drastically improve the energy efficiency of a space. Inadequate control can result in glare issues and a reduction in energy efficiency.

Dynamic (movable) solar control can be very ideal, especially for east and west facades, or cloudier climates, where incident direct sunlight is variable, occurring less than two-thirds of the time. These strategies optimize the daylight resource both when direct sunlight is present as well as under overcast skies where the dominant daylight contribution is coming from a relatively glare free sky dome.

Static solar control can also be very effective and often is associated with reduced or eliminated maintenance efforts and costs compared to an automated or dynamic (movable) strategy. In sunnier climates and for southern facades (within 20° of due south) that receive a lot of incident direct sunlight, these strategies can be most effective.

2.4 Efficient Electric Lighting Integration

Along with adequate solar control, integration with the electric lighting design of a space is essential in improving the efficiency of the lighting design and providing increased energy savings for the building.

The following electric lighting design strategies should be considered for non-daylit spaces as well as daylit spaces. These will help lower the Lighting Power Densities (LPDs) of the various spaces, reducing energy use, while maintaining the required light levels.

2.4.1 Task/Ambient Electric Lighting Design Approach

A good general strategy used when integrating daylighting into a project is task/ambient electric lighting strategies. A task/ambient electric lighting system uses two levels of lighting to provide the illuminance requirements of the space; one providing an ambient level of lighting adequate for circulation and general tasks, and one providing higher illumination localized to the specific tasks that require it. Typically, the ambient lighting is provided in a more diffuse and uniform manner. Indirect lighting is recommended whenever possible to provide the ambient lighting as it provides a more comfortable and shadow-free source of ambient light and can often integrate better with daylighting. However, high luminaire efficiencies and ceiling reflectances are important when using indirect systems as they will tend to have lower luminaire efficiency than a direct system. The task level of lighting should be provided in a more localized manner only where it is needed, i.e. the desktop, work bench, etc.

Since daylighting is an effective method for providing the ambient needs of the space, but is not as effective in maintaining high localized illuminance requirements, a task/ambient lighting approach can better integrate with available daylight. The intent is to have the daylight provide the ambient illuminance and to control the ambient level of electric lighting in response. In many cases, daylight can be designed to provide adequate ambient illuminance whenever there is daylight and the electric lighting can be controlled in a simpler fashion with on/off timer or photosensor-based controls. In addition to better integration with daylight, a task/ambient system often results in lower Lighting Power Densities (LPD's), resulting in a greater base level of energy savings, because illuminance is only provided when and where it is needed.

2.4.2 Differentiate Nighttime and Daytime Needs

Humans have evolved under high daytime illuminance levels and relatively low nighttime illuminance levels. Hence, psychologically we are accustomed to this condition and will often feel more comfortable under lower light levels at night. In fact, recent studies show that light levels are one of the main triggers that keep our human circadian rhythms (the daily rhythms that impact numerous biological functions) in sync. Once disrupted, our out-of-sync rhythms can contribute to various maladies such as SAD (seasonal affective disorder), sleep deprivation, and general lack of energy.

Electric lighting designs can take advantage of these rhythmic luminous needs, especially when daylighting is integrated into the lighting design. In spaces with adequate daylight saturation, the electric lighting can be designed to the lower nighttime requirements, since during the daytime it is truly just supplementing the more than adequate, but desirable, daylight resource. This results in lower Lighting Power Densities as well as a better psychological rhythm to the luminous environment.

2.4.3 Electric Lighting Control

Electric lighting control is essential in providing energy savings and can be addressed in several ways from very simplistic to more complex photosensor controls. In the most simplistic approach, adequate daylight saturation can allow for a general reduction in the electric lighting requirements. If daylight is present throughout the day, the electric lighting is purely supplemental and should be designed for nighttime functions, where reduced lighting levels are often adequate and even preferred. Complex control can allow for maximum energy savings and involves using photosensors, timers, or other central electronic control strategies to turn of zones of electric lighting when the daylight resource is adequate.

2.5 Daylighting Design Performance Goals

The general daylighting design approach recommended throughout the design of a project is to develop and evaluate the design alternatives against defined daylighting performance goals. Presented below are general daylighting performance goals for daylit spaces, which represent successful daylighting design characteristics as discussed above.

2.5.1 Quantity

- Provide ambient lighting requirements for the majority of the year.

2.5.2 Quality

- Uniform distribution of daylight to reduce uncomfortably high brightness ratios.
- Control direct sunlight when necessary and utilize beneficial passive solar strategies when appropriate.

2.5.3 Usability

- Allow for user adjustment and override.
- Ensure adequate daylight to all occupants of the daylit space.
- Provide view and connection to the outdoors.

2.5.4 Building Integration

- Fully integrate with the architectural expression of the building inside and out.
- Fully integrated with other building systems -- HVAC, Electrical, Lighting, Structural, Interiors.

2.5.5 Cost Effective

- Implement within overall construction budget of the project.
- Achieve significant energy savings by reducing lighting costs and associated cooling energy costs.

3.0 Daylighting Metrics / Calculation Methods

Considering the variety of issues involved in good daylighting design, determining a quantifiable metric or set of metrics that can define good daylighting is a complex task. Attempting to quantify some of the good daylighting design aspects is next to impossible while others are more feasible. For example, while the integration with the architectural expression may result in a more integrated, aesthetic, and cost effective daylight design, it is hard to quantify this benefit. While other good daylighting design aspects are quantified in other sustainable design metrics, such as the integration with HVAC systems (relative to the allowance of solar gains) and electrical systems, which shows up as energy savings in whole-building energy efficiency metrics. The daylighting design aspects that can be adequately quantified and addressed in a daylighting metric include the following:

- **Usability - Views and connection to the outdoors.** This design aspect is addressed in other metrics, typically defined as a minimum percentage of occupied area with access to views. This metric is fairly straightforward and generally well accepted and is assumed to be used as a separate metric to the ones proposed below.
- **Quantity – Provide ambient lighting requirements**. An annual Daylight Autonomy (DA) metric is proposed to address the issue of providing the right amount of daylight to a space on an annual basis.
- **Quality – Uniform distribution of daylight.** A new metric is proposed here to address the uniformity of a daylighting design that requires a minimum portion of a daylit area to have a specified Daylight Autonomy level.
- **Quality – Control direct sunlight when necessary.** A Maximum Daylight Autonomy factor is proposed to provide a metric for quantifying intense sources of daylight and patches of direct sunlight.

3.1 Daylight Autonomy

An annual Daylight Autonomy (DA) calculation is proposed for quantifying annual daylight saturation and determining the occurrence of direct sunlight. Daylight Autonomy is defined as the percentage of time over a year at which daylight can provide a given illuminance for a given point. There are at least two methods for determining a DA factor, both based on an annual hour-by-hour calculation method:

- **Incremental Method (Method #1).** This method only counts a point as daylit if the daylight illuminance exceeds the required illuminance for the given time. For example, if a space requires 50fc on the workplane, any hour that does not provide at least 50fc of daylight illuminance counts as 0% daylight and any hour that exceeds 50fc of daylight illuminance counts as 100% daylight. Essentially, this method only gives credit to daylight when it exceeds the required illuminance and does not give any credit for partially daylit points.
- **Continuous Method (Method #2).** This method allows for fractional levels of daylight illuminance to be counted. For example, when a point receives 30fc of daylight illuminance and the required illuminance is 50fc, this point is credited 30/50 or 60% daylight for that time step. This method gives credit to spaces that are not fully saturated with daylight, but do receive some daylight contribution.

The following variables also need to be addressed for standardizing the calculation of a DA factor:

- **Time Frame**. It is important to determine which times of the year to consider for the DA calculation. Obviously, counting nighttime hours does not make sense and would skew the overall calculation towards lower DA values. For spaces that are occupied during daylight hours, using only the daylight hours in the calculation makes sense. For spaces that are only occupied for a portion of the daylight hours, using the actual occupied hours for the calculation may give a better indication of ultimate design goal: how well does daylight meet the spaces ambient lighting requirements. For a space that is only occupied in the mornings, it is important to optimize the daylighting design to morning sunlight, as afternoon daylight conditions are irrelevant to that space.
- **Spatial Consideration**. Determining a specific point in a daylit space for use in calculating a DA factor can be tricky. You would want to choose a point in the space that was important (not tucked into a corner) and represented a worst-case or minimal annual illuminance level. Given the dynamic nature of daylight, it can be difficult to determine such a point and to know how well a given point represents the daylight in the rest of the space. Given that the uniformity of daylight is also an important design characteristic, a single point calculation, regardless of how representative of the overall space it is, cannot quantify how well daylight is spread over the space. To address these issues, multiple DA calculations could be performed for a grid of points covering the important task planes in a daylight space. In this way, a measure of the uniformity of daylight could be calculated and any worst case points are included in the overall calculation.
- **Target Illuminance**. Another variable to define is the illuminance threshold to use for calculating daylight's contribution towards it. It is recommended that the design illuminance for the daylit space be used. A minimum illuminance requirement could be used as well, but there is a better consensus and available recommendations for what a space's average illuminance should be than for what minimum illuminance should be achieved. Using a design illuminance for the DA calculation, rather than a set criteria, gives a better indication of how well the daylighting is meeting the spaces illuminance requirements. For example, computer-intensive spaces are better served with low levels of uniform daylight where as a large big-box retail space is better served with higher levels of daylight. Perhaps a standard reference, such as the IESNA Lighting Handbook, should be used for determining what the design illuminance for a given space should be. Another option is to use the nighttime illuminance provided by the electric lighting of a daylit space, which should also be indicative of the design illuminance.
- **Location and Climate**. The final variable to consider is the location (latitude and longitude) for the project and the climate (weather) data to use in the annual DA simulation. A standard using a single climate data or even a set of representative climate data could be defined for the annual DA calculation. A more accurate approach would be to use the most representative climate data available for a given projects site. There are 239 Typical Meteorological Year (TMY2) climate data stations in the United States with available hour-by-hour climate data.

3.2 Seasonal Daylight

One aspect of good daylighting design is the search for a balance between providing daylight to a space while minimizing solar gains when detrimental and allowing controlled (glare free) solar gains when beneficial. During times when there is a cooling load, solar gains increase this load resulting in greater annual energy use and potentially larger peak loads and hence larger, and less efficient, mechanical systems. During times when there is a heating load, the opposite is true with solar gains being beneficial, reducing annual energy use and peak heating loads.

This interaction is complicated when considering electric lighting gains in the space and daylight-responsive lighting controls. For example, for a classroom with east, south, or west fenestration during winter times (when peak heating loads typically occur), the sun is lower in the sky and solar gains and daylight saturation can be at their peak and the electric lighting is kept off. The reduction of the somewhat beneficial electric lighting heat gains offsets the beneficial solar heat gains. Likewise, during summer times (when peak cooling loads typically occur), the sun is high in the sky and solar gains and daylight saturation can be at a minimum and the electric lighting is kept on. The increase in electric lighting heat gains offsets the minimized solar heat gains. This is not always the case for a daylit classroom but can often be the case as increased daylight saturation is often associated with increased solar gains. The most optimum daylighting design would be one that controls solar heat gains during the summers while maintaining full daylight saturation in addition to allowing winter solar heat gains, but not necessarily providing full daylight saturation.

Further complications arise when one considers whether the electrical energy savings from controlling electric lighting provides an overall greater benefit than the heating load savings from keeping the lights on. This issue is dependent on the source and delivery of electricity and the source and delivery of heating energy. Another further complication is related to the HVAC system and delivery of conditioned air. For example, with an underfloor air system, electric lighting heat gains may not contribute much to the occupied zone while solar heat gains can.

An additional metric was explored in attempt to quantify the beneficial interaction that can occur between daylighting and HVAC systems: using a Winter (heating load) Daylight Autonomy factor and a Summer (cooling load) Daylight Autonomy factor. The Winter DA was calculated only considering times in the year when the Dry Bulb temperature is below 50°F. The Summer DA was calculated only considering times when the temperature is above 50°F. For this study, 50°F was used as it represents a typical break point between Heating and Cooling loads for typical school internal gain to envelope load ratios. However, further research to determine the best breakpoint metric is recommended. Integration with an annual energy simulation, such as DOE-2, would likely be the best way to quantify this interaction.

Figure 3-1 and Figure 3-2 present comparisons, using the 17+ test classrooms presented in Section 4.0, of the normal DA, Winter DA, and Summer DA calculations for a Base Daylight Autonomy and Max Daylight Autonomy, respectively (refer to Sections 3.4 and 3.5 for further discussion of these calculations. For base Daylight Autonomy, there is not huge difference between the three metrics, with most test classrooms having a higher DA under summer conditions than under winter conditions. There are only a few classrooms that have a higher DA under winter conditions, all of which have designs with dominantly south facing fenestration. For max Daylight Autonomy, there is a bigger difference between winter and summer DA. Again, only the cases with dominantly south fenestration have a higher Max DA during winter than summer.

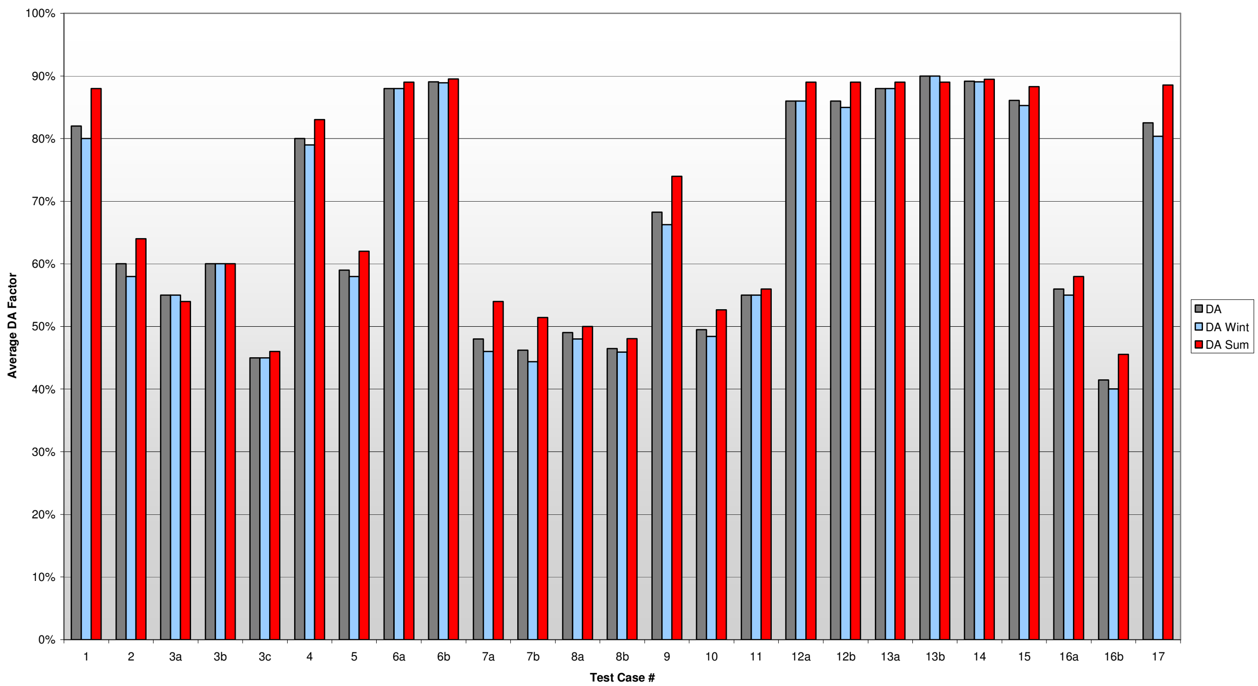

Figure 3-1: Comparison of Method #2, Winter (Heating Load), and Summer (Cooling Load) Calculations for Base Daylight Autonomy

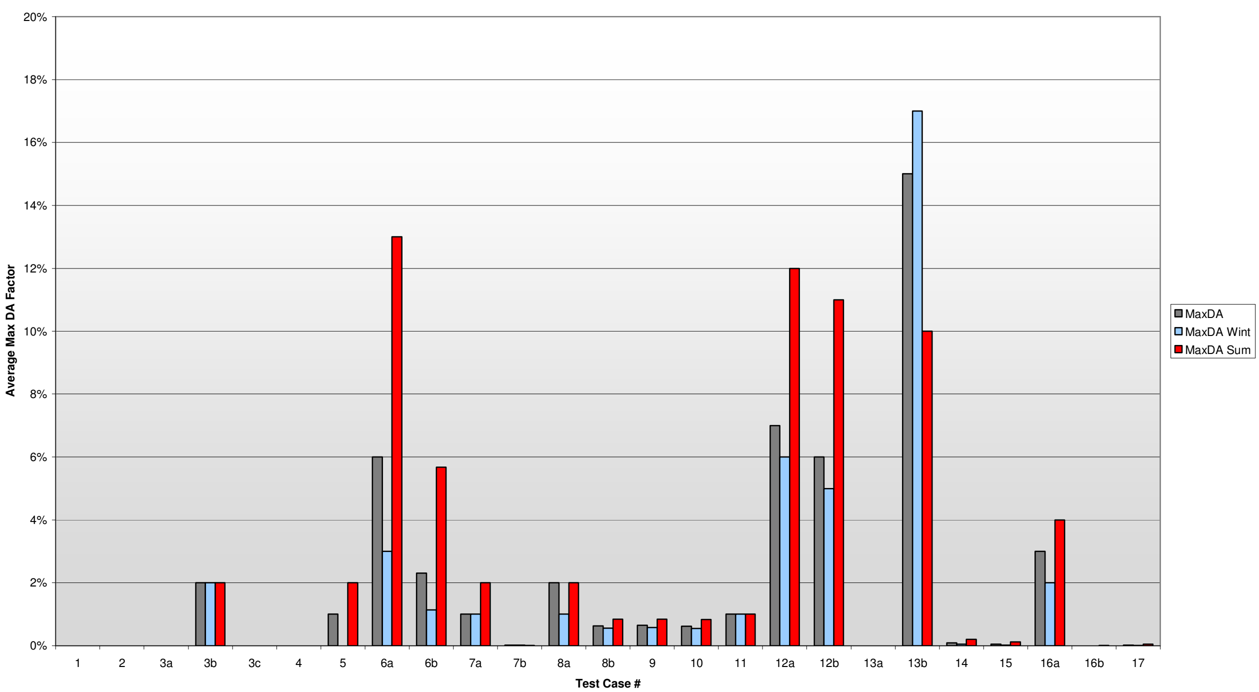

Figure 3-2: Comparison of Method #1, Winter (Heating Load), and Summer (Cooling Load) Calculations for Max Daylight Autonomy

Because of the discussed complexity when considering the interaction with daylighting and heating loads, because some of this interaction is typically quantified in whole building energy use metrics, and because it would also further complicate the calculation and documentation of the daylighting metric, seasonal differentiation is not recommended for use at this time.

3.3 Climate Specific Daylight

Figure 3-3 and Figure 3-4 illustrate the impact of using specific climate data for the annual DA calculation, showing a comparison of DA and MaxDA, respectively. Daylighting designs optimized towards sky dome daylighting (dominantly northern fenestration and controlled southern fenestration) score higher under Seattle's cloudy climate than under Boulder's sunny climate. Alternatively, daylighting designs optimized towards direct sunlight daylighting score higher under Boulder's and Los Angeles' sunny climates. This illustrates the effectiveness of using specific climate data for the DA calculation, encouraging daylighting designs to be more responsive to their given location.

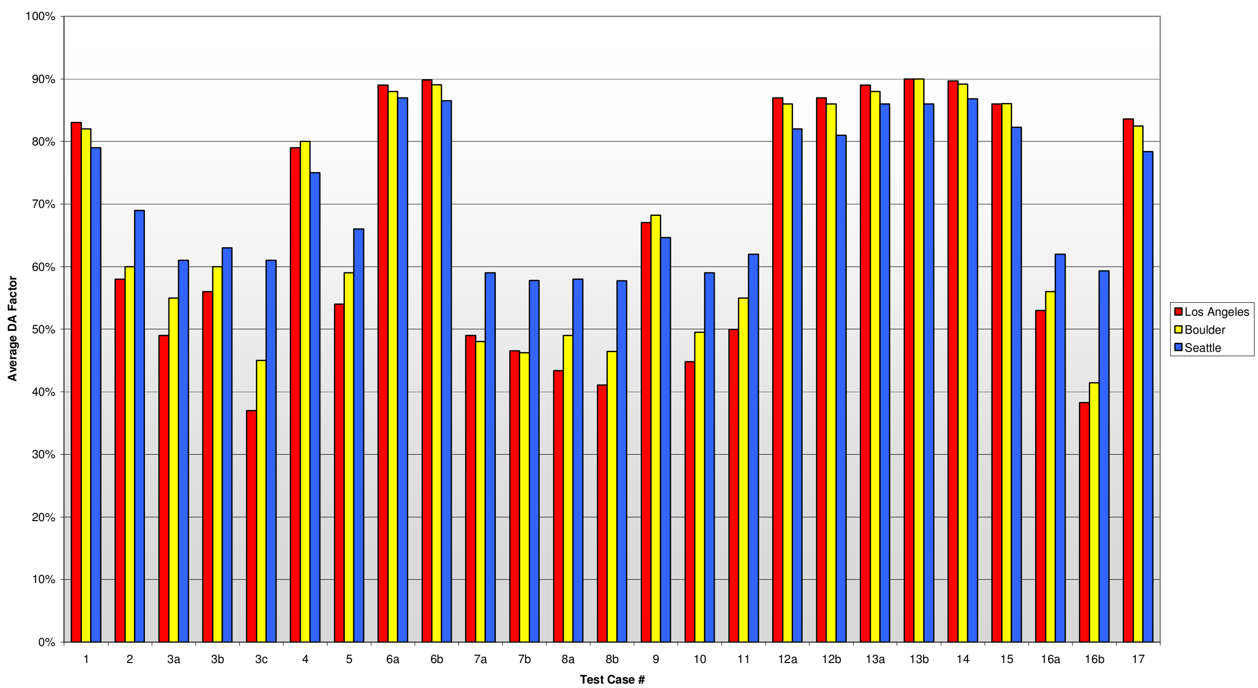

Figure 3-3: Comparison of DA Calculation Method #2 under Various Climates

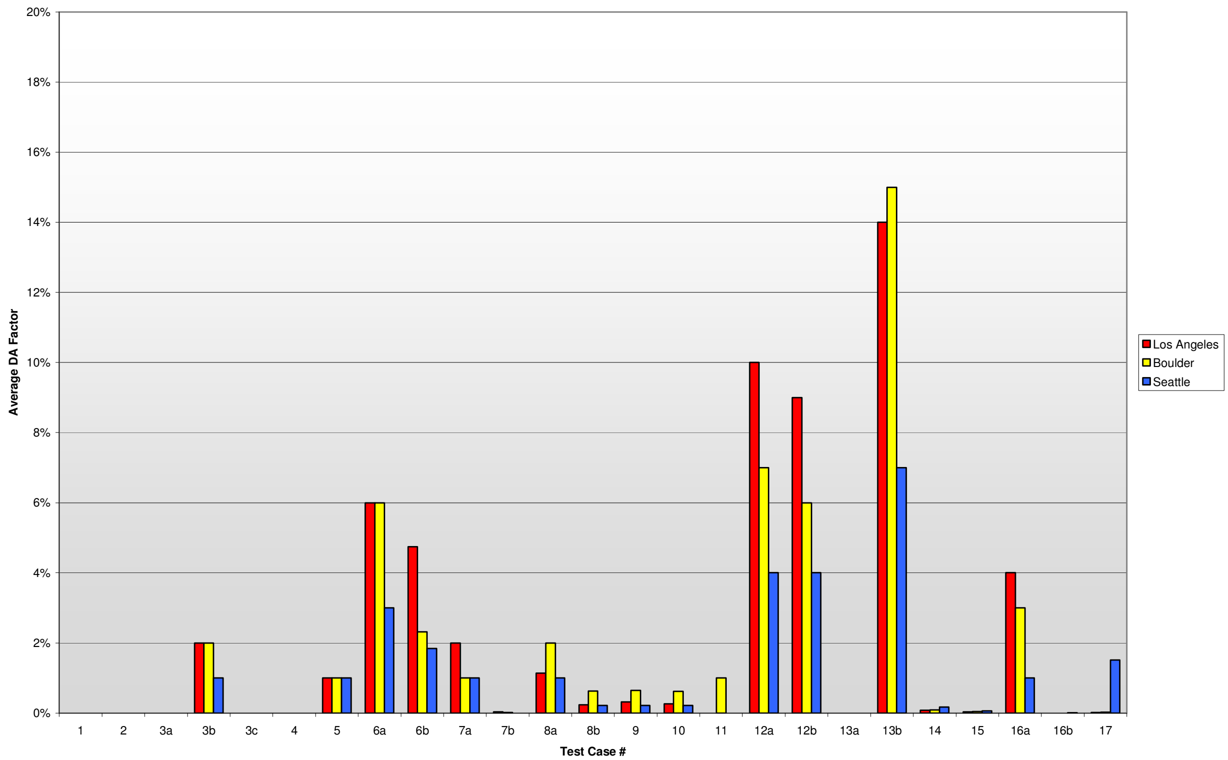

Figure 3-4: Comparison of Max DA Calculation Method #1 under Various Climates

3.4 Daylight Quantity

The proposed metric for quantifying the annual saturation of daylight involves the use of a base Daylight Autonomy calculation using the target illuminance of the daylit space. Figure 3-5 presents a comparison of DA Calculation Method #1 (incremental method) and Method #2 (continuous method) for the test classrooms. In the case of a base DA calculation, Method #2 can provide a more accurate measure of the daylight saturation since it allows “partial credit” for significant daylight contributions that don’t quite meet the design illuminance. Method #1 only gives credit for daylight contributions that exceed this threshold. In all cases, Method #2 results in a higher DA then Method #1.

The following extreme case further justifies the use of Method #2: Consider a daylighting design that provides 35fc of daylight illuminance at all times, yet the design illuminance is 40fc, such a space would receive a 0% DA under Method #1 yet an 87.5% DA under Method #2. Such a daylighting design should be given credit for providing such a significant daylight contribution and so Method #2 would be the better calculation.

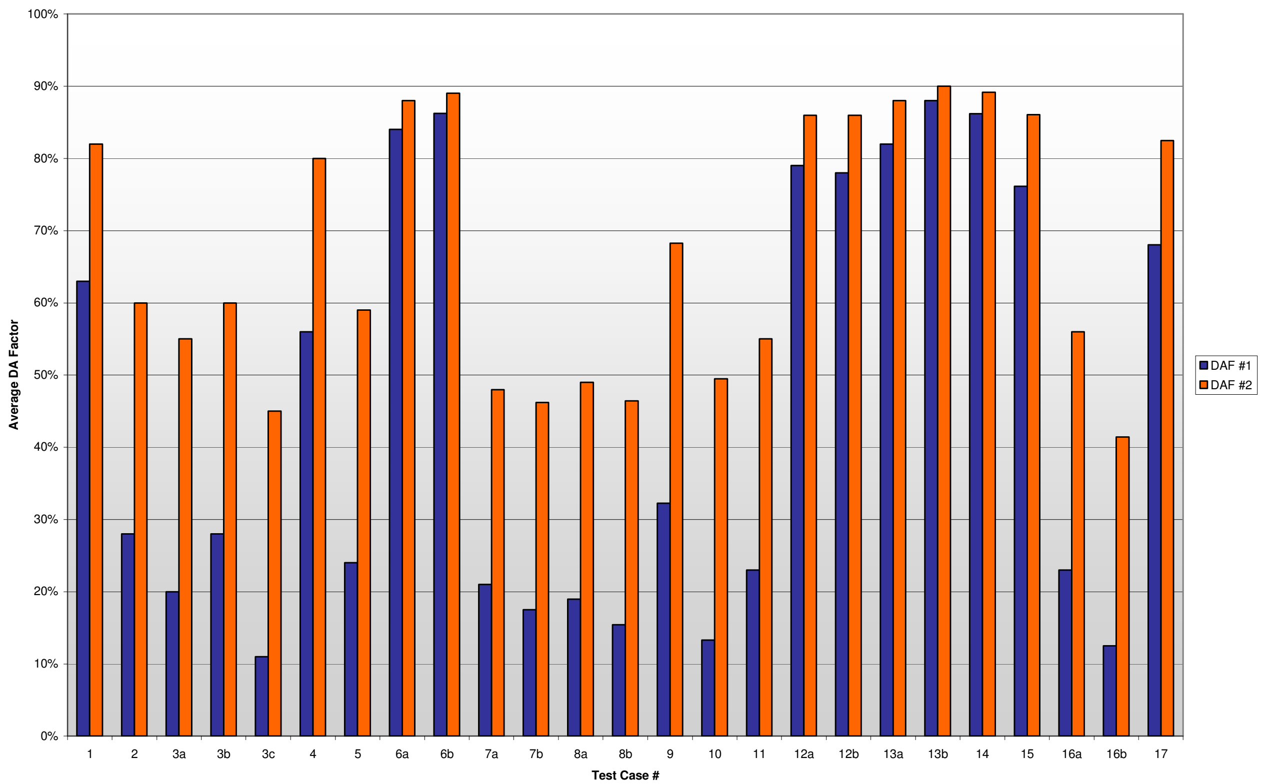

Figure 3-5: Comparison of Calculation Method #1 and #2 for Base Daylight Autonomy

3.5 Daylight Quality

Two metrics are proposed to address the issue of daylight quality; one addresses the occurrence(s) of direct sunlight in a daylit space and the other addresses the uniformity of daylight.

3.5.1 Direct Sunlight Penetration

To address the occurrence of direct sunlight in a daylit space, a Maximum Daylight Autonomy factor (MaxDA) is defined as the Daylight Autonomy for an illuminance threshold equal to 10 times the base design illuminance. A patch of direct sunlight on a workplane will produce an illuminance much greater than the average, diffused daylight illuminance in a space and hence, can be detected by measuring the occurrence of greatly higher daylight illuminances. A patch of illuminance at least 10 times greater than the design illuminance typically represents an occurrence of direct sunlight that could potentially cause glare and other visual comfort problems in a daylit space.

Figure 3-6 presents a comparison of DA Calculation Method #1 and Method #2 for the MaxDA factor. In the case of a MaxDA calculation, Method #1 provides a more accurate measure of the occurrence of direct sunlight. Since illuminance less than 10 times the design illuminance is not necessarily detrimental to the space, this illuminance should not count against the daylighting design. Only illuminance greater than this 10 times the design illuminance threshold should be considered. Hence, calculation Method #1 provides the better measure of the occurrence of direct sunlight. With Method #2, even perfectly acceptable daylight illuminance equal to the design illuminance, count as 10% in the MaxDA calculation. It is apparent that Method #2 results in much higher -- and misleading -- MaxDA's then Method #1.

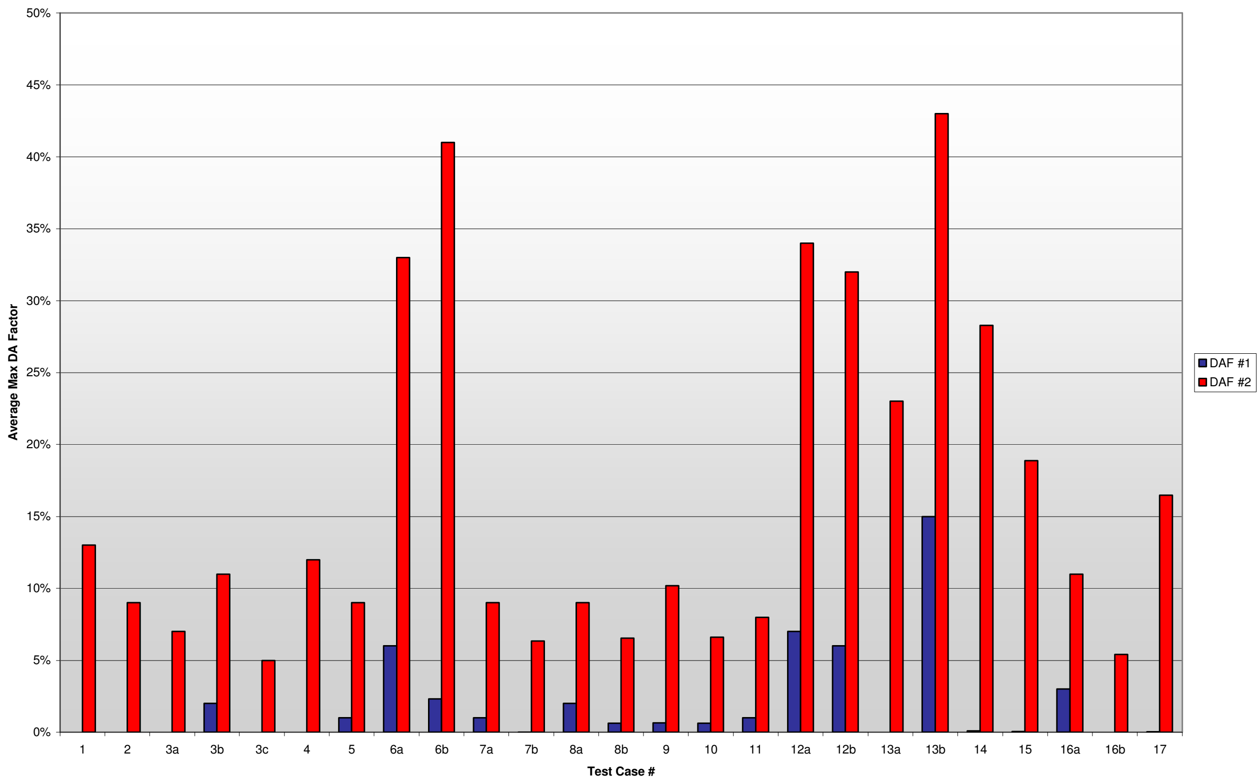

Figure 3-6: Comparison of Calculation Method #1 and #2 for Max Daylight Autonomy

3.5.2 Uniformity

To adequately address the uniformity of daylight in a space, Daylight Autonomy is calculated for a grid of points within a daylit space. In this way, the annual distribution of daylight saturation is determined, providing a quantifiable measure of the daylight uniformity for a given space. The proposed metric is to require a certain percentage of the illuminance field (typically a workplane field but it also could be a field representing any critical daylit surface) to meet a certain Daylight Autonomy threshold. Figure 3-7 compares the DA distribution for the various test classrooms. In general, the classrooms with good uniform daylight saturation achieve adequate DA for at least 60% of the workplane (60% indicated by the green line on the figure). There were six classrooms that did not receive this level of uniform saturation.

Different daylight credit levels are suggested and indicated by the warmer colors on the graph, with yellow representing DA's between 40% - 60% (DA1), orange representing DA's between 60% - 80% (DA2), and red representing DA's greater than 80% (DA3). Daylit spaces that achieve 40% - 60% DA over 60% of the workplane will receive a base daylight credit, spaces achieving between 60% - 80% DA over 60% of the workplane will receive an additional credit, and spaces achieving greater than 80% DA over 60% of the workplane will receive another additional daylight credit. There were ten test classrooms that would receive the highest level of saturation, two that would receive the middle level of saturation, seven that would receive the base level of saturation and only six that do not have adequate daylight saturation.

A similar uniformity measure for the MaxDA calculation is presented in Figure 3-8. In this graph, red represents MaxDA's greater than 5%, orange represents MaxDA's between 3 – 5%, yellow represents MaxDA's between 1% - 3% and blue represents MaxDA's less than 1%. Given a workplane that accurately represents the critical task surfaces, direct sunlight on even 5% of this area (represented by the green line on the graph) could result in problematic glare conditions for some of the space's occupants. The MaxDA represents the duration of time throughout the year a given point receives direct sunlight. Even a single occurrence of problematic direct sunlight for an occupant can result in complaints and an override of the daylighting resource, and so this criterion should be aggressive. Given a criterion of less than a 1% MaxDA for less than 5% of the workplane area, there are 14 of the test classrooms that would pass with adequate direct sunlight control.

It is proposed that the MaxDA calculation be used as an all or none metric. If a daylit space exceeds the MaxDA threshold, indicating that a portion of the workplane received daylight illuminance greater than 10 times the design illuminance for at least a set percentage of the year, the space does not qualify for any daylight credits as the design has too much glare potential.

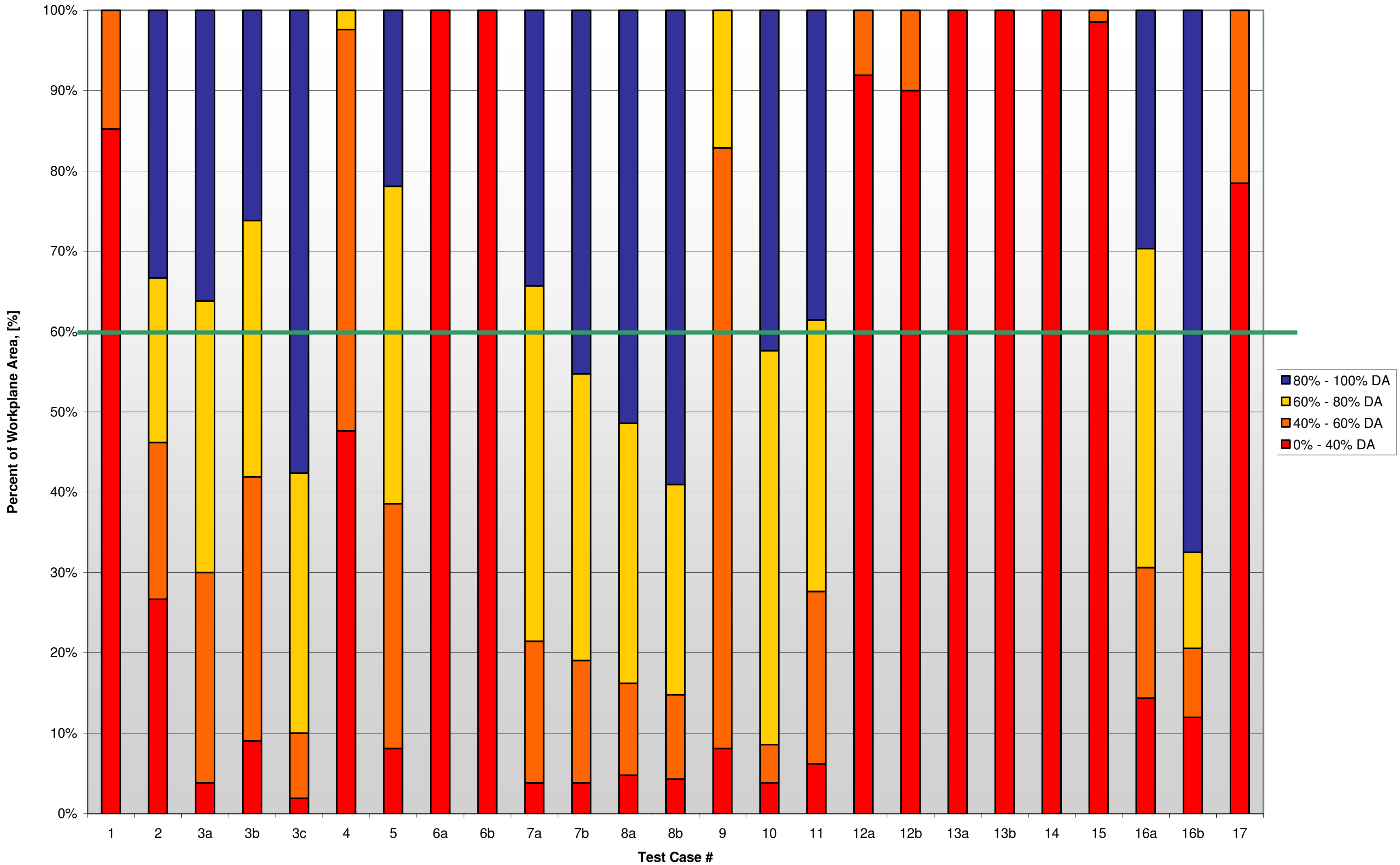

Figure 3-7: Comparison of DA Distribution for Los Angeles, CA

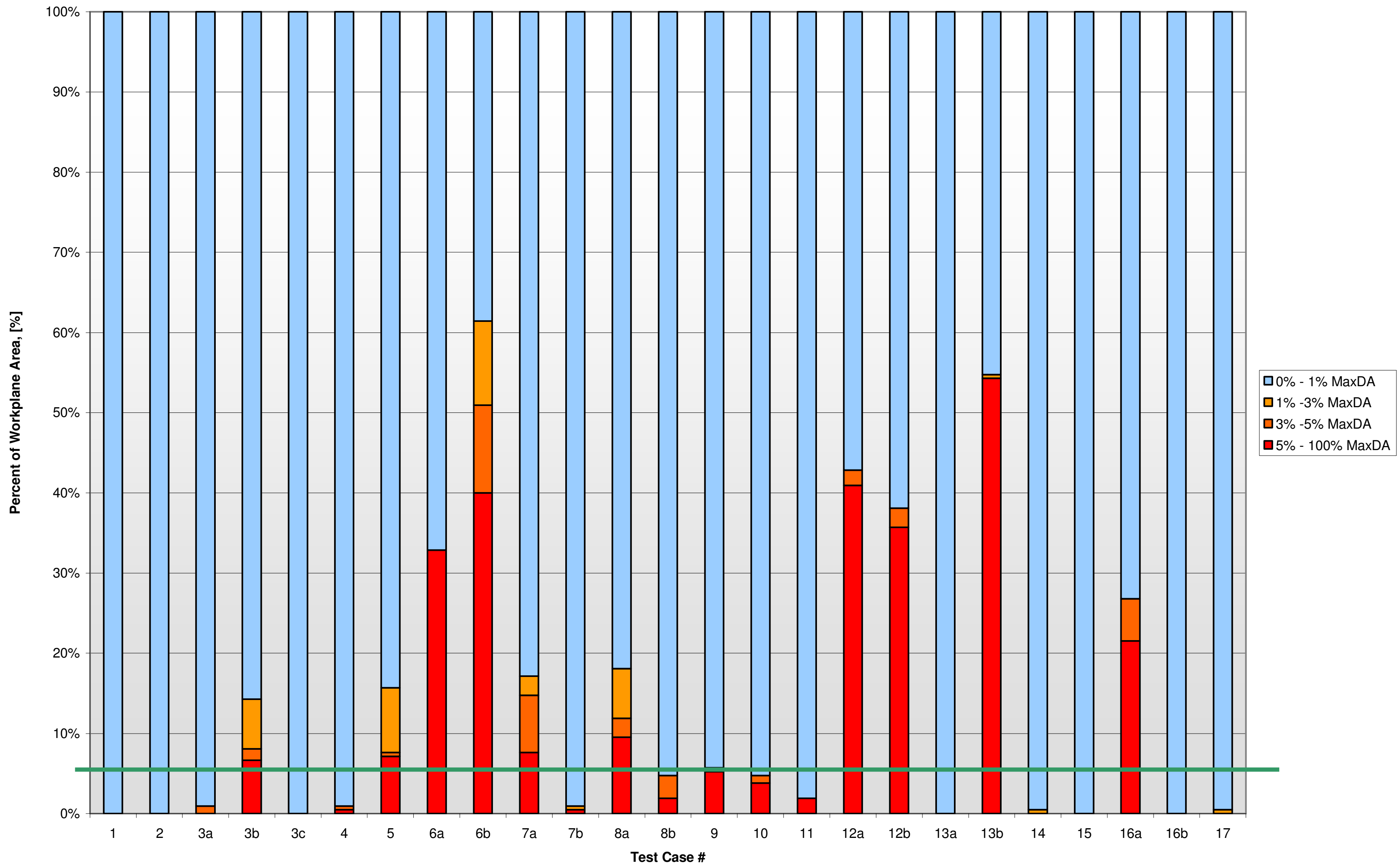

Figure 3-8: Comparison of MaxDA Distribution for Los Angeles, CA

3.6 Daylighting Metric Conclusions

Relative to the above analysis and discussion, the following set of daylighting metrics and calculation assumptions are proposed for use in the CHPS program:

- **Daylight Quantity** – Perform a base DA calculation using calculation Method #2, the space's design illuminance, only for occupied times, under representative climate data, and for a grid of points representing the critical task surfaces. The metric will require the space to exceed DA thresholds of 40% for one credit, 60% for two credits and 80% for three credits.
- **Daylight Quality (uniformity)** – Require that a minimum of 60% of the daylit space's workplane points meet the given level of daylight quantity as measured by the above base DA.
- **Daylight Quality (direct sunlight)** – Perform a MaxDA calculation using calculation Method #1, the space's design illuminance times ten, only for occupied times, under representative climate data, and for a grid of points representing the critical task surfaces. The metric will require the space to not exceed a 1% MaxDA threshold for 5% of the workplane.

The following section presents the calculation of these metrics for 17+ test daylit classrooms to determine the appropriate thresholds that should be defined. Several variations were performed on some of the classrooms to look at the impact of a single variable, such as the addition of shades, making a total of 25 classrooms scenarios analyzed.

4.0 Test Daylit Classrooms

To determine appropriate benchmark levels that define good daylighting in a classroom using the various daylighting metrics discussed above, a series of test classrooms were identified and the recommended metrics were calculated for each. Examples of classrooms with good, fair and poor daylighting conditions were modeled to represent a variety of conditions. Each classroom was simulated in three climate zones to represent varying conditions: Los Angeles, California; Boulder, Colorado and Seattle, Washington. Boulder represents a very clear and sunny climate, Seattle represents a very overcast climate, and Los Angeles represents a climate in between, with cloudier mornings and sunnier afternoons. The DA calculations assumed a typical school occupancy schedule, with summers off, and used a design illuminance of 40fc.

Some parameters were held constant throughout the case studies. Classroom dimensions were typically 30 feet by 32 feet based on standard California classroom dimensions. Exceptions were made to this for relocatable classrooms that were modeled at 24 feet by 40 feet. Workplane height was set at 30" above the floor and walls were assumed to be 8" thick. See Table 4-1 for the assumed surface characteristics in the model.

Table 4-1: Model Surface Characteristics

Model Element	Characteristic
Floor Reflectance	20%
Wall Reflectance	60%
Ceiling Reflectance	75%
Ground Reflectance	25%
Mullion Reflectance	50%
Lightshelf Reflectance	50%
Overhang Reflectance	50%
View Window Transmittance	36%
Daylight Window Transmittance	50%

Table 4-2 summarizes the test classrooms used in the analysis, representing a variety of daylight saturation levels and direct sunlight control. The table lists the relative saturation level, the Window-to-Wall Ratios (WWR) for the various fenestration elements, and the window treatment (if any) used on the fenestration. The classrooms were categorized into eight key categories: north-facing, south-facing, skylights only, east- and west-facing, the CHPS classroom, finger-style, and relocatable.

The following sections present the geometry of each test classroom and the results for each recommended metric. The results were calculated with the Sensor Placement Optimization Software (SPOT™) V2.2.55. The following definitions are used to make the discussion more consise: DA1 = 40% - 60% DA's, DA2 = 60% - 80% DA's, and DA3 = 80% - 100% DA's. Given the thresholds defined as a result of this study, SPOT™ will be modified to calculate the exact elements for the CHPS daylighting metric, providing a standardized report for the documentation of this credit.

Table 4-2: Summary of Test Classrooms

Test Case #	Description	Daylight Level	Window to Wall Ratio (WWR) North	East	South	West	Ceiling	Window Treatment
1	North classrooms w/ southside Solatubes	High	41%	0%	0%	0%	1%	None
2	North classrooms	Med	34%	0%	0%	0%	0%	None
3a	South classrooms w/ lightshelves	Med	0%	0%	30%	0%	0%	None
3b	South classrooms w/ lightshelves	Med	0%	0%	30%	0%	0%	Shade :Vision
3c	South classrooms w/ lightshelves and shades	Low	0%	0%	30%	0%	0%	Shade: All
4	South classrooms w/ lightshelves and north clerestory	High	21%	0%	30%	0%	0%	Shade :Vision
5	Corner classroom - south and west facing glass	Med	0%	0%	30%	10%	0%	Shade: All South
6a	Classroom w/ skylights only	High	0%	0%	0%	0%	20%	None
6b	Classroom w/ skylights only	High	0%	0%	0%	0%	20%	Translucent
7a	West Facing Classroom w/ lightshelf	Med	0%	0%	0%	34%	0%	None
7b	West Facing Classroom w/ lightshelf	Med	0%	0%	0%	34%	0%	Shade: Vision
8a	East Facing Classroom w/ Lightshelf	Med	0%	34%	0%	0%	0%	None
8b	East Facing Classroom w/ Lightshelf	Med	0%	34%	0%	0%	0%	Shade: Vision
9	West Facing Classroom w/ east clerestory & West Clerestory	High	0%	23%	0%	34%	0%	Shade: Vision
10	West Facing Classroom w/ east clerestory	Med	0%	23%	0%	11%	0%	Shade: Vision
11	South-east w/ some direct sunlight	Med	0%	0%	30%	0%	0%	Shade :Vision
12a	The CHPS Classroom	High	0%	0%	19%	0%	7%	None
12b	The CHPS Classroom w/ shades	High	0%	0%	19%	0%	7%	Shade :Vision
13a	50's Finger Style w/Clerestory	High	31%	0%	70%	0%	0%	Shade: South
13b	50's Finger Style w/Clerestory w/o shades	High	31%	0%	70%	0%	0%	None
14	50's Finger Style w/ clerestory & skylights	High	31%	0%	70%	0%	3%	Shade: Vision Translucent Skylights
15	50's Finger Style w/ skylights	High	0%	0%	70%	0%	3%	Shade: Vision Translucent Skylights
16a	Relocatable E-W	Med	0%	15%	0%	15%	0%	None
16b	Relocatable E-W	Med	0%	15%	0%	15%	0%	Shade :Vision
17	Relocatable E-W w/Skylights	High	0%	15%	0%	15%	5%	Shade :Vision Translucent Skylights

4.1 North Classrooms

Classrooms receive indirect natural light through north facing windows, thus reducing the potential for glare problems. This set of models evaluated the Daylight Autonomy Factor (DAF) for classrooms with a northern exposure.

4.1.1 Classroom #1 – North Fenestration with Solatubes

A typical classroom at Kinard Middle School in Fort Collins, Colorado was used for this case study. This classroom was selected because it is known to have good daylighting. A north facing clerestory and vision windows provide 145 s.f. of glazing for a WWR of 41.2% (see Figure 4-1). The end windows are full-height and placed adjacent to the perpendicular wall. The two Solatubes are modeled as 2'-0" x 2'-0" skylights resulting in 8sf of opening in the ceiling for a WWR of 0.8%. Shades were not included in the model as they were not needed for direct sunlight control.

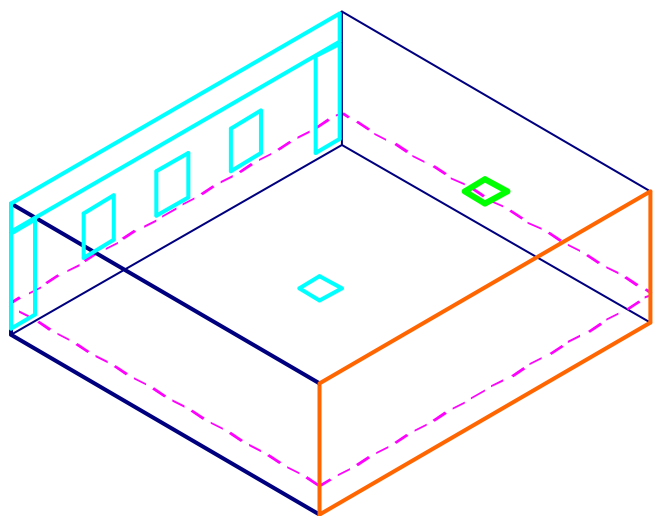

Figure 4-1: Classroom #1 Geometry

This example results in a DA1 (for at least 60% of the workplane) for Los Angeles and Boulder and a DA2 for Seattle with a 0% MaxDA for each (see Figure 4-2). While some of the high DA's may be attributed to the higher glazing count on the north façade, the fact that the sunnier climate of Los Angeles scores the highest is indicative that the skylights have a large impact on the daylight distribution within the classroom.

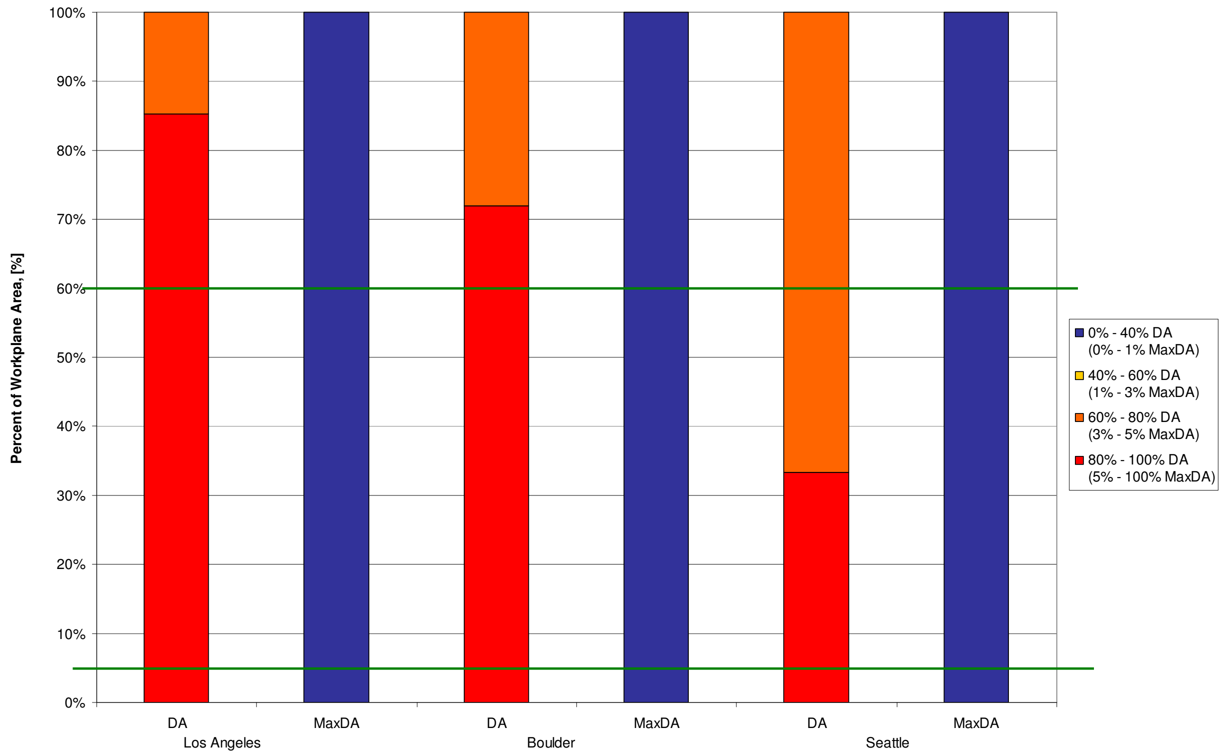

Figure 4-2: Classroom #1 Results

4.1.2 Classroom #2 – North Fenestration

This classroom has three 4'-0" x 3'-8" vision windows and a 2'-4" high, full width clerestory window on the north façade (see Figure 4-3). There is a total of 118sf of glazing or a window to wall ratio (WWR) of 33.5%. Shades were not included in the model since the effect on the north would be negligible.

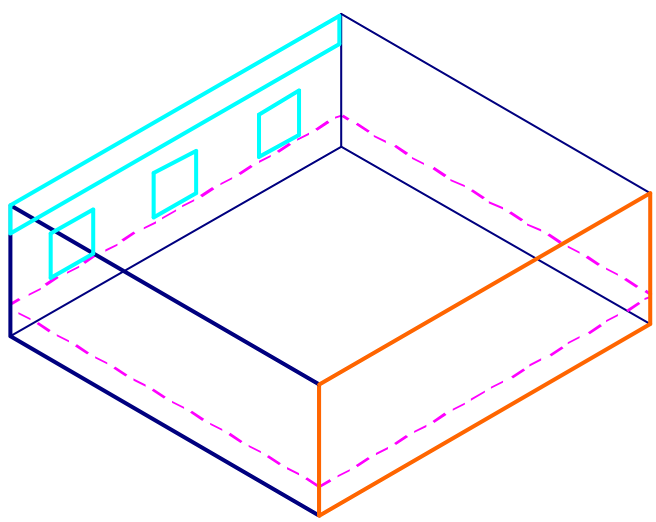

Figure 4-3: Classroom #2 Geometry

Without the additional skylights, the DA's in this classroom are lower with LA and Boulder achieving at least DA1 and Seattle achieving a DA2. Again, none of the climates registered above a 0% MaxDA (see Figure 4-4). It is interesting to note that Seattle, the climate with the highest number of overcast days, now has the higher DA when the Solatubes are not present. North facing windows are an ideal solution for the diffuse light of the overcast skies and this metric appears to capture this.

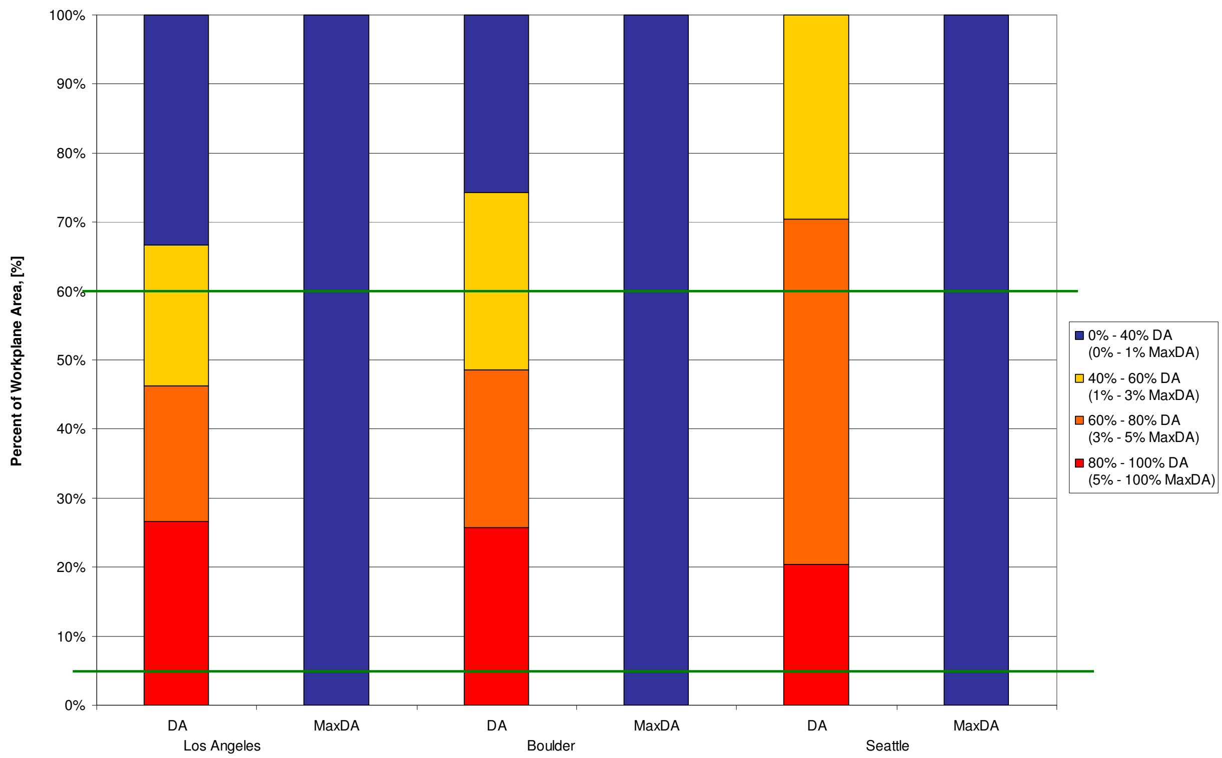

Figure 4-4: Classroom #2 Results

4.2 South Classrooms

South classrooms have the potential for direct solar penetration during the midday hours, and to a lesser extent during morning and late afternoon hours. South facing windows can be shaded relatively easy compared to east or west orientations. The direct sun incident on a south fenestration can also be reflected into the building with lightshelves, providing for deeper penetration and more diffused daylight.

4.2.1 Classroom #3a – South Fenestration w/ Lightshelf, Overhang and View Window Shades

Two 4'-0" x 4'-0" view windows are placed near the corners to provide lighting onto the side walls and a daylighting window spans the south wall above eye height. There is 107sf of glazing, for a WWR of 30.4%, provided on the south façade. A 2' overhang is provided above the daylight window and a 3' wide lightshelf prevents glare while bouncing the light deeper into the classroom (see Figure 4-5). Shades were modeled in this example for the view windows, automatically activated by SPOT when direct sunlight is incident on the south façade.

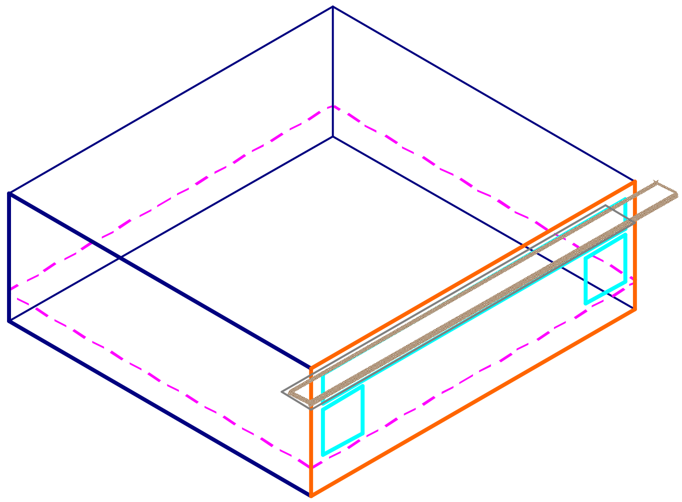

Figure 4-5: Classroom #3 Geometry

This classroom results in a DA1 for all climates and a 3% MaxDA exceeding 5% of the floor area for Seattle only (see Figure 4-6). This is due to the lower winter sun angles that occur in Seattle which penetrate the daylight window past the lightshelf and overhang. This is a classroom with a fairly good daylight design, indicating that a DA1 (40% - 60%) for at least 60% of the floor area is a good indication of good daylighting. The MaxDA numbers are low and acceptable for LA and Boulder but perhaps not acceptable for Seattle. The high MaxDA for Seattle indicates the better solar control is needed.

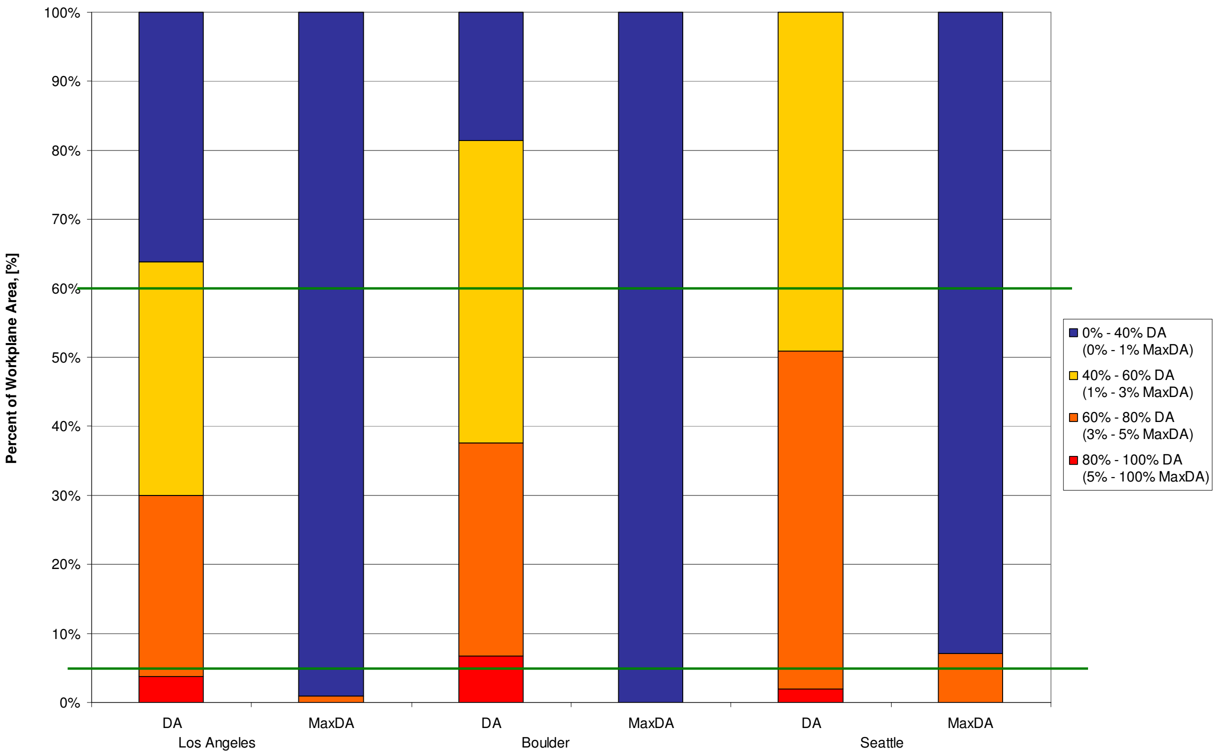

Figure 4-6: Classroom #3a Results

4.2.2 Classroom #3b – South Fenestration w/ Lightshelf and Overhang

This case study is the same classroom as 4.2.1 except with no view window shades (see Figure 4-5).

Without window shades, the DA's are slightly higher than the previous case (see Figure 4-7), and the MaxDA's are significantly higher, indicating a greater occurrence of direct sunlight in the space. Seattle receives a longer duration of direct sunlight but also less intense, indicated by the greater 0% - 5% MaxDA's yet smaller >5% MaxDA's. This indicates the importance of shading windows while providing for more daylight harvesting in sunnier locations.

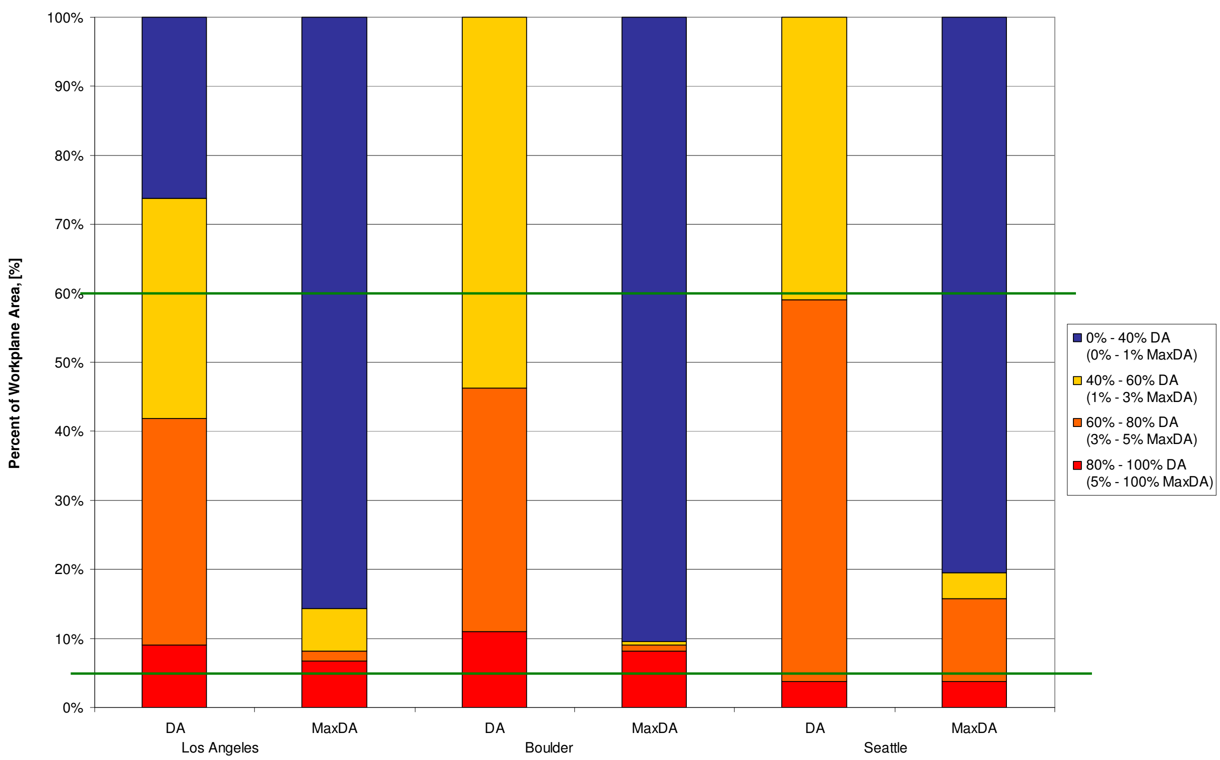

Figure 4-7: Classroom #3b Results

4.2.3 Classroom #3c – South Fenestration w/ Lightshelf, Overhang and Shades on All Windows

This is the same model as the previous two examples except that shades are modeled on all windows.

Here the DA's drop for all climates, with LA and Boulder no longer receiving at least DA1 for 60% of the floor area (see Figure 4-8). This is due to the increased amount of time that the daylight window, already protected by an overhang and Lightshelf, has a view window shade drawn. SPOT assumes the shades are drawn when sun is incident on a façade, and so the control of the daylight window shade was more aggressive than necessary and hence the results are somewhat misleading. Seattle, with its lower winter sun angles and higher percentage of cloudy days, still receives a DA1 for at least 60% of the space. The MaxDA is 0% in all cases. The daylight window shades provide some benefit for the Seattle climate but add little benefit due to the already well controlled daylight window for the LA and Boulder climates.

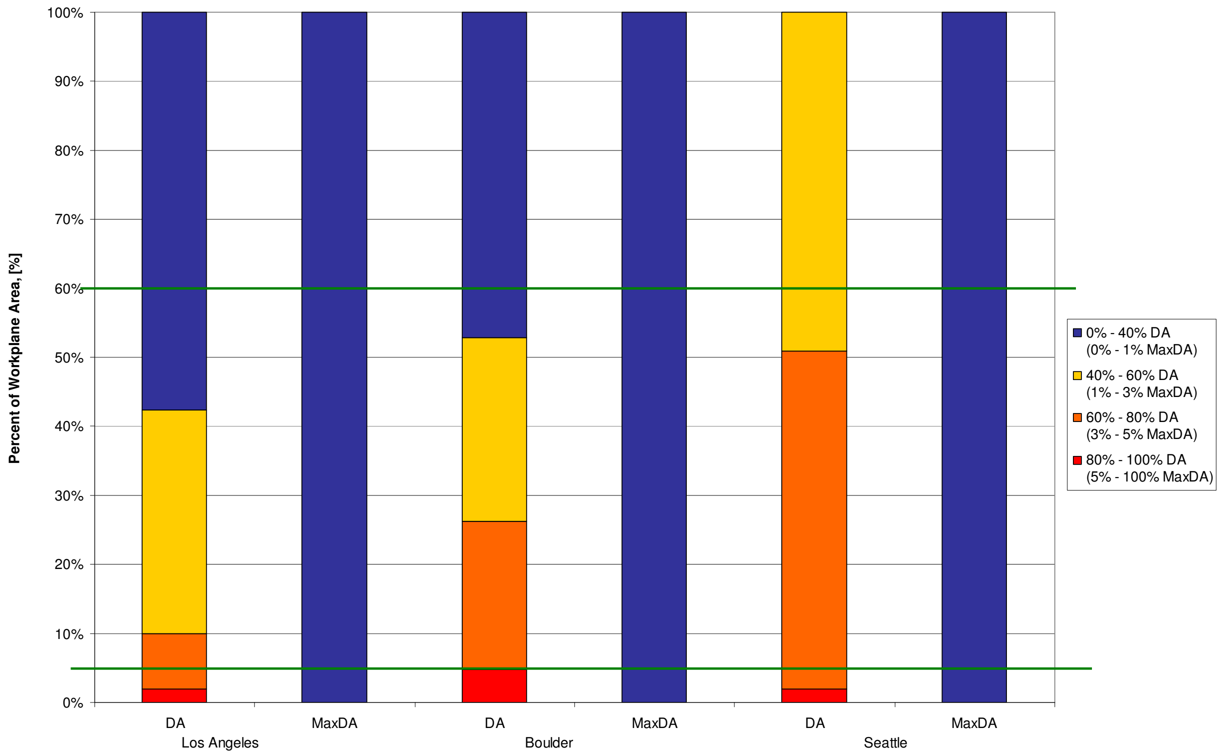

Figure 4-8: Classroom #3c Results

4.2.4 Classroom #4 – South Fenestration w/ Lightshelf, Overhang and Shades and North Clerestory

This classroom is similar to the previous south facing classrooms except that a daylight window has been added to the north façade. This adds 75sf of glazing for a 21.3% WWR on the north wall (see Figure 4-9). As in test classroom #3a, shades have been modeled on the south view windows only.

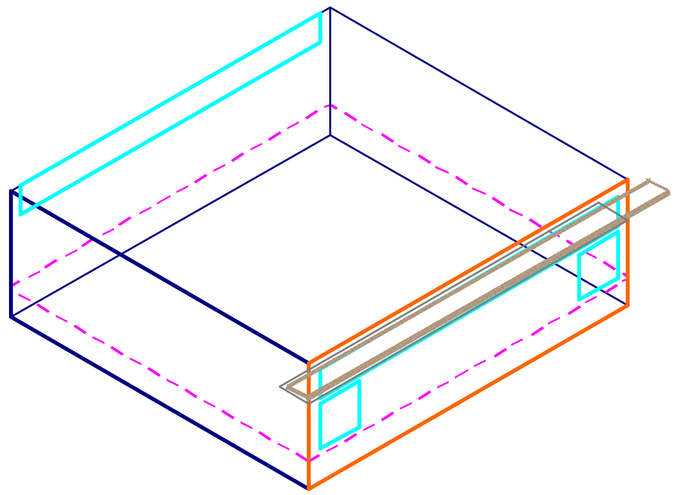

Figure 4-9: Classroom #4 Geometry

The north clerestory boosts the daylight saturation, with all climates receiving a DA2 for 60% of the floor area. The MaxDA is similar to the Classroom #3 examples with windows shades as the north clerestory did not add any additional direct sunlight penetration concerns. Seattle, like Classroom #3a, receives some direct sunlight through the daylight window and exceeds the MaxDA requirement indicating that additional solar control is necessary.

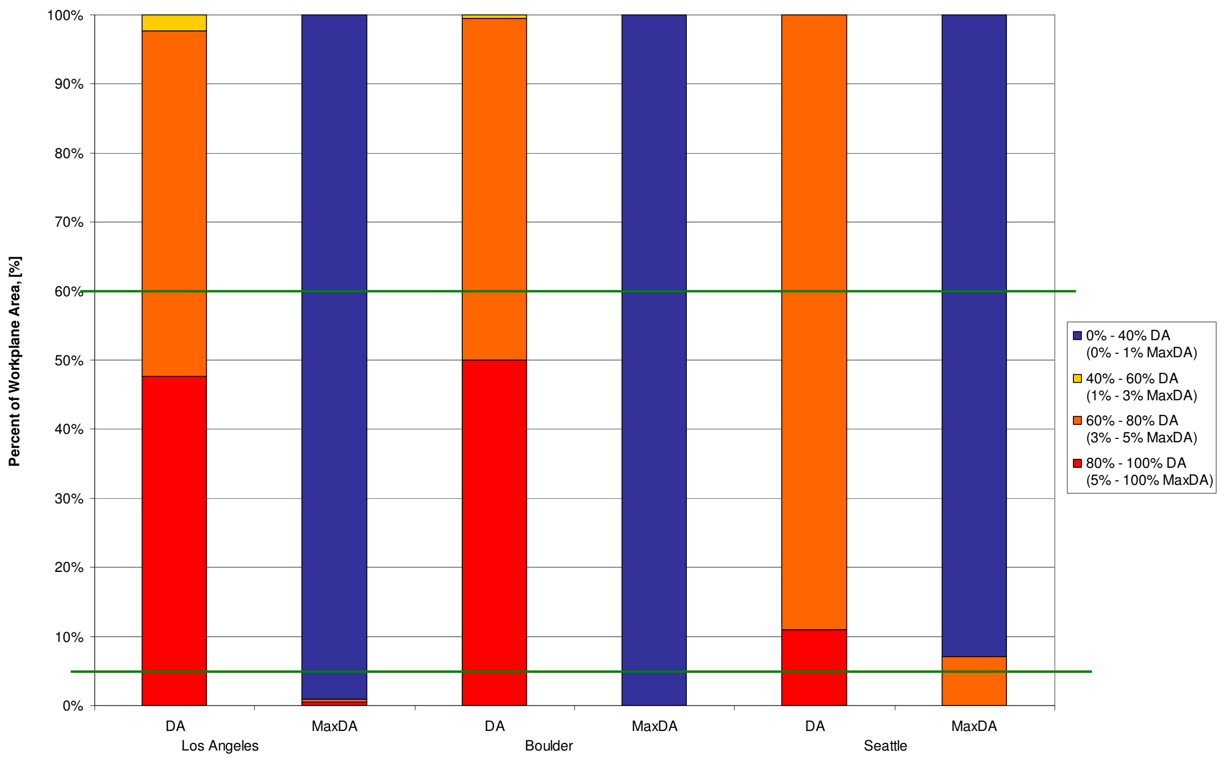

Figure 4-10: Classroom #4 Results

4.2.5 Classroom #5 – South Fenestration w/ Lightshelf, Overhang and Shades and West View Windows

This case study is also based on the previous examples in this section. It is the same model as test Classroom #3a (including shades on all south facing glazing), with an additional two 4’-0” x 4’-0” view windows on the West façade (see Figure 4-11). These account for 32sf of glazing and a WWR of 9.7%. No shades are provided on the west windows in this case.

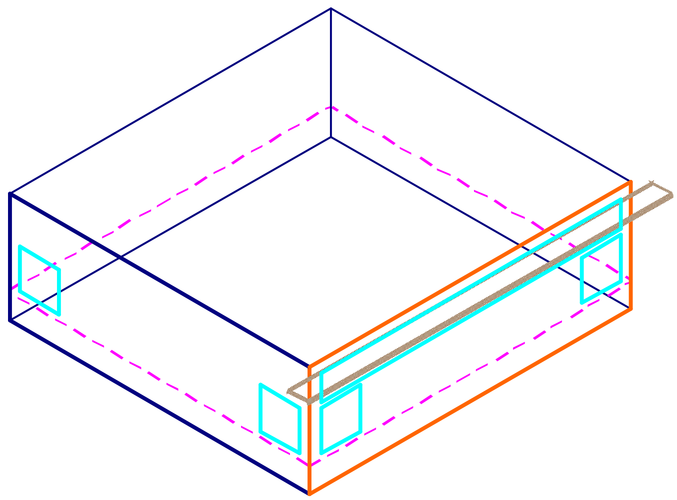

Figure 4-11: Classroom #5 Geometry

This daylighting scenario results in higher DA's than Classroom #3 due to the added view windows with LA and Boulder receiving a DA1 and Seattle receiving a DA2. However, due to the uncontrolled west facing view windows, the MaxDA requirement is exceeded for each climate.

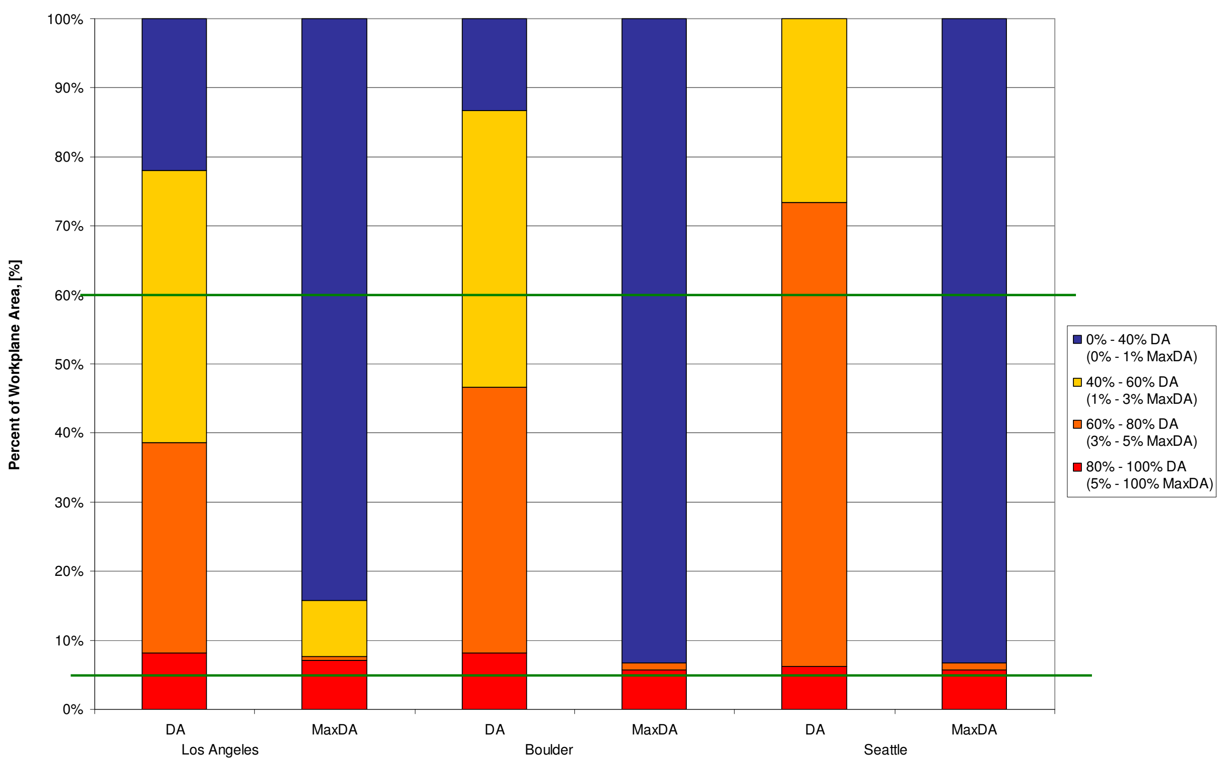

Figure 4-12: Classroom #5 Results

4.3 Classroom with Skylights Only

While interior classrooms with no exterior windows are rare they do occur occasionally occur in schools. Examples of classrooms with skylights only are modeled here.

4.3.1 Classroom #6a – Six Transparent Skylights

This example models a classroom with six 4'-0" x 8'-0" skylights (see Figure 4-13). There is 192sf of glazing giving a 20% WWR. The skylights are modeled as 50% T_{vis} clear glazing with no shades or other controls.

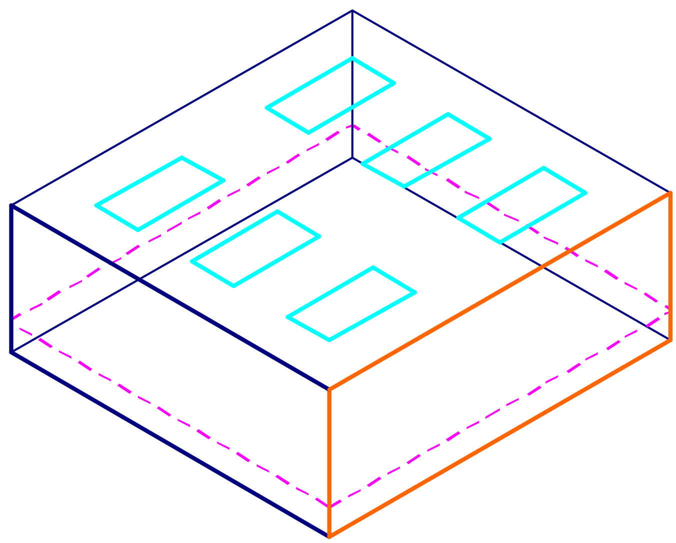

Figure 4-13: Classroom #6 Geometry

The DA's are extremely high in this over daylit example, with every climate receiving a DA3 (see Figure 4-14). The MaxDA's are also extremely high, indicative of the high amount of direct sunlight. This suggest an over reliance on skylights can have negative consequences in regard to glare. This is especially true in the sunnier climates.

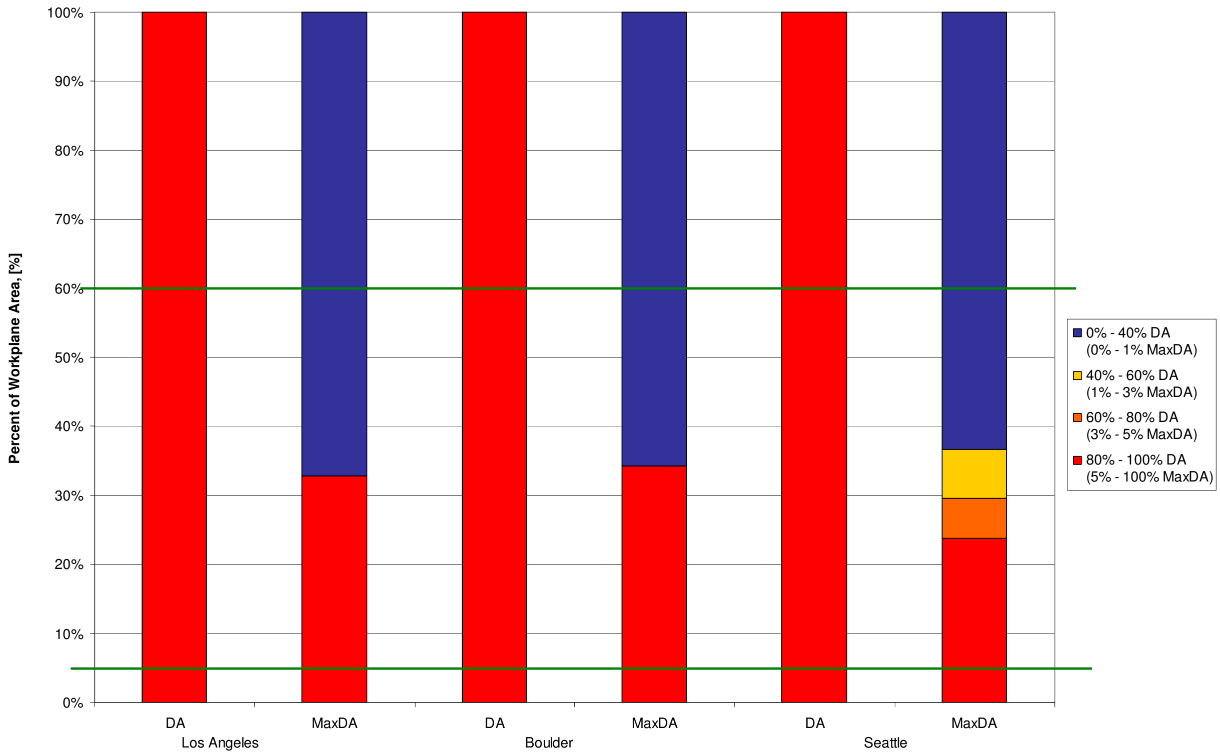

Figure 4-14: Classroom #6a Results

4.3.2 Classroom #6b – Six Translucent Skylights

This example uses the same geometry as Classroom #6a (see Figure 4-13) except the skylight glazing was changed to 40% T_{vis} translucent glazing with no shades or other controls.

In this example the DA's are still extremely high (see Figure 4-15) while the MaxDA's see some reduction though still exceeding the MaxDA requirement. This example still sees very high DA's due to the large amount of skylights provided, the space has a 20% Skylight-to-floor ratio (SFR). This is also why the MaxDA's are still so high; even though the daylight is uniform and there are no direct sunlight patches, the average illuminance on the floor during the summers is 450fc. This is a good example of how the metric can determine and fail a space if it is overly daylit.

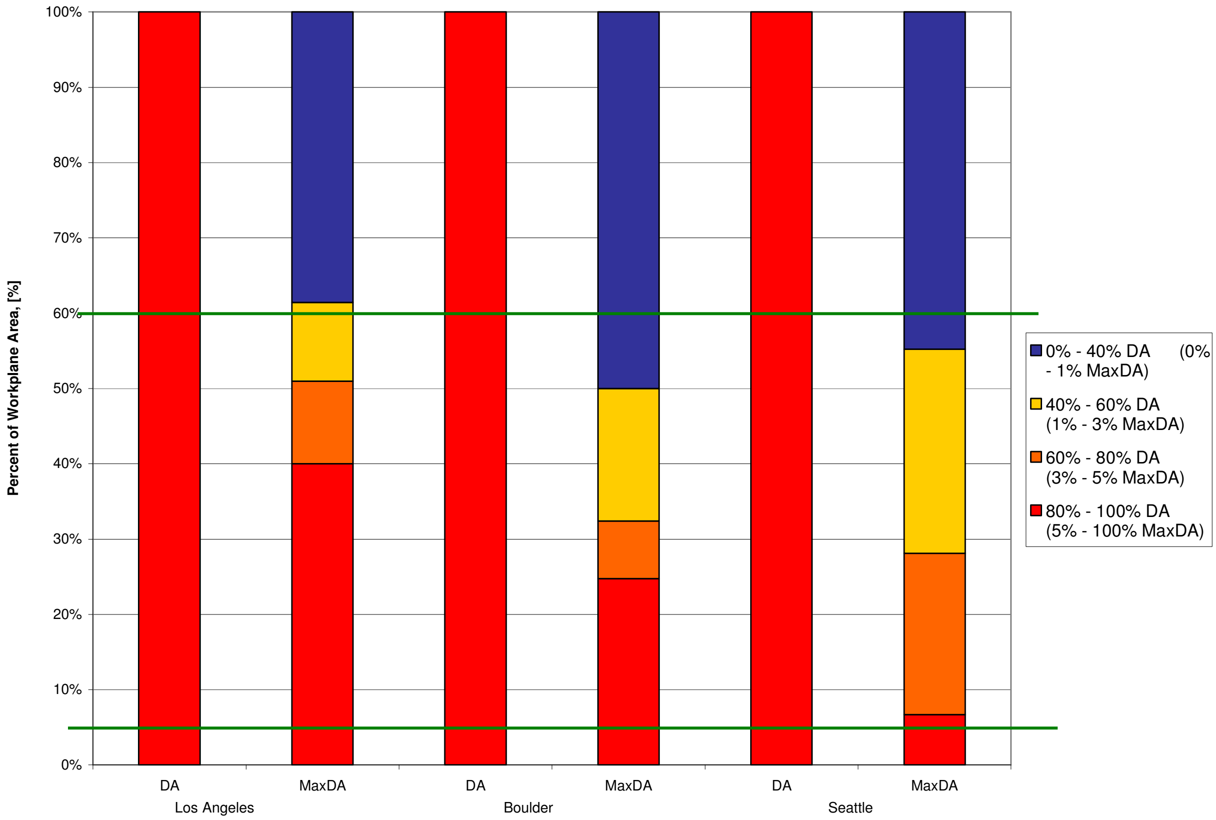

Figure 4-15: Classroom #6b Results

4.4 East and West Classrooms

East and West facing windows are the most difficult to provide exterior shading for as the sun is low in the sky when the sunlight strikes these windows, making horizontal shades ineffective against the early morning and late afternoon sun. West facing windows receive more detrimental solar radiation, often leading to overheating problems, but on the other hand classrooms typically are unused during that portion of the day. East facing windows receive the less detrimental morning sun, but alternatively are often occupied during these hours.

4.4.1 Classroom #7a – West Fenestration w/ Lightshelf and Overhang

An example similar to the south classrooms is modeled here with a west exposure. Two vision windows with a clerestory are modeled totaling 102sf of glazing and a 34% WWR (see Figure 4-16). This classroom also has a 2' roof overhang and a 3' wide lightshelf. No shades are provided in this example.

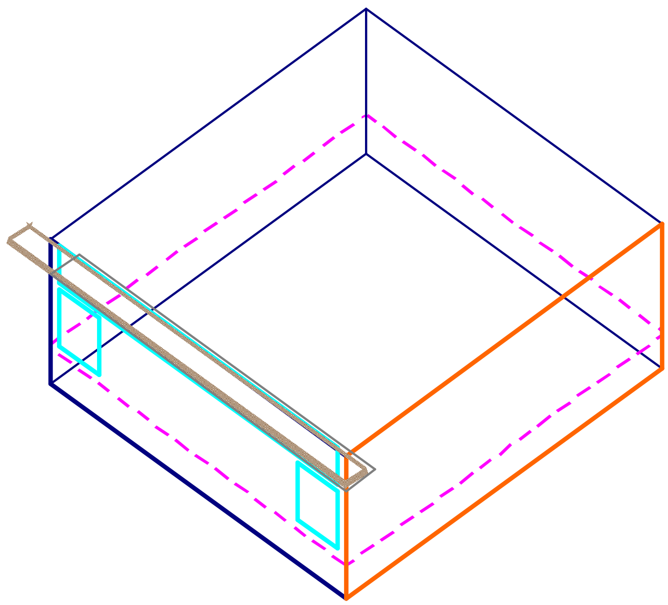

Figure 4-16: Classroom #7 Geometry

The DA's for this classroom are similar to those for Classroom #3b (same geometry but south-facing) but less intense due to the west orientation (Figure 4-17). A DA1 is achieved for all climates. The MaxDA is exceeded for each climate due to the lack of solar control on the view windows.

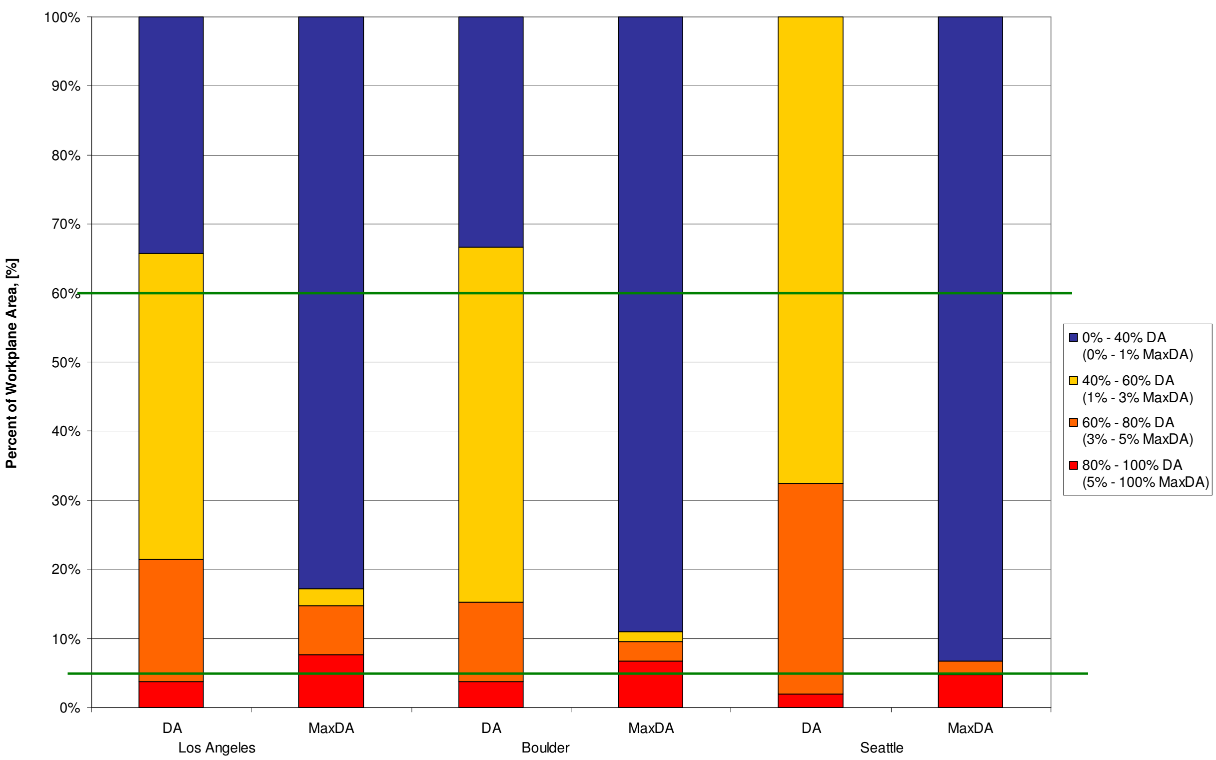

Figure 4-17: Classroom #7a Results

4.4.2 Classroom #7b – West Fenestration w/ Lightshelf, Overhang and Shades

This is the same classroom as the previous test classroom #7 except that view window shades have been added (see Figure 4-19).

The DA's for this classroom are slightly less than those for Classroom #7a (same geometry but with no shades), see Figure 4-17. A DA1 is only achieved for Seattle where the low winter sun angles were not intense enough to trigger the view window shades. The MaxDA is no longer exceeded for any climate. Compared to Classroom #3a, the addition of view window shades, while providing the necessary solar controlled, reduced the quantity of daylight enough to fail this design under the Los Angeles and Boulder climates.

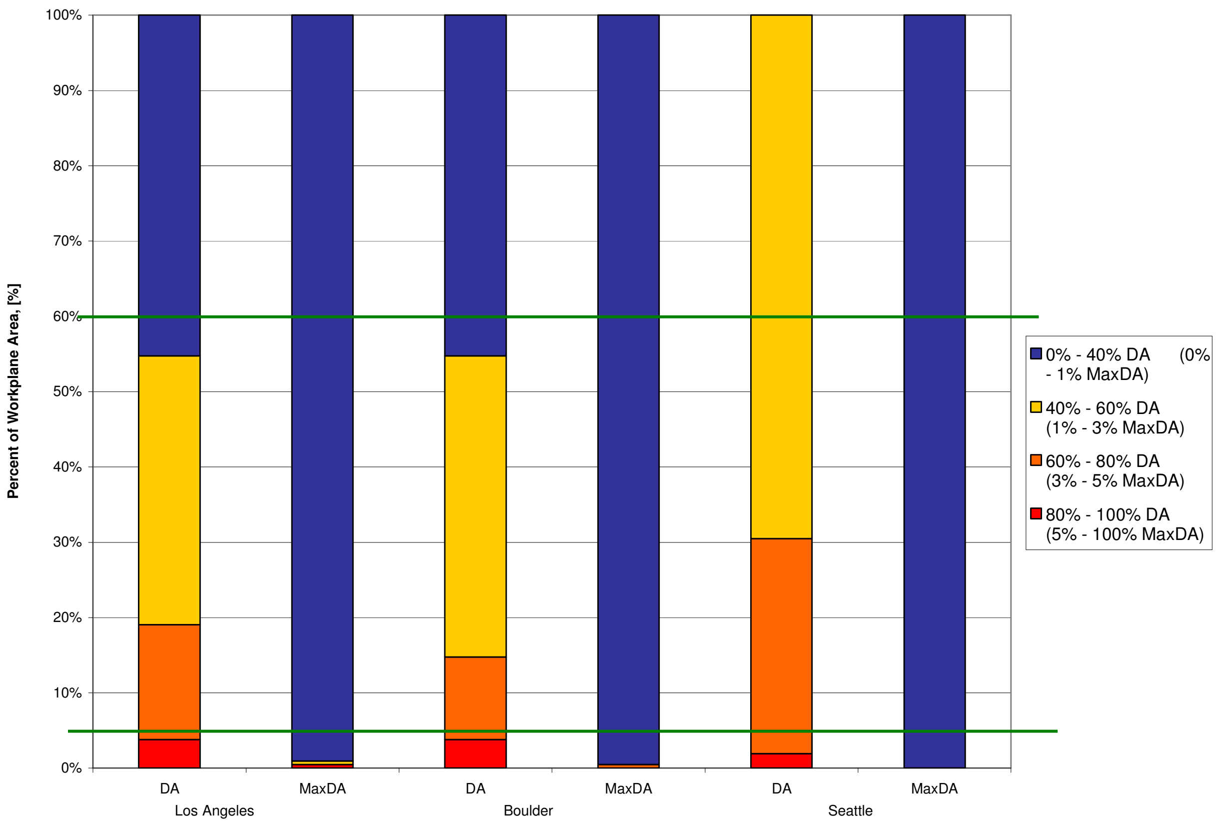

Figure 4-18: Classroom #7b Results

4.4.3 Classroom #8a – East Fenestration w/ Lightshelf and Overhang

This is the same classroom as the previous test classroom #7 except that it is oriented to the east (see Figure 4-19).

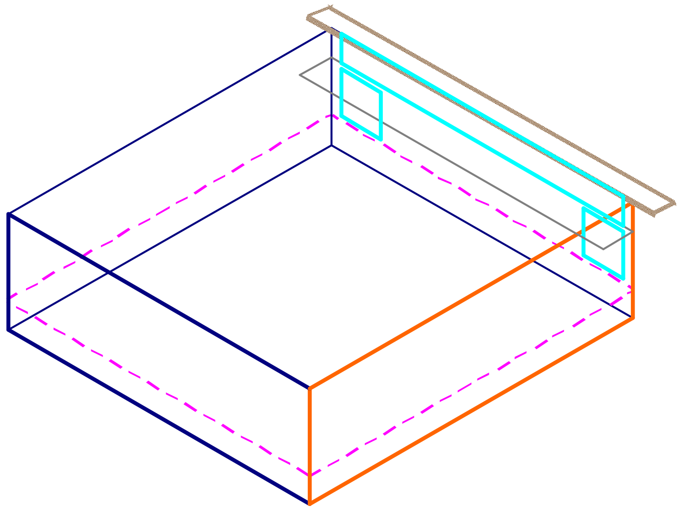

Figure 4-19: Classroom #8 Geometry

The DA's for this example (Figure 4-20) are similar to the west facing classroom with variations reflecting the heavier morning school schedule and the overcast Los Angeles mornings. Compared to the west, this design no longer passes for the Los Angeles climate, reflecting the heavier morning sky cover experienced here. Seattle passes because of the brighter general sky dome that is providing more daylight during the midday and afternoons than the other two climates. The MaxDA's are more intense than the west classrooms due to the heavier occupancy experienced in schools in the mornings than the afternoons.

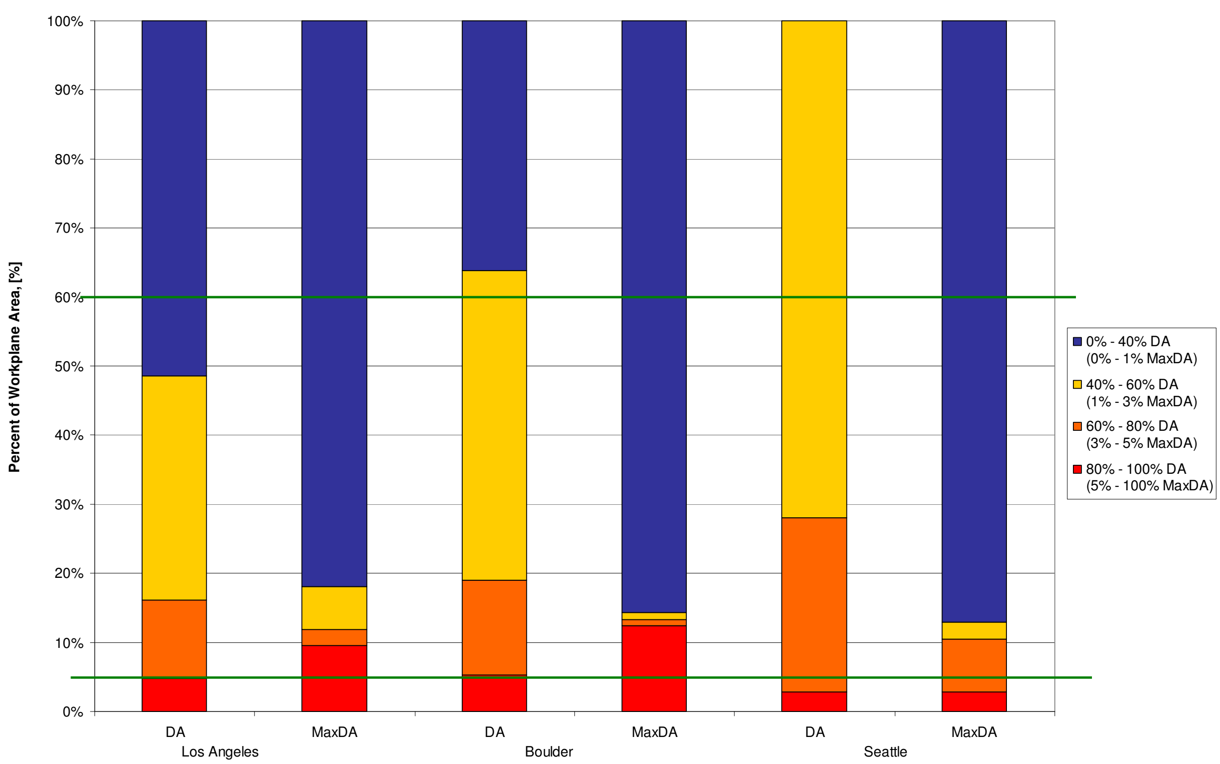

Figure 4-20: Classroom #8a Results

4.4.4 Classroom #8b – East Fenestration w/ Lightshelf, Overhang and Shades

This classroom is the same as Classroom #7b except that it is oriented to the east (see Figure 4-19).

The DA's are slightly less than the previous example due to the addition of view window shades (Figure 4-21). Los Angeles and Boulder no longer receive adequate daylight saturation. The MaxDA's are adequately low reflecting the effectiveness of view windows shades.

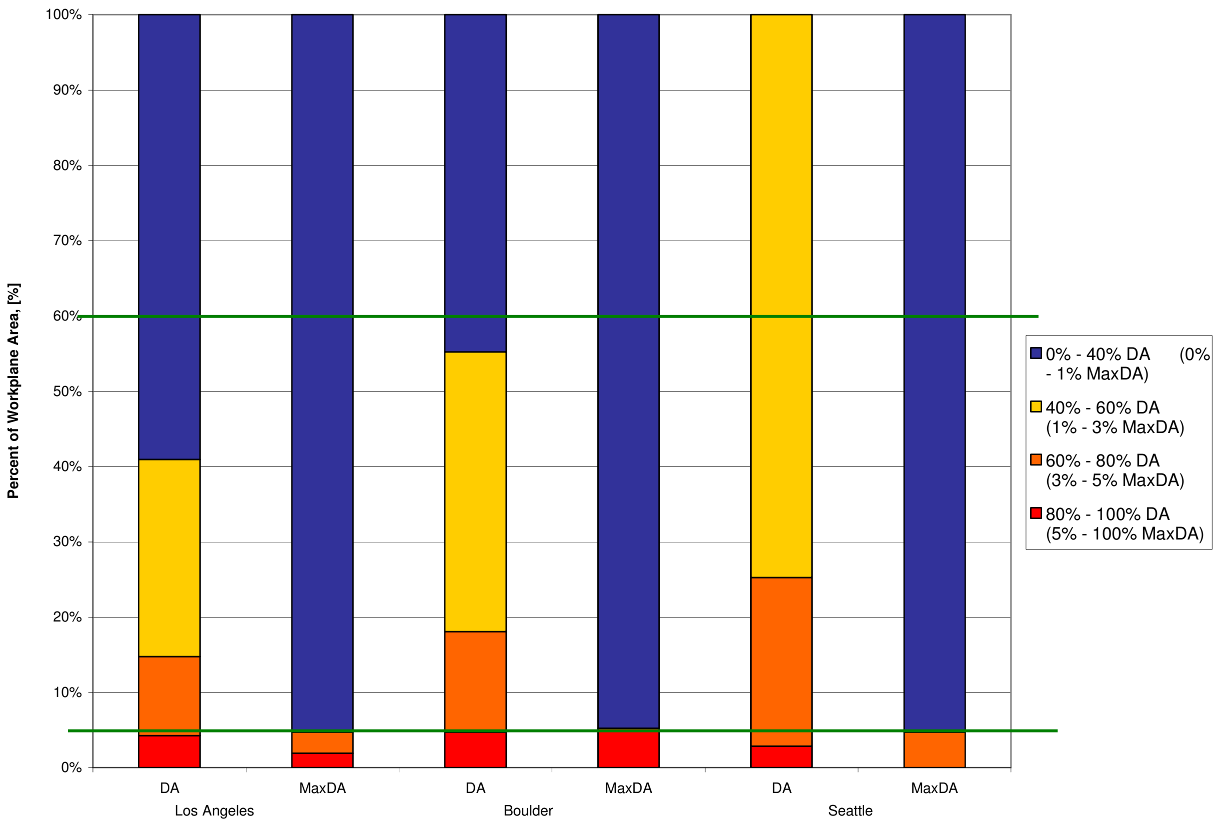

Figure 4-21: Classroom #8b Results

4.4.5 Classroom #9 - West Fenestration w/ Lightshelf, Overhang and Shades and East Clerestory w/ Lightshelf and Overhang

This classroom is the same as Classroom #7b except that a clerestory has also been added on the east facade with 70sf of glazing and a WWR of 23.3% (see Figure 4-22).

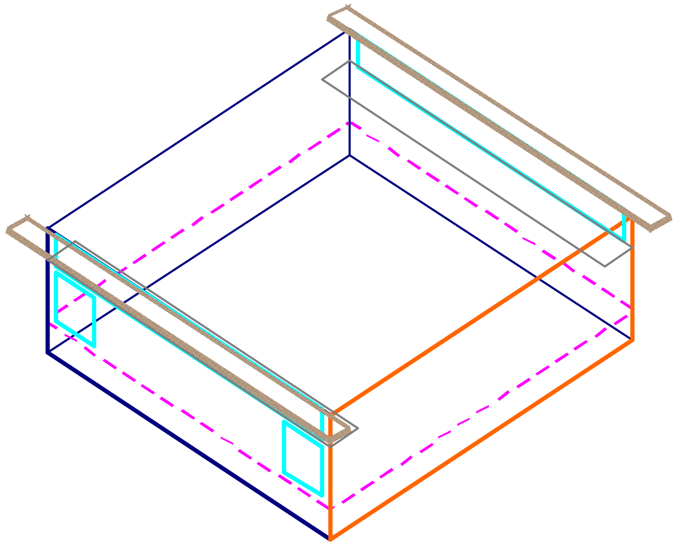

Figure 4-22: Classroom #9 Geometry

The addition of daylight glazing on the rear wall has boosted the DA's, with each climate receiving a DA2 (Figure 4-23). The MaxDA's are very close to acceptable with each climate very close to the cut-off. This illustrates the benefit of daylight glazing on a second surface within the classroom.

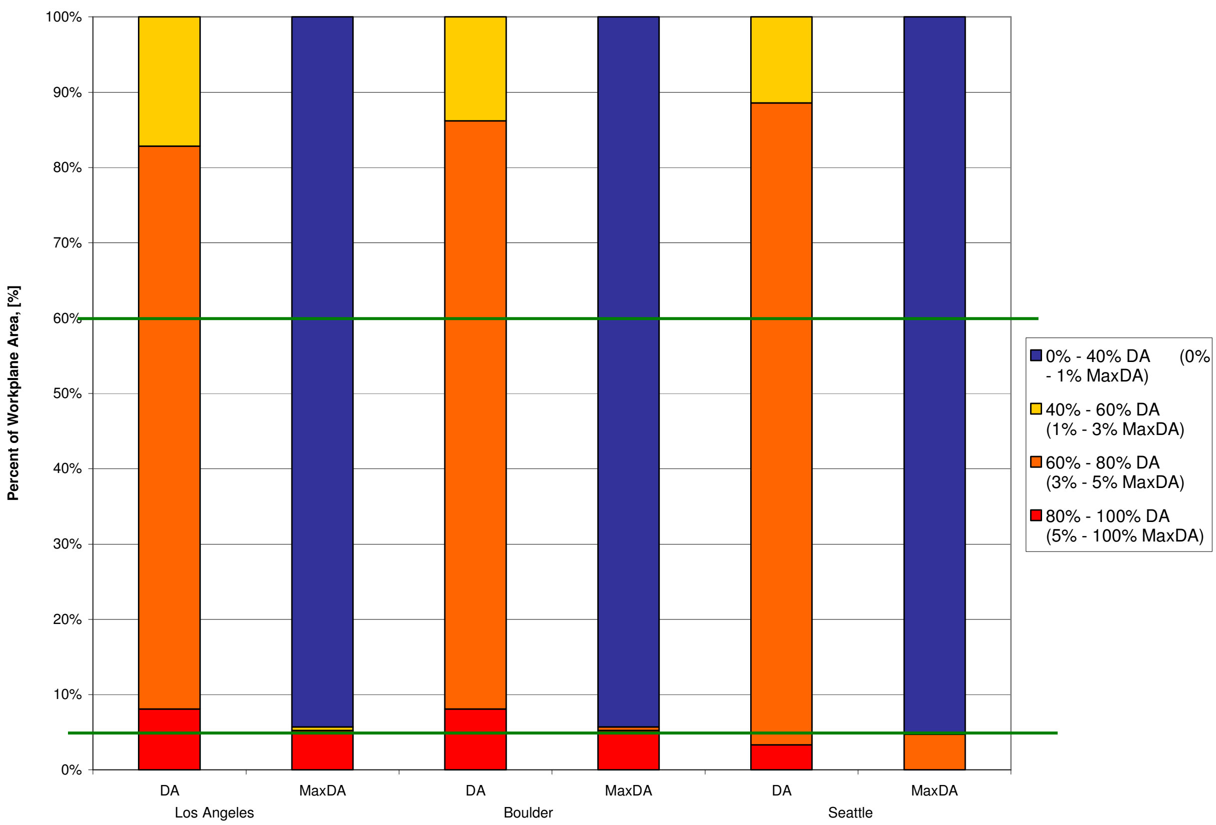

Figure 4-23: Classroom #9 Results

4.4.6 Classroom #10 – West View Windows w/ Overhang and East Clerestory w/ Lightshelf and Overhang

This example is similar to Classroom #9 but the west clerestory has been removed while the east clerestory remains (see Figure 4-24).

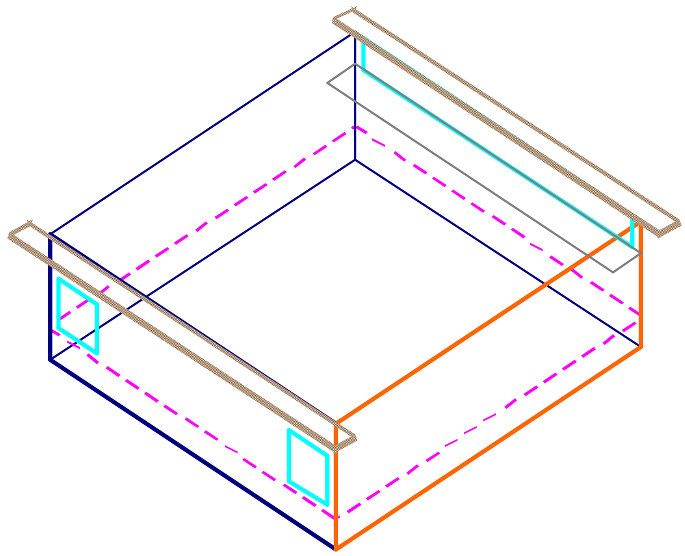

Figure 4-24: Classroom #10 Geometry

The DA's are lower than the previous example due to the elimination of the west clerestory (Figure 4-25) with only Boulder and Seattle receiving a DA1. This design scores lowest under the Los Angeles climate due to the cloudier mornings and the east clerestory as the main daylight resource. The MaxDA is acceptable for each climate.

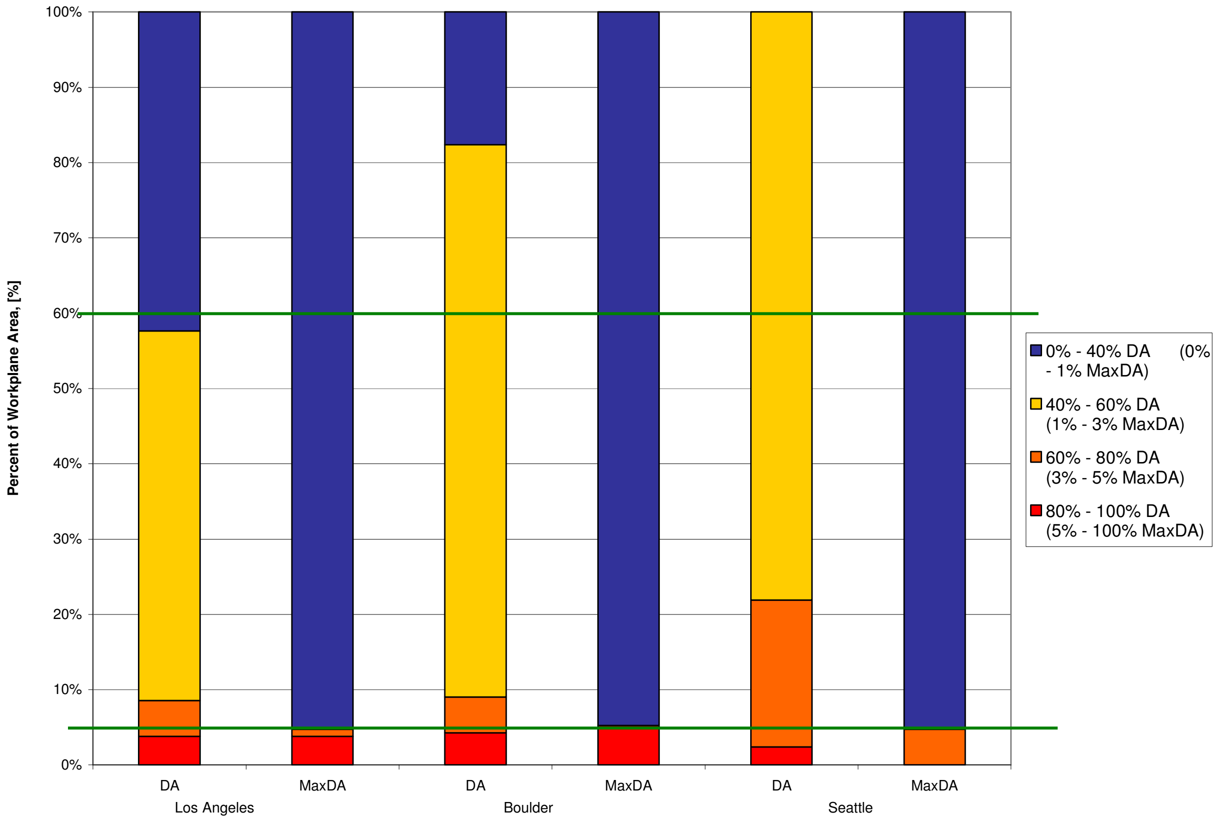

Figure 4-25: Classroom #10 Results

4.4.7 Classroom #11 – Southeast Fenestration w/ Overhang, Lightshelf and Shades

A classroom with the same geometry as Classroom #3 was modeled with a Southeast exposure (see Figure 4-26). This orientation is also difficult to shade properly with exterior devices. Shades were modeled on the vision windows but not the daylighting window in this case.

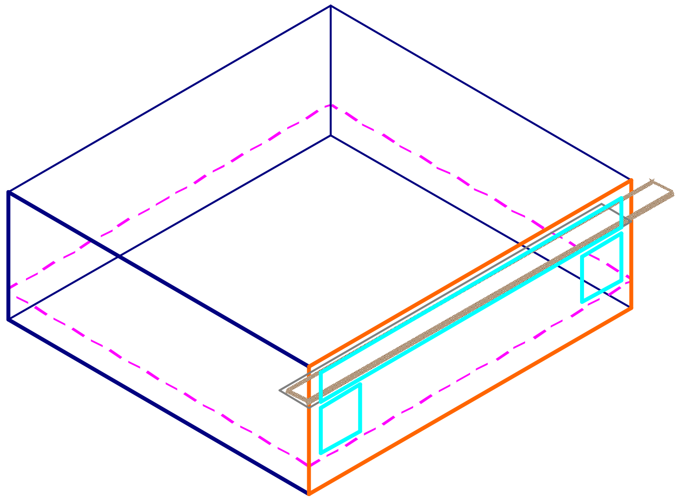

Figure 4-26: Classroom #11 Geometry

Each climate receives a DA1 under this daylight design (Figure 4-27), similar to Classroom #3a but slightly less intense. These DA numbers are higher than the west facing classrooms but the fact that there are more intense MaxDA's with shades indicates that this is a troublesome orientation relative to cut-off angles for the daylight windows.

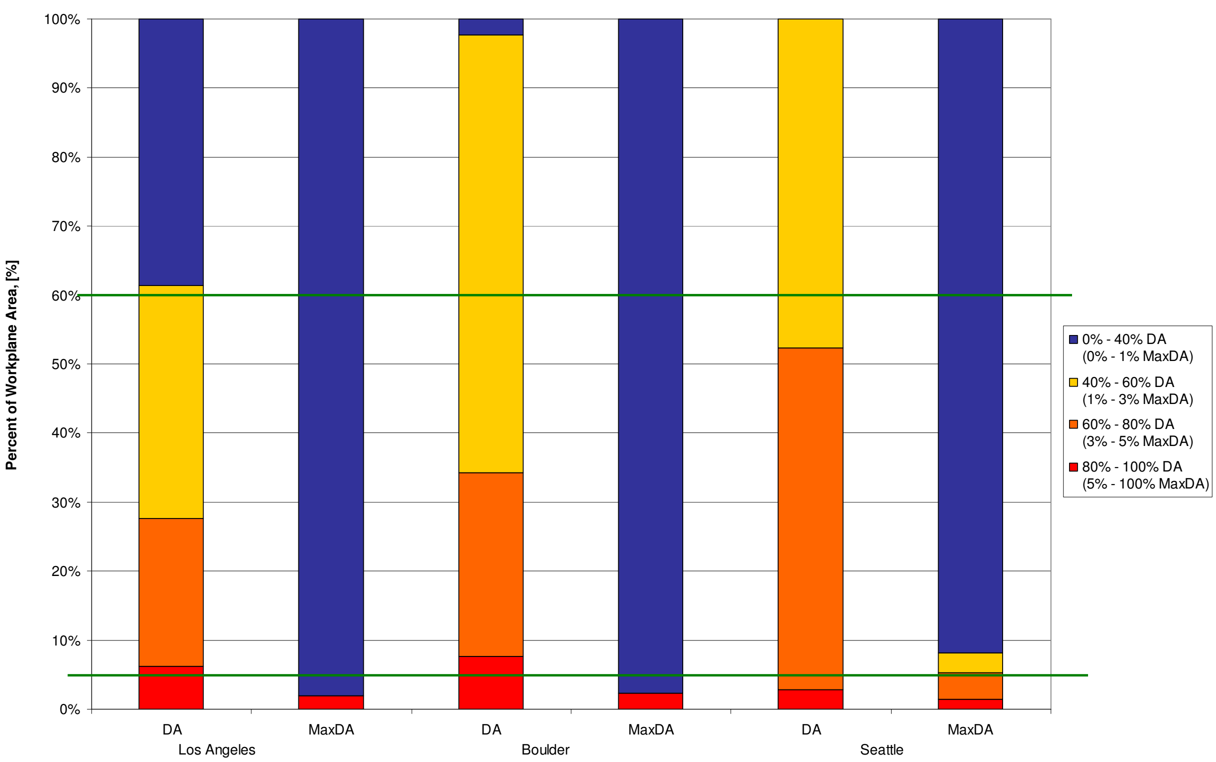

Figure 4-27: Classroom #11 Results

4.5 The CHPS Classroom

The CHPS organization has designed an ideal classroom for use in California schools. The CHPS classroom has recommendations for acoustics, classroom layout, furnishings and finishes, displacement ventilation, electric lighting and daylighting. The daylighting recommendations of the CHPS classroom include skylights, vision windows and daylighting windows with lightshelves.

4.5.1 Classroom #12a – CHPS Classroom w/out Shades

The CHPS classroom contains two 2'-0" x 4'-6" vision windows and two 8'-0" x 2'-6" daylight windows with lightshelves. The windows are located in the corners to more effectively daylight the teaching surfaces. Two 4' x 8' skylights are located near the rear wall (see Figure 4-28). The south wall contains a total of 60 s.f. of glazing (18.8% WWR) and the ceiling has a total of 64 s.f. of translucent glazing (6.7% WWR). Shades were not included in this model.

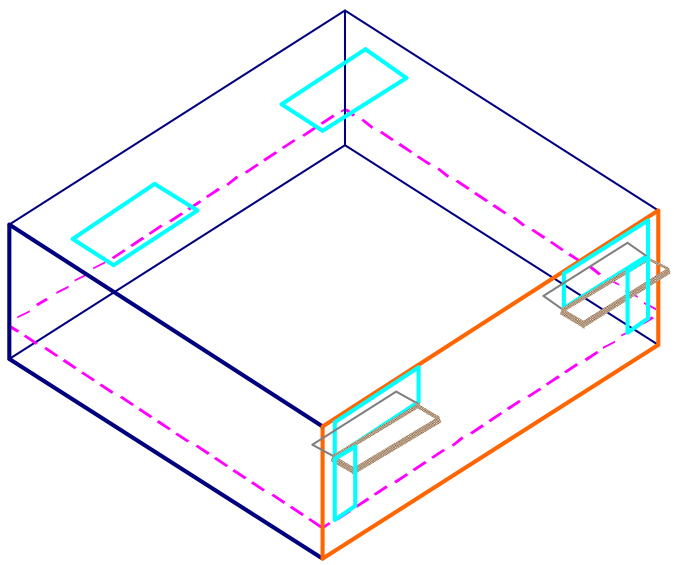

Figure 4-28: Classroom #12 Geometry

The DA's are fairly high with a DA3 achieved in Los Angeles and Boulder and a DA2 achieved in Seattle (Figure 4-29). The MaxDA's are also extremely high due to the relatively small lightshelf and unprotected view windows.

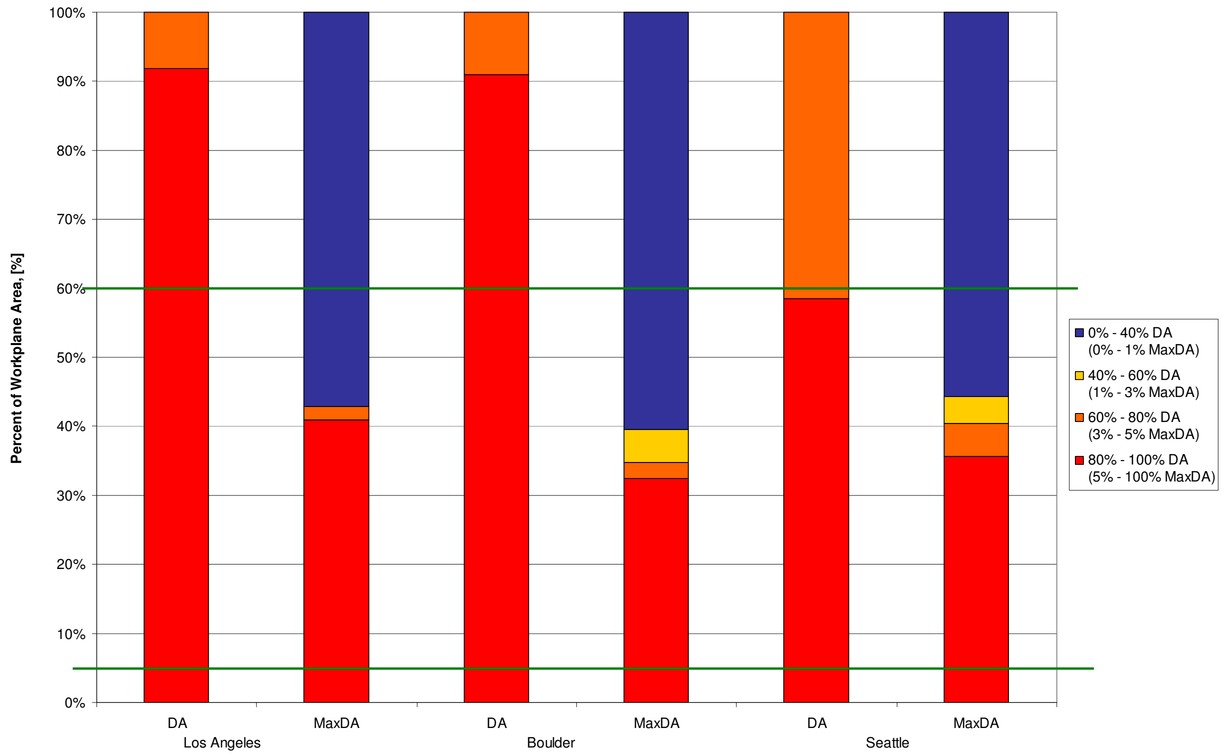

Figure 4-29: Classroom #12a Results

4.5.2 Classroom #12b – CHPS Classroom w/ Shades

The same CHPS classroom was modeled with shades on the vision windows (see Figure 4-28).

The DA's slightly less due to the shade but still extremely high with only Seattle receiving a DA2 rather than a DA3 (Figure 4-30). The MaxDA's are nearly identical to the previous example (4.5.1). This indicates that the glare is not provided from the vision windows which are shaded in this instance, but most likely from the large skylights and the daylight windows with the inadequate lightshelves.

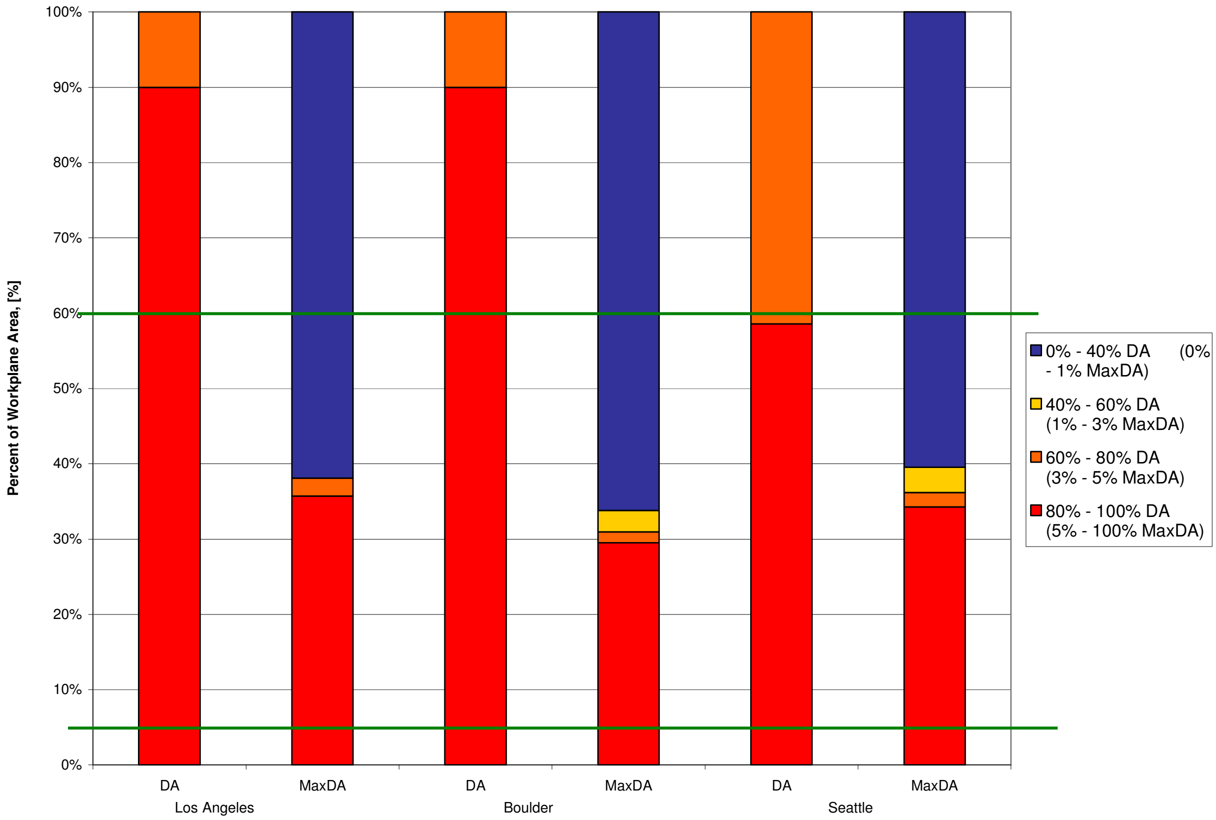

Figure 4-30: Classroom #12b Results

4.6 "Finger Style" Classrooms

During the 1950's and early 1960's many schools were built using the "finger style" layout with multiple rows of single classrooms each with windows on two sides. Typically, full height, wall to wall windows with large overhangs faced south and a clerestory was located along the north wall. This design is generally regarded as an excellent example of daylighting.

4.6.1 Classroom #13a – "Finger Style" Classroom w/ Shades

This model has 270sf of glazing, a 6' overhang on the south (70.3% WWR) and a 4' high, full width clerestory on the north (120sf, 31.3% WWR). Shades are included in this model for the south windows (see Figure 4-31).

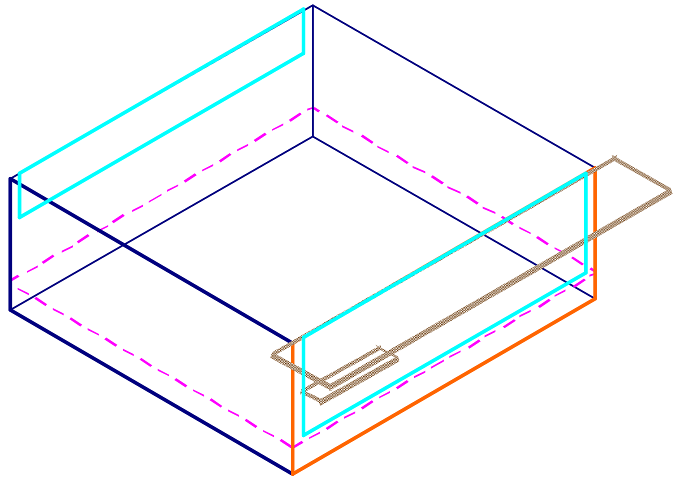

Figure 4-31: Classroom #13 Geometry

This model has excellent DA's, with each climate receiving a DA3 and also has excellent solar control with minimal MaxDA's (Figure 4-32). The large amount of glazing overall attribute to the high DA's and the complete solar control on the south contribute to the minimal MaxDA's.

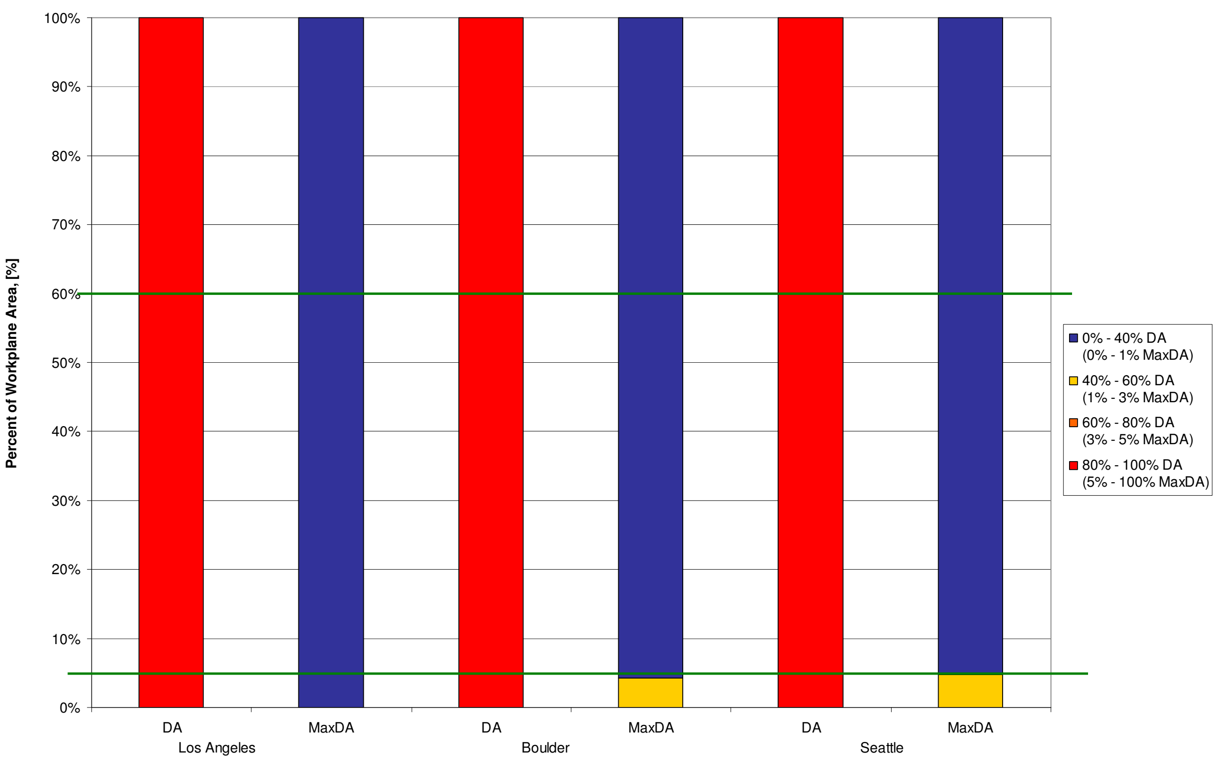

Figure 4-32: Classroom #13a Results

4.6.2 Classroom #13b – "Finger Style" Classroom w/out Shades

This example is the same as the previous case (4.6.1) with the exception that shades are not included on the south window.

This example also has excellent DA's but now results in very extreme MaxDA's in all climates (Figure 4-33). This indicates the importance of shades with this type of design.

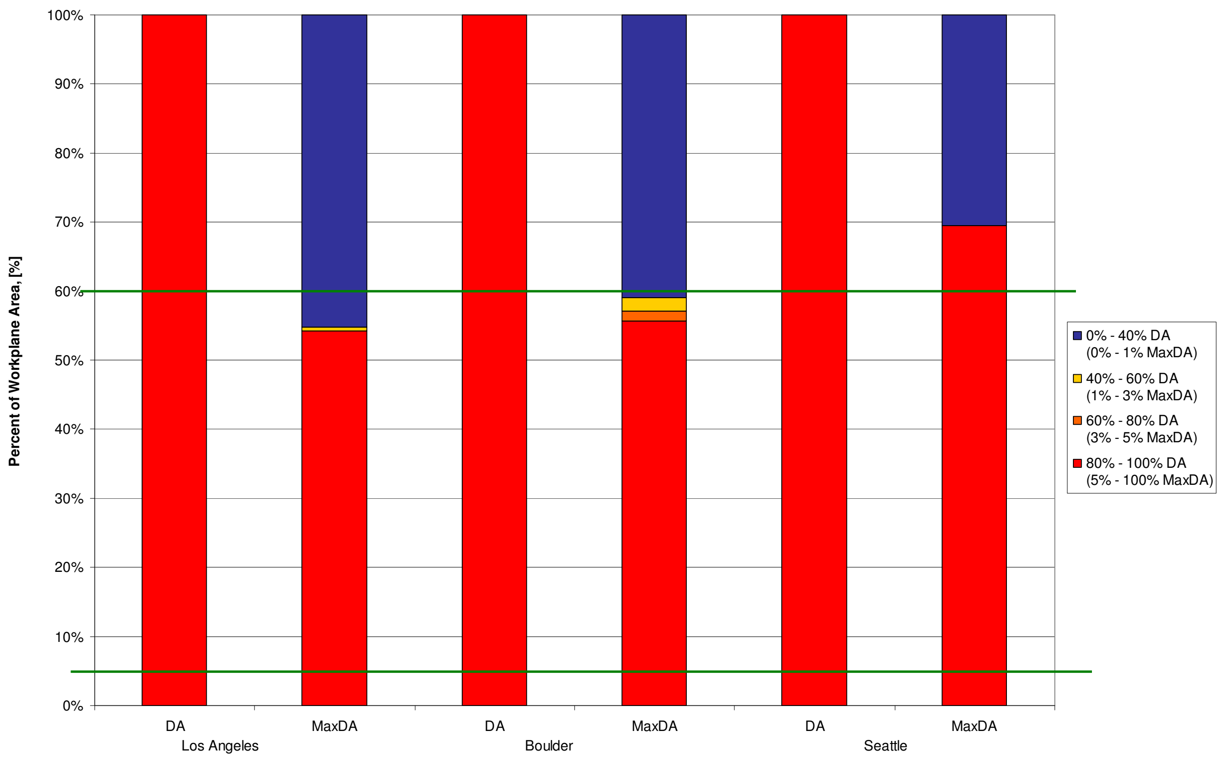

Figure 4-33: Classroom #13b Results

4.6.3 Classroom #14 – "Finger Style" Classroom w/ Shades and Skylights

This model is the same as Classroom #13a except that three 2' x 4' skylights have been added in the center of the classroom (see Figure 4-34). The translucent skylights total 24sf of glazing for a WWR of 2.5%.

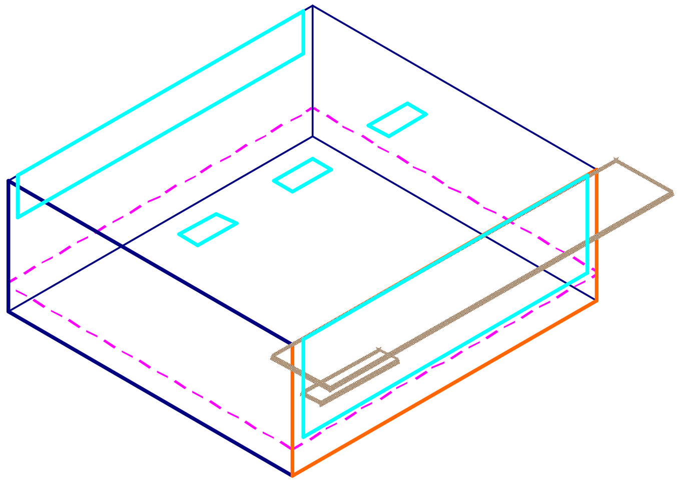

Figure 4-34: Classroom #14 Geometry

The skylights have little effect on the DA's as the space was already very well saturated with daylight (Figure 4-35). The MaxDA are still acceptable due to the translucency of the skylights and the south window shades. In this instance the classroom would be better off without the added skylights.

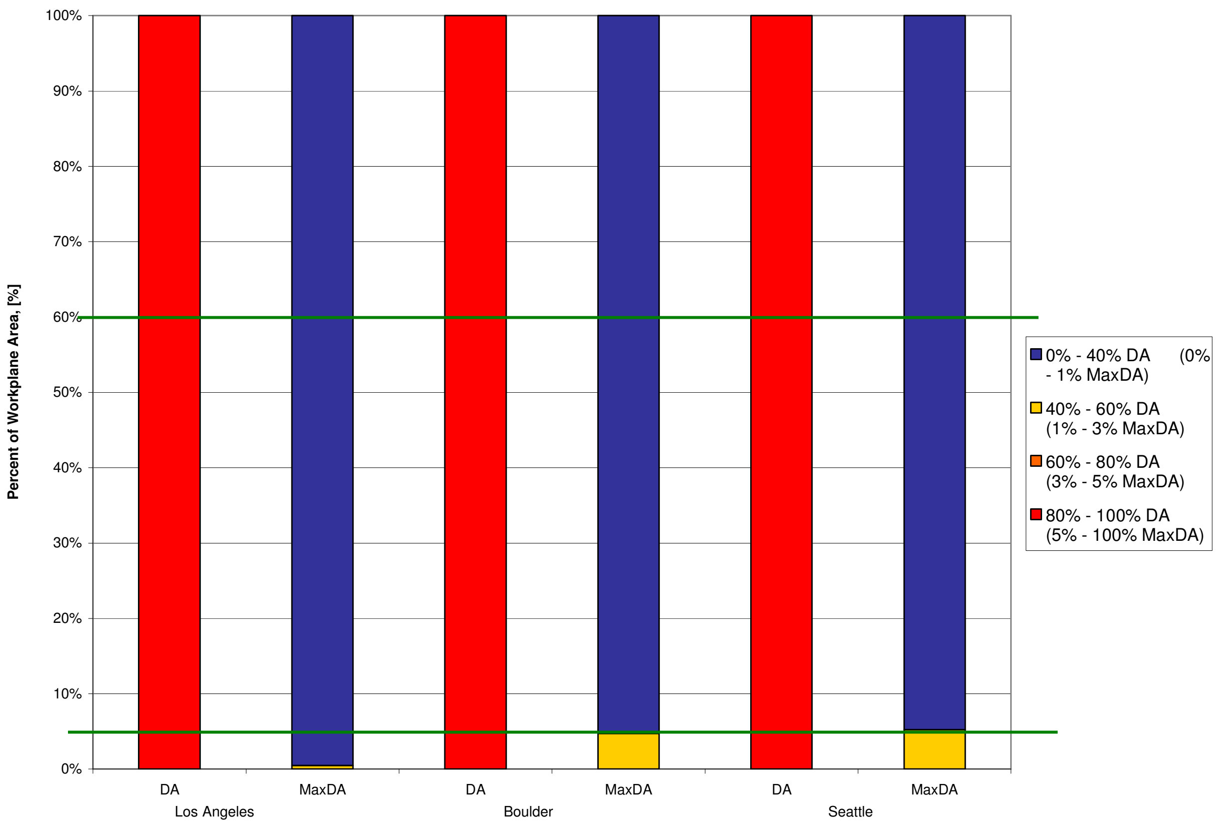

Figure 4-35: Classroom #14 Results

4.6.4 Classroom #15 – "Finger Style" Classroom w/ Shades and Skylight and No North Clerestory

This example is similar to the other "Finger Style" classrooms but without the clerestory on the north side and with skylights located to the rear of the classroom (see Figure 4-36).

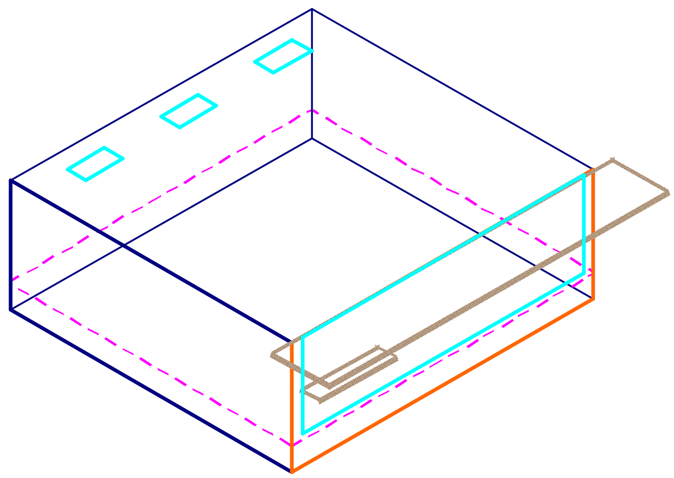

Figure 4-36: Classroom #15 Geometry

This design still has excellent DA's, while the repositioned skylights are distributing the daylight better (Figure 4-37). The MaxDA's in this example are lower than classroom #14 because the skylights and south windows are lighting different parts of the room rather than "doubling" on the south side, and this is a good example of how the metrics can identify design problems such as this. The decision of whether to use clerestories or skylights in this type of design would depend on issues other than daylighting.

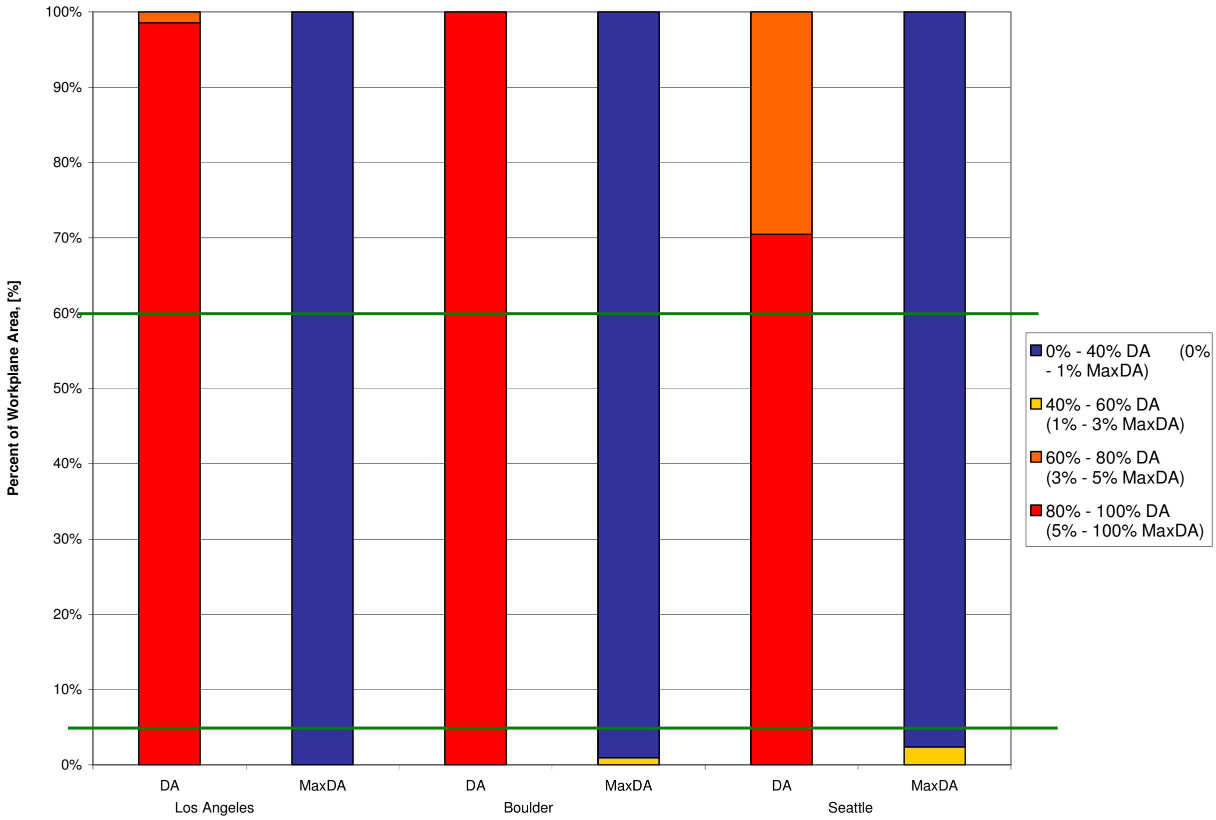

Figure 4-37: Classroom #15 Results

4.7 Relocatable Classrooms

Relocatable classrooms are prevalent in California and other states with mild climates. With a reputation as inferior learning environments the typical relocatable classroom plan is longer and narrower (40' x 24') than a typical classroom. Windows are usually placed on the ends, thus limiting the penetration of daylight into the classroom.

4.7.1 Classroom #16a – Relocatable Classroom w/ East-West Axis

A typical relocatable classroom, this example is a modeled as a 24' x 40' classroom oriented on an East-West axis. A single 8' x 4' window (32sf, 14.8% WWR) is located near a corner on each end. A roof over hang of 3' on the east and 5' on the west is also included in the model (see Figure 4-38). No shades were included in this model.

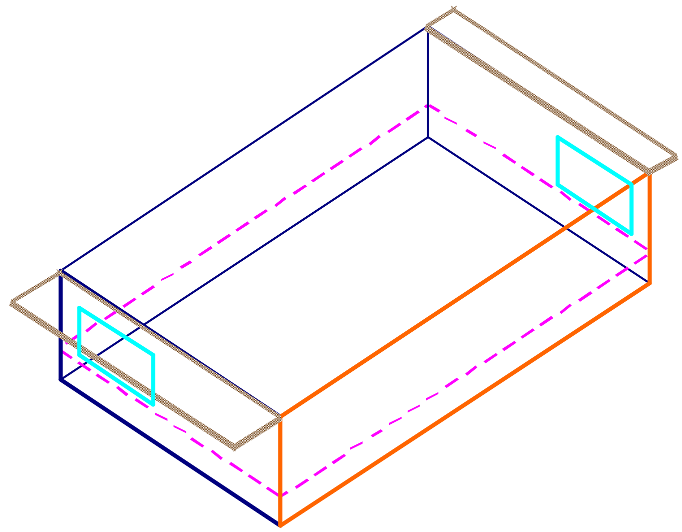

Figure 4-38: Classroom #16 Geometry

With no shades and an east-west orientation, the relocatable classroom should not perform well from a daylighting standpoint and the metric reflects that. Only one DA credit would be awarded in all three climates, and that comes with the attendant glare from the unshaded windows – and that is verified by the MaxDF being over the 5% threshold in all cases as well.

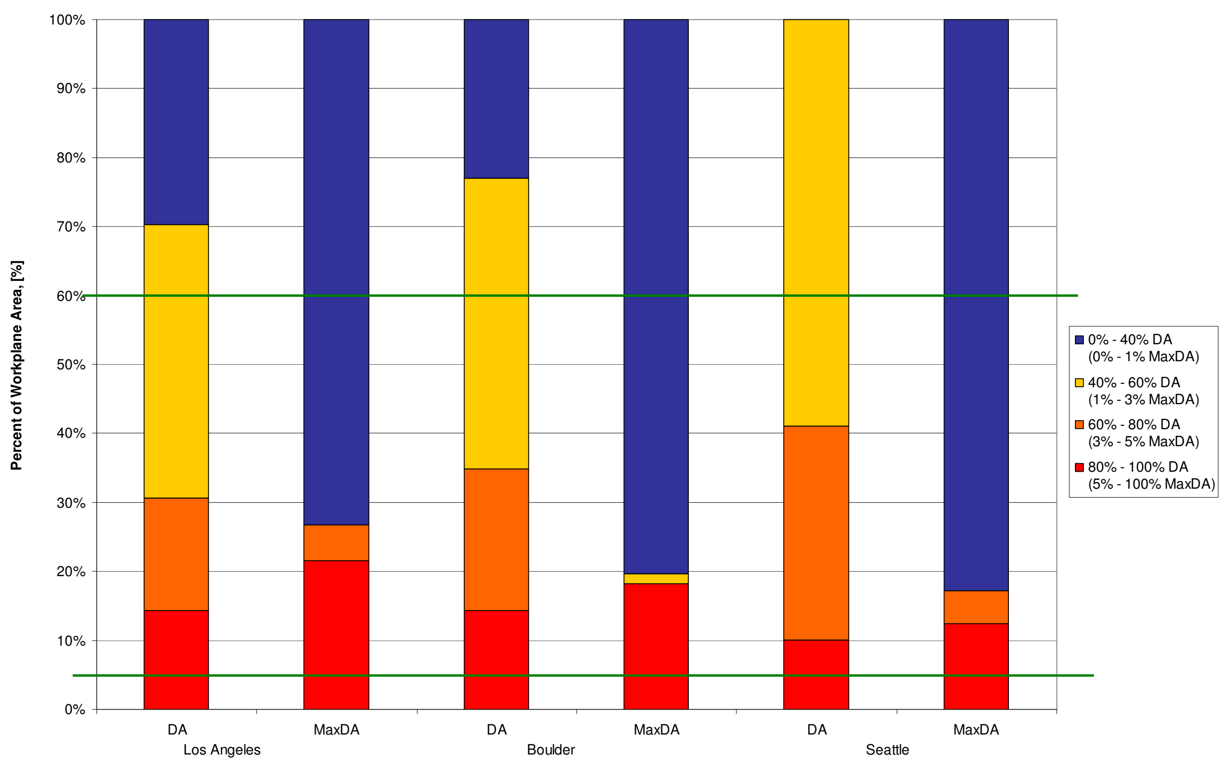

Figure 4-39: Classroom #16 Results

4.7.2 Classroom #16b - Relocatable Classroom w/ East-West Axis and Shades

The shades in classroom #16b are mitigating the glare, pushing the MaxDF well below the threshold, but that comes at the expense of DA's below thresholds in the sunnier climates as well. Because the design does not have any daylight redirecting devices, the large solar resource of the sun is being wasted on clear days and the lower-luminance clear sky is the only resource. Overcast skies are brighter than clear skies, and therefore this classroom gets one daylight credit in Seattle but none in Boulder or Los Angeles.

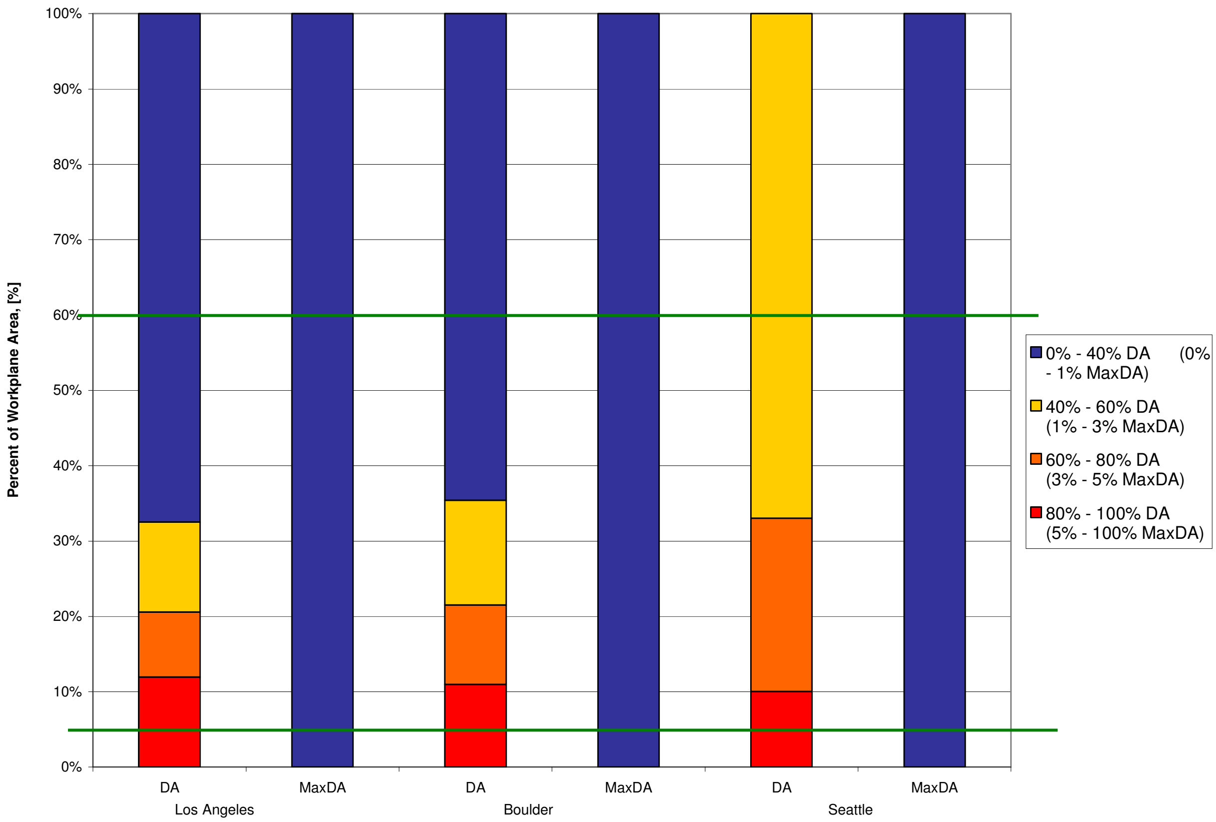

Figure 4-40: Classroom #16b Results

4.7.3 Classroom #17 – Relocatable Classroom w/ Six Skylights and Shades

In this example the same relocatable classroom design was used and six 2' x 4' skylights were added to the ceiling (see Figure 4-41). The skylights total 48sf of translucent glazing for a WWR of 5.0%.

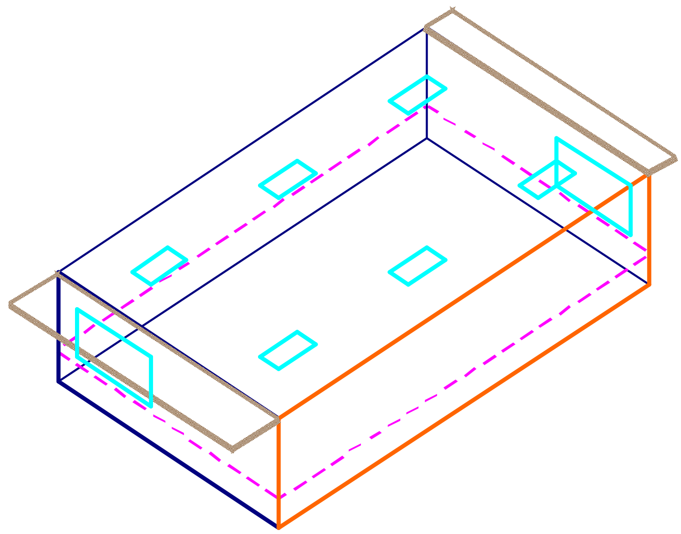

Figure 4-41: Classroom #17 Geometry

The skylight addition contributes a high quantity of diffuse illumination to the space, driving the DA's up with a negligible impact on MaxDA's. The MaxDA for Seattle is above threshold, likely due to the "doubling" effect of the east & west windows and the skylights located near them. Better placement and number of skylights in this design – more synergistic with the windows – could probably bring the MaxDA below threshold while still getting the two daylight credits that it already gets.

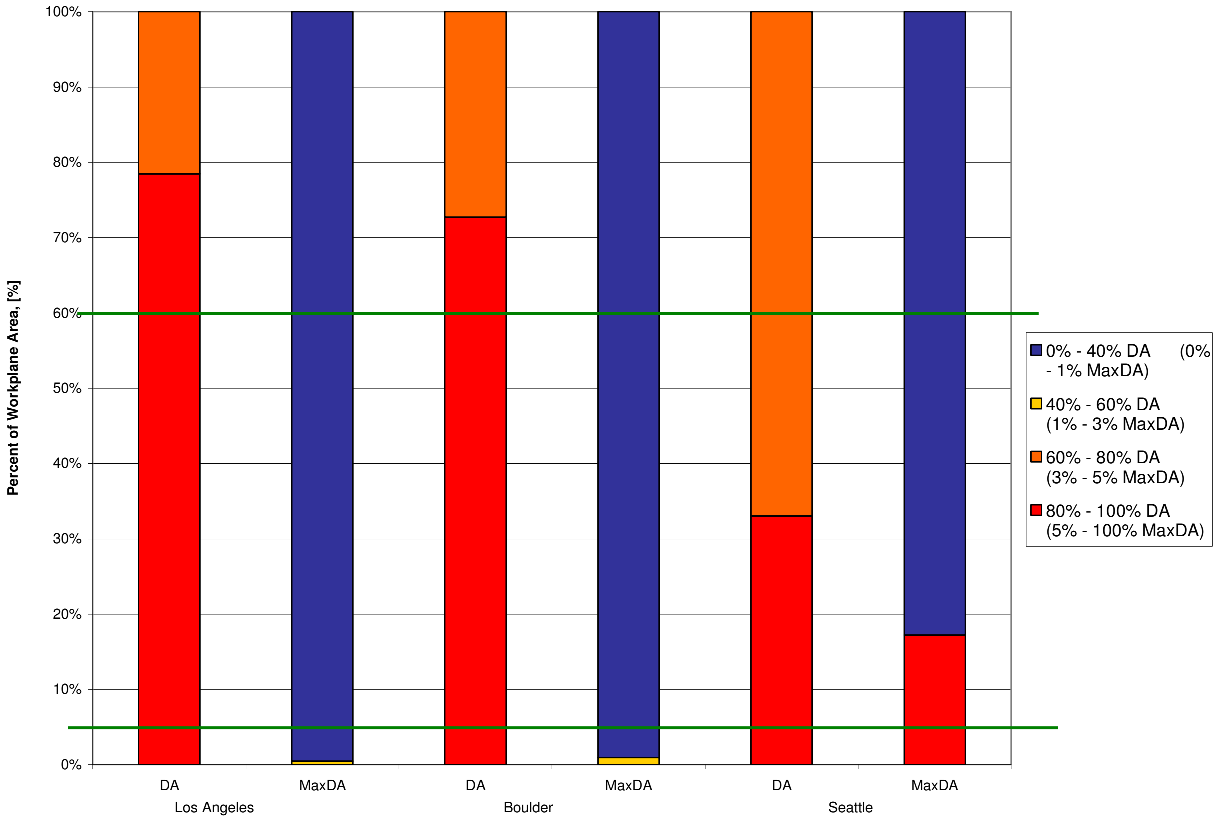

Figure 4-42: Classroom #17 Results

4.8 Modeling Conclusions

The test Classrooms modeled as part of this project represents several different classroom types and both good and bad daylighting examples. The breadth of the examples illustrates the ability of the proposed metrics to adequately quantify the quality of daylight in a given space. By comparing the DA and MaxDA distributions calculated for these test classrooms, many of which are known to have good or bad daylighting designs, the recommended thresholds for the CHPS Criteria is verified.

DA levels of 80% - 100% represent some of the excellent daylight designs, while good daylighting designs fall in the 60% - 80% DA range, and adequate daylighting designs fall in the 40% - 60% DA range. The MaxDA adequately quantifies the amount of glare in a classroom and is as important to the overall daylighting design as the DA. Classrooms with an 80% DA but a high MaxDA can not be considered a good daylight solution. The ideal MaxDA is 0%, representing no glare within the classroom and anything above 5% can be a serious problem. The requirement that the DA must be achieved for 60% of the workplane area ensures a more uniform daylight design and the requirement that the MaxDA must be less than 5% minimizes the potential for glare in a daylit space.

These proposed daylighting metrics are recommended for use in place of the static and overly simplified Daylight Factor (DF) approach. This report presents a broad definition of what comprises good daylighting, and illustrates through a series of comparisons of a variety of daylit classrooms, the ability of the proposed daylighting metrics to quantify the quality of daylighting.