# MODELLING FOR DAYLIGHT AUTONOMY FOR LEED V4 – IMPLICATIONS FOR CITIES IN NORTHERN LATITUDES

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## ABSTRACT

The daylight performance metrics and requirements in LEED Version 4 are increasingly applied to Canadian projects, either as an explicit target in separate documents defining requirements, such as for public-private partnership (P3) projects, or as a target that teams choose to pursue under the LEED Version 4 rating system. The required daylight levels in LEED Version 4 are identical throughout North America, however, the available daylight outside varies significantly based on latitude and local weather. In this research we use DIVA-for-Rhino to model spatial Daylight Autonomy (sDA) levels reached for the same building in 5 Canadian locations and 1 American location. This paper discusses the degree to which daylight performance is affected by latitude and weather in the respective locations, as well as the effect of floor plate depth and glare control devices. The paper includes a proposed alternative compliance path for projects located in northern latitudes to demonstrate compliance to LEED Version 4. The purpose of this alternative path is to incentivize daylight design in locations where occupants would benefit the most from increased access to daylight. This paper focusses on sDA requirements indicated in LEED Version 4; it does not provide an in depth analysis of other daylight requirements in LEED Version 4, such as annual sunlight exposure.

## INTRODUCTION

The benefits of daylighting to human wellbeing are well-documented and in recent years there has been increasing interest in providing this amenity to occupants in high-performance buildings. Access to quality daylight has positive physiological effects as it reinforces our natural circadian rhythm, leading to improved hormone regulation, higher levels of alertness, better digestion and improved sleep quality. For businesses, this translates to tangible benefits such as higher productivity, reduced employee sick time, improved employee morale and lower lighting costs (USGBC, 2013; WELL Building, 2015; Su &Yu, 2014). Daylighting is emphasized in leading green building standards, from the WELL Building standard to the Leadership in Energy and Environmental Design (LEED) rating system, but we also see it being requested on projects not pursuing such certifications. For example, in the authors' current work in building design and energy performance within the Canadian market, we are seeing an increase in the number of public-private partnership (P3) projects specifying daylight performance thresholds, a testament to the rising importance of this design strategy.

LEED Version 4 (LEED v4) and the WELL Building standard both incorporate credits in their respective certification systems to reward buildings that are designed to provide daylit spaces. Both rating systems follow the Illuminating Engineering Society's metric for measuring daylight sufficiency, where spaces are considered daylit if illuminance levels from daylight reach at least 300 lux for more than 50% of occupied hours (IES, 2012) specified at hours between 8AM and 6Pm. LEED v4 allows three compliance methods to achieve credit for daylighting: illuminance simulation, illuminance site measurement, and sDA and annual sunlight exposure simulation. Projects may earn 2 points using illuminance simulation or up to 3 points by field measuring illuminance levels post construction. While field measurement is fairly simple, credit achievement cannot be determined until the project is built and occupied. The third compliance method, the sDA simulation path, is the fastest and most cost-effective (Su & Yu, 2014; Reinhart, 2015) option for design teams, and allows for up to 3 LEED points to be achieved. Moreover, daylight simulation allows immediate feedback during an iterative design process and gives the project team flexibility to evaluate the interaction between daylighting and building energy performance targets. The USGBC is incentivizing the use of sDA in building design by providing more points for this option. However, daylight simulation for sDA is based on climate data, which is new to the industry, so designers are hesitant to adopt it in their projects.

Readers should note that while LEED v4 compliance via the sDA simulation path includes a requirement to model Annual Sunlight Exposure (ASE) values as a proxy for potential for visual discomfort resulting from daylighting. ASE simulation is outside the scope of this research paper. Refer to the discussion section where we provide additional commentary on the potential implications for ASE analysis.

Through daylight simulation modeling in DIVA-for-Rhino (DIVA, 2016), this paper models the amount of floor area that can achieve the specified sDA levels in 6 locations in North America and includes the interactive effects of glare control devices. In doing so, this paper includes a rule-of-thumb method to help designers estimate the feasibility of achieving the Daylighting credit in LEED v4, by using a visual tool with several floor plate depths. Our findings are especially significant to cities at more northern latitudes, such as Whitehorse and Inuvik. These cities experience the shortest winter daylight hours, yet it is here where building occupants stand to benefit the most from having well daylit buildings. In this paper, we provide more clarity and guidance to practitioners around daylight design in northern locations, and whether the LEED v4 daylight requirements are even achievable in northern latitudes.

We also suggest that different an alternative compliance path in LEED v4 may be needed to incentivize daylighting especially in higher latitude projects where there may be greater occupant benefit from this design strategy.

## METHODOLOGY

Simulations for daylight autonomy levels were run using DIVA-for-Rhino version 3.0 software based on a prototypical office space across 6 locations in North America. A prototypical office space (see Figure 1) was created with windows on one facade, and 4 simulations were run at each location, for the window facing North, East, South and West. Locations were chosen at varying latitudes as indicated in Table 1. As a convenient first indicator of the daylight availability in the selected locations, the table also shows the numbers of bright sunlight hours for each location. There is no source for the sunlight hours which lists all locations; the data for Inuvik and Whitehorse are sourced from *Atlas of Canada*, 1957, for Edmonton, Vancouver and Toronto from Environment Canada's website (Canadian Climate Normals, 2015), and for San Francisco from Wikipedia (*Sunshine Duration*, 2016). As expected, San Francisco receives significantly more sunlight because of its lower latitude; however, although Vancouver is lower in latitude compared to Edmonton, it nonetheless receives less sunlight hours because of its frequently overcast sky condition.

Both the LEED v4 reference guide and IES LM-83-12 approved method for sDA simulations state that simulations are to be based on local climate weather files, such as typical meteorological year data. The weather files used for the simulation are CWEC weather data for Canadian locations and TMY3 weather data for San Francisco. The weather files include metered data of observed light levels.

There are differences between CWEC and TMY3 data files. For example, CWEC is based on TMY2 methodology, which is based on 30 years of data, while TMY3 files are based on 15 years of data. While there is a difference between CWEC and TMY3 weather files, the respective file types were used at the locations as noted because the intent was to use typical files that would be used by a design team. As a result, the results presented here should be representative of what would be seen by a team in the calculations for LEED v4.

**Table 1** - Locations of Daylight Simulation (based on CWEC and TMY3 data)

| **Location** | **Latitude (°N)** | **Bright Sunlight Hours** |
|---|---|---|
| Inuvik | 68 | 1500 |
| Whitehorse | 60 | 1650 |
| Edmonton | 53 | 2345 |
| Vancouver | 49 | 1938 |
| Toronto | 43 | 2066 |
| San Francisco | 38 | 3062 |

The goal of the simulations is to calculate daylight levels for a typical office environment with a maximized window size, but not to include other specific design strategies to improve daylight (such as light shelves, light reflecting blinds, skylights, or clerestory windows).

The simulated office space has dimensions of 10m wide by 10m deep by 2.7m high, as shown in Figure 1, and located at grade. A depth of 10m from the window represents 4 typical workstations each of depth 2.5m. A width of 10m means that there is some effect from light reflecting off walls, but the results are expected to be more representative of an open office than a small enclosed office space. A ceiling height of 2.7m was chosen to represent a typical office space height. Glazing starts at 0.8m above finished floor, representing a typical sill height at desk level, and continues up to the ceiling. No external fixed shades are included. This office space is modeled 4 times in each location, with the window rotating to face North, East, South, and West in each simulation in order to gauge the daylight potential attributable to each orientation.

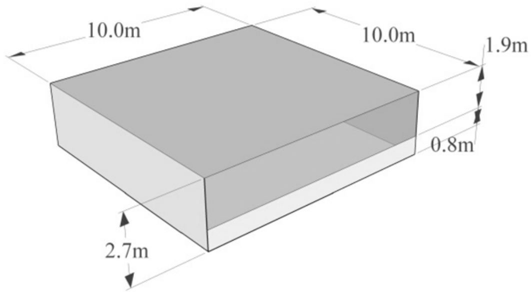


**Figure 1** – Geometry of modelled office space. For daylight simulation results in each cardinal direction, this geometry is rotated so that the window is facing the respective direction

Daylight simulation parameters were setup following IES LM-83-12 (IES 2013) approved methodology for analysis areas and points. All other modeling parameters are listed in Table 2 and are held constant for all simulation runs.

**Table 2**- Simulation Parameters for all simulation orientations and locations

| Parameter | Input Value |
|---|---|
| Exterior Glass Visible Transmittance | 65% |
| Ceiling Internal Reflectance | 70% |
| Wall Internal Reflectance | 50% |
| Floor Internal Reflectance | 20% |
| Outside Ground | 10% |
| Ambient Bounces | 6 |
| Ambient Division | 1000 |

LEED v4 requires that glare control devices be included for sDA simulations. Glare control devices are to be activated whenever more than 2% of the analysis points receive direct sunlight, where direct sunlight is defined as the condition when a beam of direct sunlight of more than 1000 lux is received at the analysis point. There is a wide variety of glare control fabrics, blinds, and shades available on the market, each with unique light transmission properties. In these simulations, blinds that reflected all direct sunlight and allowed only 25% of diffuse sunlight into the space were simulated – this is the default dynamic shading model used in DIVA for LEED v4 simulations.

LEED v4 also requires that furniture be included in sDA simulations, however, furniture was excluded in these simulations as this research seeks to examine only the impact of window orientation and project location on daylight levels. When modelling for compliance with LEED V4, furniture layouts and reflectance characteristics could have a significant effect on whether daylight values can be achieved for a project. For example, tall furniture partitions would prevent daylight from reaching into the space, and conversely, highly reflective work surfaces would allow daylight to reflect more deeply into the space.

## SIMULATIONS

Simulations were run to calculate the sDA values, or the percentage of floor area reaching illuminance levels of 300 lux for more than 50% of occupied hours between 8AM and 6PM, as specified by LEED v4 and IES LM 83-12, at each of the selected locations in Table 1. The space geometry described in Figure 1 was simulated at the four major orientations with the window facing to the South, East, West, and North. This first set of simulations included glare controls.

Secondly, simulations were repeated with the same conditions as above, except without glare controls in order to simulate the space without any shading devices. This gives a baseline understanding of how much daylight is available at each location and orientation, thus determining the effect of the shades on percentage floor area achieving 300 lux for 50% of occupied hours between 8AM and 6PM.

Lastly, simulations for Inuvik, Whitehorse and San Francisco, were repeated using an alternative schedule to include all hours between 8AM and 6PM when the sun was also up. This is as opposed to only between the operating hours of 8AM to 6PM as specified by LEED v4 and IES LM-83-12. This allows us to examine the implications of LEED v4’s specification of operating hours on projects in northern latitudes where few sunlight hours are experienced in winter time. For example, if a location had sunlight for only 1 hour in the day between 1PM and 2PM, that would be the only hour of the day included in the sDA calculation. Inuvik and Whitehorse were included as they represent the most northern locations, and San Francisco as it is the southernmost location in order to determine sensitivity of simulating using this alternative method.

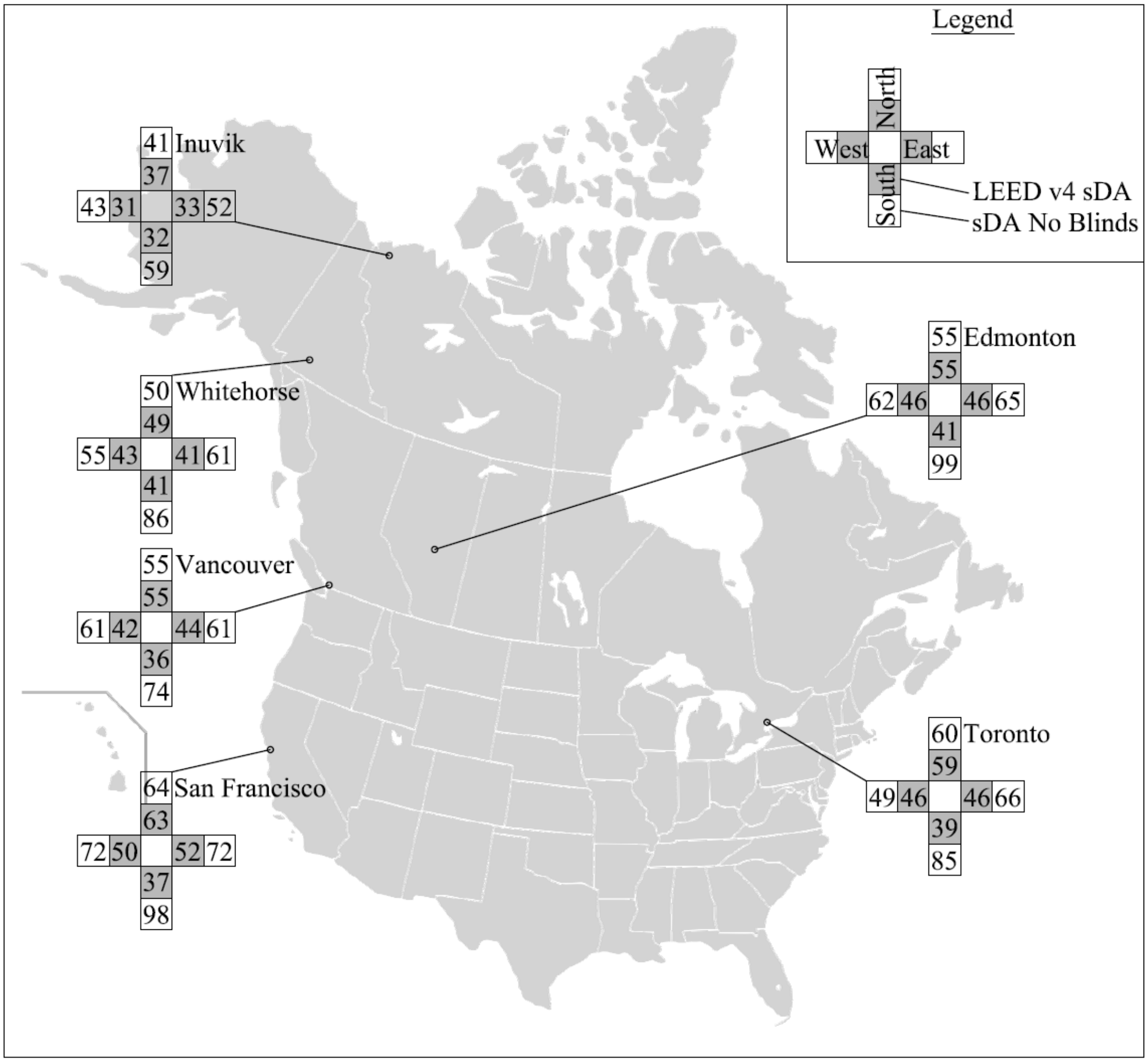


**Figure 2** –Simulation results for % of floor area achieving sDA targets with and without glare control devices/ blinds

## SIMULATION RESULTS

Figure 2 shows the sDa values, or percentage of floor area receiving 300 lux of luminance from daylight for at least 50% of operating hours between 8AM and 6PM. Each number at each orientation indicates the results based on simulating the window facing that orientation. Two sets of values are listed for floor areas achieving daylight autonomy levels: the shaded numbers indicate simulation results with glare control as per LEED v4 sDA requirements (with blinds); unshaded numbers represent results without glare control (without blinds).

Figure 3 shows additional simulation runs performed for San Francisco, Whitehorse and Inuvik. The listed results indicate the percentage of floor areas achieving the sDA target, both when the sun is up and within the operating hours of 8AM to 6PM. Figure 2 results in comparison are based only on the scheduled operating hours between 8AM and 6PM as per LEED v4 and LM-83-12 requirements.

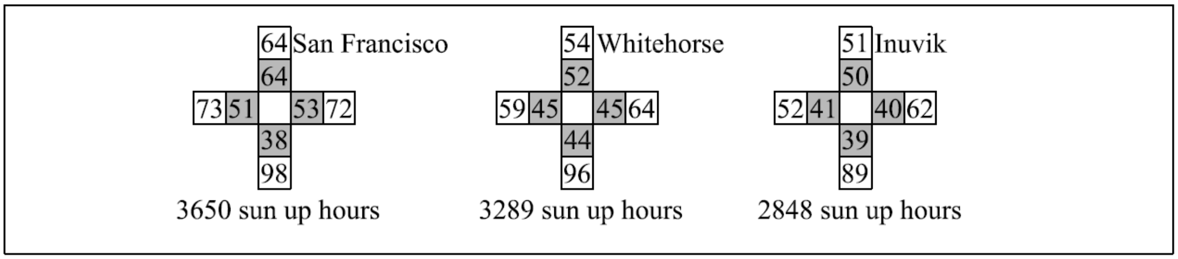


**Figure 3** –Simulation results for % of floor area meeting sDA targets based on sun-up hours between 8AM and 6PM, with and without glare controls

## DISCUSSION

To understand how the sDA simulation results relate to LEED v4 points, the overall percentage of daylight in a rectangular building can be estimated using the depth of daylight penetration indicated in Figure 2. For example, the east orientation in Edmonton has a LEED sDA of 46%, which means approximately 4.6m deep of daylight penetration into the 10m deep space.

Figure 4 shows the results of overlaying the daylight depths for each respective façade onto a generic rectangular office footprint. It is assumed that windows on all four sides of the office building follow the geometry shown in Figure 1. Figure 4 also shows the same daylight penetration applied on different floor plate depths: 5m, 7.5m and 10m deep. These results are high-level estimations, and are not a replacement for daylight simulations. However, Figure 4 gives designers a starting point to estimate how many LEED v4 points for daylight are possible at each respective location.

Looking at spaces oriented to the South, comparing glare control to no glare control, all locations show a significant reduction in sDA as a result of glare control. This means there is a lot glare and that the glare control device is blocking a lot of light. Consequently,the choice of blind fabric / material will have a significant impact on the amount of daylit area. As well, it suggests that the use of fixed external shading devices will be an effective strategy to remove glare from direct sun and allow the blinds to stay open longer. LEED sDA values are similar in all locations (32% to 40%) while the sDA with no shades has a wider range (59% to 99%) – this too indicates the significant impact that blinds have on sDA in South facing spaces. As indicated in Reinhart 2015, further research into blind controls is definitely warranted.

Looking at the sDA without blinds as one moves to more northern latitudes, the biggest reduction in sDA with occurs in Inuvik. Interestingly, Vancouver has a lower value than Whitehorse and Edmonton. Whitehorse and Edmonton are at a higher latitude and consequently have less annual sun-up time. However, the sun comes at a lower angle, bringing light deeper into the space. As well, Vancouver has a significant amount of cloudy weather that reduces the amount of available daylight.

Looking at spaces oriented to the North, blinds are rarely activated. Inuvik is the location with the largest sDA reduction due to blinds and this is because Inuvik is above the Arctic Circle, with sunlight occasionally coming from the North. The sDA value without blinds generally drops as the latitude increases.

Looking at spaces oriented to the East and West, sDA values are within a few percentage points of one another. The lowest LEED sDA values are in Inuvik at 31% and 33% compared to San Francisco at 50% and 52%. The locations between San Francisco and Inuvik do not follow a clear trend by latitude, which suggests that sDA is significantly influenced by the weather.

In LEED v4, the threshold for the daylight credit is for 55% of daylit floor area to achieve 2 points and 75% for 3 points. Looking at Figure 2, one can see that despite having desk to ceiling glazing, it is nearly impossible for a project in Inuvik achieve 3 points.

Compared with San Francisco, there is less floor area meeting LEED v4 sDA requirements in all 5 Canadian locations simulated. This appears to be an unintended bias introduced by LEED's adoption of IES LM-83-12 method for basing daylight autonomy solely between the operating hours of 8AM to 6PM. Not every LEED credit is suitable or practical for every project, however, the larger goal of LEED is to incentivize the market towards better design. The way this credit is structured may even be a disincentive to target a well daylit design for projects in Canada, particularly in the most northern locations. It is here where occupants stand to gain the most health benefit from having access to daylight during the few hours that it is available.

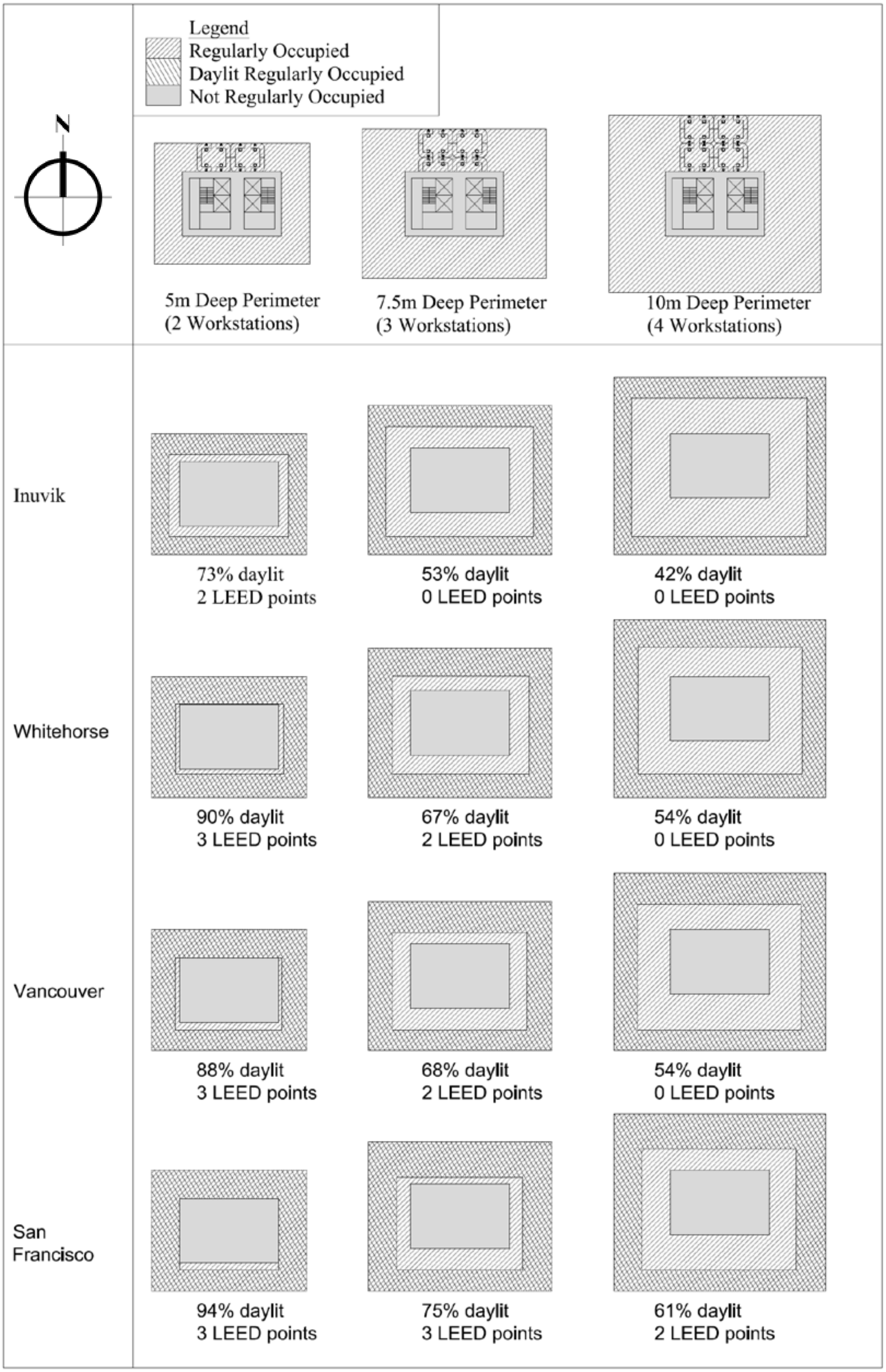


**Figure 4** – Estimated Daylit Area for an Open Office
Based on an overlay of the simulated daylit depth for each respective orientation, LEED sDA results from Figure 2

A possible response is to provide an alternative compliance path for projects in northern, allowing compliance using an occupancy schedule that follows sunlight hours – results as presented in Figure 3. This strategy brings Inuvik's daylit area more closely in line with other Canadian locations and allows more opportunity to achieve daylight credits in LEED v4. As seen in Figure 3, this method would slightly improve the sDA values for Whitehorse, while there is negligible change to the sDA values for San Francisco.

We caution that the daylighting credit in LEED also has a requirement for calculating Annual Sunlight Exposure (ASE) in addition to sDA. ASE describes the potential for visual discomfort from daylighting. In LEED v4 ASE is capped at a maximum of 10% of floor area being exposed to illuminance levels of less than 1000 lux for more than 250 hours annually between 8AM to 6PM. The sDA value indicates whether the building has sufficient access to daylight, while ASE indicates if that light is too bright and likely to cause discomfort. This paper has not taken ASE into account. Following LM-83-12, blinds and shades are not deployed in the ASE analysis, however, exterior and interior obstructions from the building form are included. Because blinds are not included in ASE calculations, LEED daylight requirements favour building geometry, fixed shades, as well as window size as a means to control ASE. While this research has focused on the understanding the available light (sDA) in buildings in the North, projects pursuing LEED certification will also need to give consideration to ASE and the visual discomfort due to direct light.

## CONCLUSIONS

As expected generally, there is a noticeable reduction in the LEED sDA daylit area in a typical office floor plate as one moves northwards. This effect is most obvious for Inuvik, a location that is North of the arctic circle. But it is also noticeable for the other Canadian locations simulated. The simulation results suggest that projects in Inuvik will achieve 2 LEED v4 credits if they have regularly occupied spaces within 5m of the perimeter, and that projects will not likely achieve 3 credits. Results suggest that projects elsewhere in Canada will need to have regularly occupied spaces less than 7.5m deep from the perimeter in order to achieve 3 points. In comparison with a project in San Francisco, Canadian projects need shallower floorplates to achieve the same number of LEED daylight points.

For spaces oriented South in all locations, there is a lot of glare, so glare control devices are frequently turned on per LM-83-12. Consequently, the light transmission properties of the glare control device will be important for design teams to consider. As well, results suggest there is opportunity to increase sDA through use of fixed external shades.

An alternative compliance path was investigated for northern climates to demonstrate LEED daylight compliance. The goal of this alternative path is to incentivize daylighting in locations where occupants stand to gain the most health benefit. This alternative method was based on reducing the sDA operating hours to be within both sun-up periods as well as 8-6 operational hours. This alternative was seen to make noticeable benefit for projects in Inuvik and a lesser impact in other Canadian locations.

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