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EVALUATING GLOBAL DAYLIGHT METRICS

A Comparative Analysis

Presenters:
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AGENDA

Overview of Daylight Assessment

Daylight Factor, Daylight Coefficient and the rise of Climate-based daylight modeling.

Climate-based Daylight Metrics

Daylight Autonomy, Continuous Daylight Autonomy, Useful Daylight Illuminances, Spatial Daylight Autonomy and Annual Solar Exposure.

CBDM Daylight Assessment Methods

Assessment period, daylight requirements and the inclusion of shading devices in daylight assessment.

Complications of Daylight Metrics

The problem of applying one daylight metric uniformly across one region.

Case Study

A comparative assessment of EN17037 and LM83 in four Canadian climates across three building types.

Conclusion

Research limitations and further research directions.

WHY STUDY DAYLIGHT METRICS?

Benefits of Daylight

Daylight offers numerous benefits such as enhancing health and well-being and reducing building energy consumptions.

Significance of Daylight Metrics

Metrics are essential for accurately assessing daylight performance.

Accurate Daylight Assessment

Understanding how daylight performance is assessed can improve how we measure daylight and ensure it meets modern standards and expectations.

DAYLIGHT ASSESSMENT TIMELINE

1911 — **1983** — **2000**

STATIC ASSESSMENT

Daylight Factor (DF) was the earliest attempt to assess daylight sufficiency and has been undisputedly used ever since.

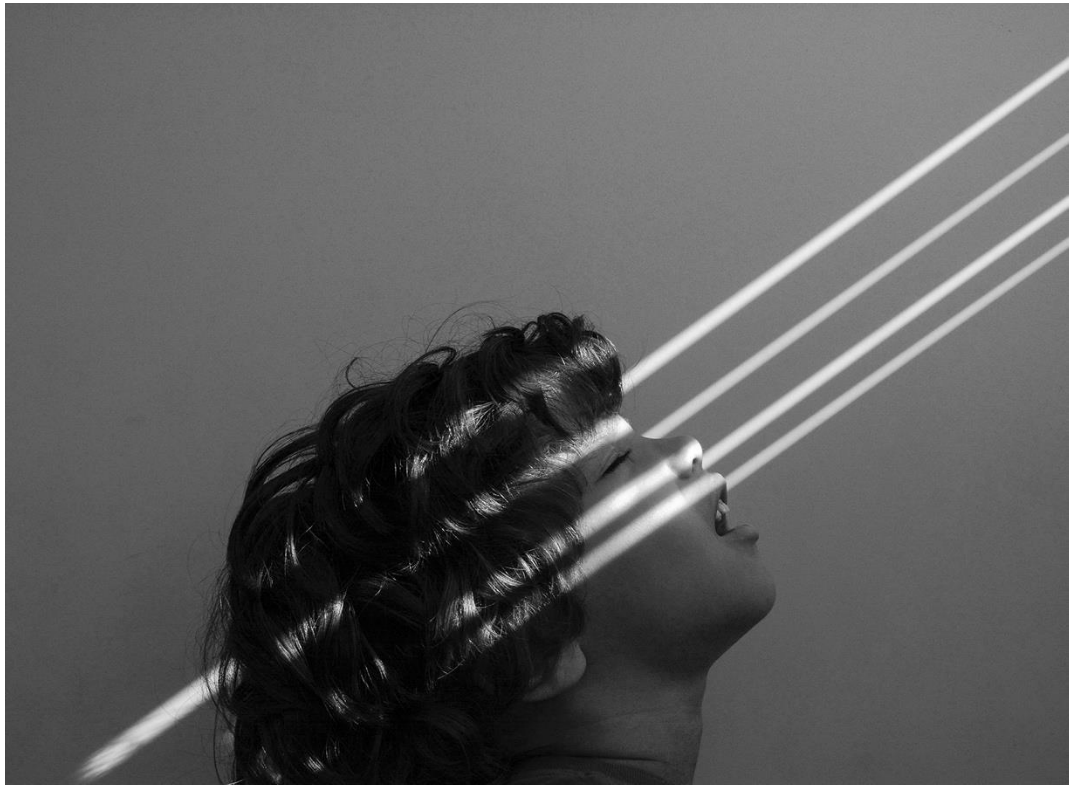
DYNAMIC ASSESSMENT

Daylight Coefficient (DC) was introduced to address the oversimplified DF method and to accelerate the calculations under different sky conditions.

CLIMATE-BASED METRICS

Based on DC, CBDM tools provide hourly illuminance data at control points throughout the year that were climate dependent, location dependent and orientation dependent.

INTRODUCTION TO DAYLIGHT FACTOR (DF)



Definition: The ratio of internal illuminance at a point in a building to the unshaded, external horizontal illuminance under an overcast sky.

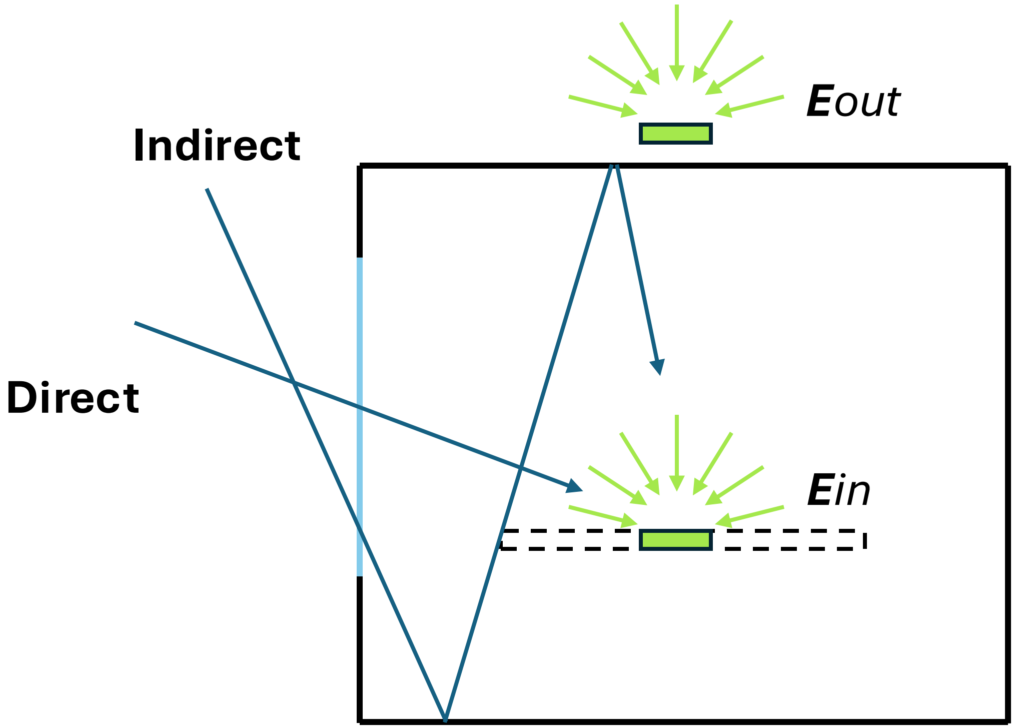
Historical Background: In early days, illuminance ratios were primarily used as legal evidence in court as legal rights of light. Therefore, daylight factor was never meant to be a measure of good daylighting design but a minimum legal lighting requirement.

DAYLIGHT FACTOR (DF) CALCULATION & USAGE

DF = Ei/ Eo

Where:
- Ei is the indoor illuminance
- Eo is the outdoor illuminance from a sky of known luminance distribution, excluding direct sunlight.

Usage: DF is easy to understand and calculate (raytracing, BRE equation), leading to its use in codes and standards in the UK and Europe.



DAYLIGHT FACTOR (DF) REQUIREMENTS

2%

Daylight Factor Threshold: Typically, a daylight factor of 2% is considered as a threshold by many metrics including the early LEED rating system.

Example Calculation:

- 500 lx on the work plane is often recommended for office work.
- Assuming an outside illuminance of around 10,000 lx under an overcast sky.
- Daylight Factor = 500 lx / 10,000 lx
- **Daylight Factor = 2%**

LIMITATIONS OF DAYLIGHT FACTOR (DF)

1

STATIC NATURE

Reports instant daylight conditions under overcast sky, disregarding direct sunlight and changing weather conditions.

2

CONTEXT SENSITIVITY

Does not account for building orientation, geographic location, sun position, or daily/seasonal changes.

3

DESIGN LIMITATIONS

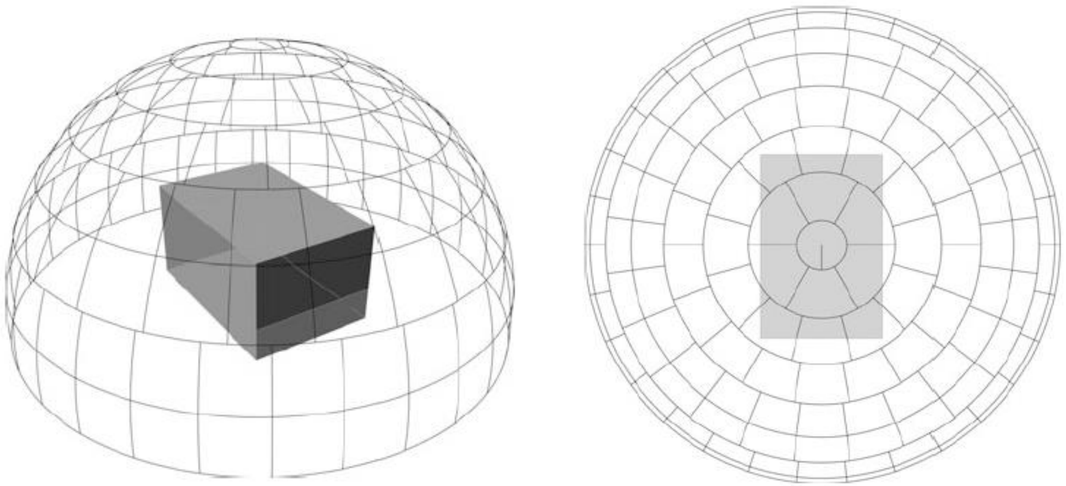
Does not support glare prevention strategies, evaluation of dynamic shading devices, or considerations of building type and occupant requirements.

INTRODUCTION TO DAYLIGHT COEFFICIENT (DC)

Definition: Mathematical functions that relate the luminance distribution of the sky to the illuminance at a point in a room.

Historical Background: The Daylight Coefficient method was introduced to address the limitation of the static Daylight Factor. It allows for more dynamic and accurate daylight assessments under various sky conditions.

DAYLIGHT COEFFICIENT (DC) SKY MATRIX



Example of Tregenza's sky matrix consisting of 145 patches.

Sky Matrix: Tregenza divided the sky hemisphere into 145 circular patches. Reinhart and Walkenhorst further developed this by creating ellipsoid patches.
Method Overview: The Daylight Coefficient method uses matrix-based operations and Finite Element Methods to calculate internal illuminance for multiple points.

DAYLIGHT COEFFICIENT (DC) CALCULATIONS

$$DC\alpha(\mathrm{x}) = \frac{E\alpha(x)}{L\alpha \cdot \Delta\, S\alpha}$$

Where:

- (x) is a point in space.
- (α) is the sky patch.
- $E\alpha(x)$ is the internal illuminance at point (x) due to sky patch (α).
- $L\alpha$ is the sky patch luminance.
- $\Delta S\alpha$ is the solid angle of the sky patch.
- $DC\alpha(x)$ is the amount sky patch a contributes to the internal illuminance at point (x) per unit luminance and solid angle $(\Delta S\alpha)$.

$$E(x) = \sum_{\alpha=1}^{N} DC\alpha(x) \cdot L\alpha \cdot \Delta S\alpha$$

Where:

- $E(x)$ is the total internal illuminance at point (x) with the contributions from all sky patches.

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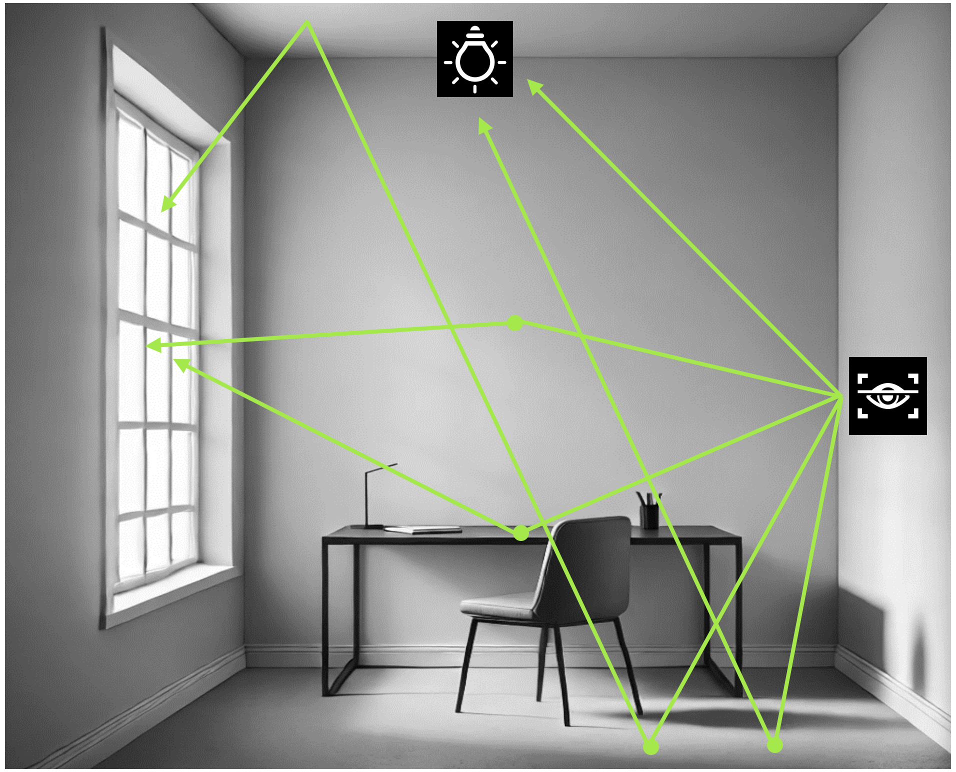
COMPUTATIONAL TECHNIQUES FOR DAYLIGHT COEFFICIENT (DC)



Example of raytracing (backward) calculation method.

Raytracing: Raytracing sets the foundation for practical computation of DC.

Benefits: Raytracing reduces the computational load required for annual DC calculations. The DC method can estimate internal illuminances and reflected sunlight for various sky models, considering space geometry, external obstructions, internal surfaces, and glazing properties.

ADVANTAGES OF DAYLIGHT COEFFICIENT (DC)

1

Accuracy

Daylight coefficient method improved accuracy to climate over traditional static Daylight Factor method.

2

Dynamic Assessment

It allows for dynamic assessment, considering varying sky conditions, latitude, time of the year, hour of day and weather conditions.

INTRODUCTION TO CLIMATE-BASED DAYLIGHT MODELING (CBDM)

Definition: CBDM involves using physically based daylight simulation tools to quantify absolute illuminance values considering the variability of sky luminance distributions from representative weather data.

Historical Background: Established in 2000 by Mardaljevic (2000) and Reinhart & Herkel (2000).

TECHNOLOGY ADVANCEMENTS AND GROWTH OF CBDM

1

ENHANCED COMPUTING POWER

Enhanced computing power at affordable prices.

2

PROFICIENCY IN 3D CAD TOOLS

Widespread proficiency in 3D CAD tools among architecture students.

3

USER-FRIENDLY INTERFACES

User-friendly interfaces for generating building models and conducting daylight simulations.

ADVANTAGES OF CBDM

1

Dynamic Assessment

It enables project development that responds to unique solar and weather of the project site. It considers daily and seasonal variations of daylight.

2

Dynamic Daylight Apertures

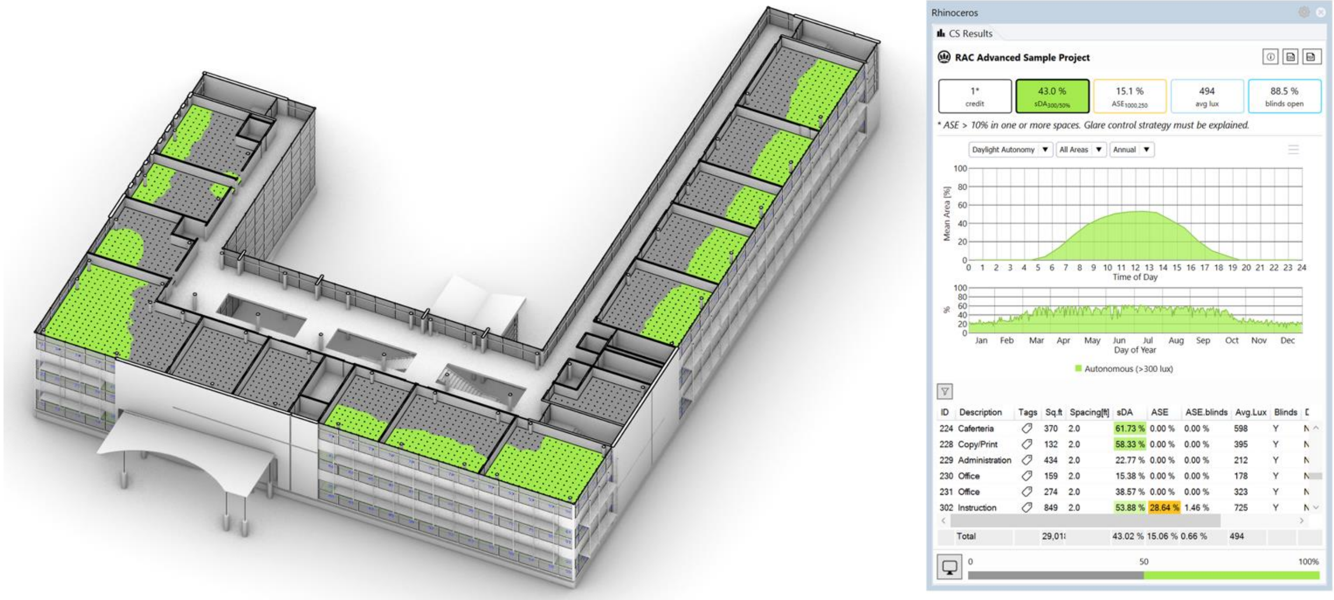
It facilitates the implementation of dynamic daylight apertures, such as automated shading devices.

3

Enhanced Visualization and Communication

It includes advanced visualization capabilities through simulations, renderings and graphical representations.

CBDM & TRADITIONAL METHODS



Example of CBDM (Solemma, ClimateStudio).

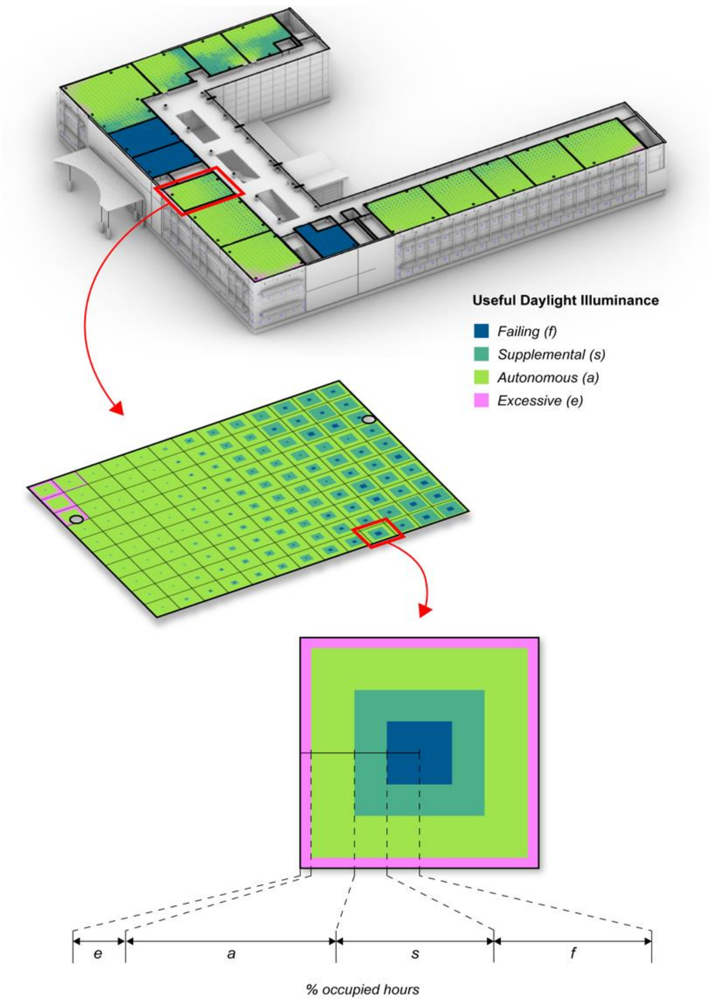
Temporal Assessment: Unlike static daylight factor assessments, CBDM requires temporal assessments over specified intervals.

Simulation Time: CBDM uses the daylight coefficient approach to reduce simulation time.

Dynamic Assessment: CBDM considers various factors, including location, orientation, geometry and material properties.

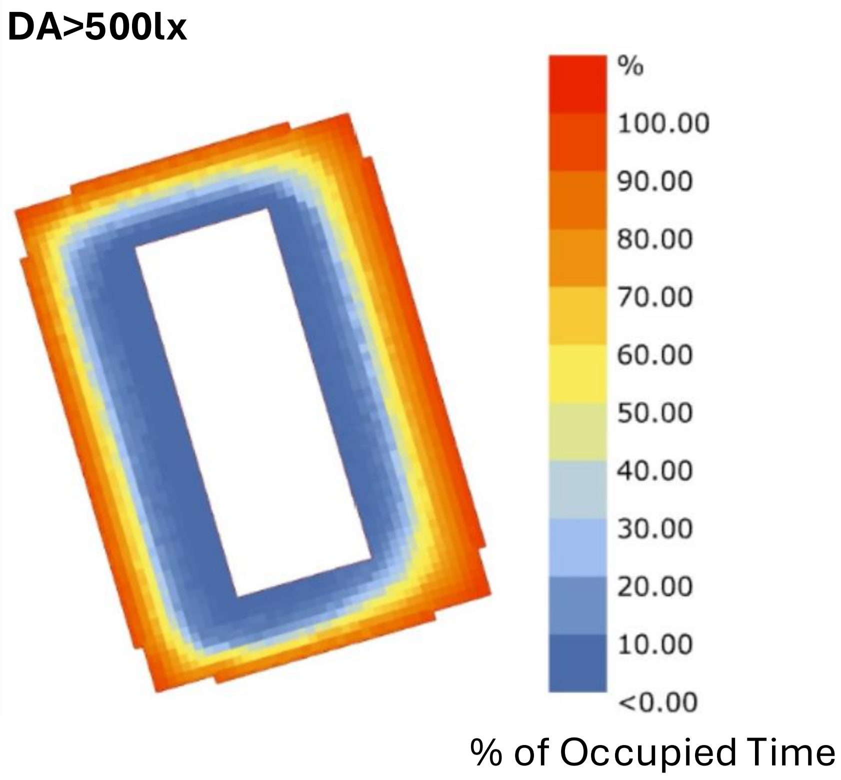
INTRODUCTION TO CBDM METRICS

Static Metrics: Static metrics define instant conditions under individual sky, neglecting the effect of the changing climate.
Dynamic Metrics: Dynamic metrics report long-term performance considering timeseries of sky luminances. These metrics incorporate temporal and spatial criteria to quantify internal daylight, describe direct sunlight penetration, and estimate glare-induced discomfort.



Example of CBDM metric, UDI (Solemma).

DAYLIGHT AUTONOMY (DA)



Example of DA assessment (Ladybug).

Background

Daylight Autonomy (DA) was introduced in 1989 and later refined by Reinhart & Walkenhorst in 2001.

Definition

The percentage of occupied times of the year when a minimum work plane illuminance threshold can be maintained by daylight alone.

Limitations

It does not consider target illuminance below the limit, indicating higher energy demand, or above the limit, which can cause visual discomfort.

CONTINUOUS DAYLIGHT AUTONOMY (CDA)

Background

Continuous Daylight Autonomy (DA) was proposed in 2006 by Rogers & Goldman to address the binary threshold approach of DA.

Definition

The percentage of occupied times of the year when a minimum work plane illuminance threshold can be maintained by daylight alone. CDA assigns partial credit to illuminances below the suggested limit.

DA & CDA

DA assigns partial credit to illuminances below the suggested limit, recognizing underlit conditions and provide a more nuanced view of daylight performance.

EXAMPLE CDA CALCULATIONS

- Illuminance threshold : 500 lx
- Illuminance level: 300 lx
- CDA credit = Illuminance level / Illuminance threshold
- CDA credit = 500 lx / 300 lx
- CDA credit = **0.8**

MAXIMUM DAYLIGHT AUTONOMY (DAmax)

Background

Maximum Daylight Autonomy (DAmax) was proposed in 2006 by Rogers & Goldman to consider over-lit conditions.

Definition

The percentage of occupied times of the year when the illuminance levels exceed ten times the predefined threshold.

USEFUL DAYLIGHT ILLUMINANCE (UDI)

Background

Useful Daylight Illuminance (UDI)was developed by Nabil and Mardaljevic in 2006 to determine the usefulness of daylighting conditions.

Definition

The percentage of occupied times of the year when Useful Daylight Illuminance was achieved, fell-short, or exceeded. The three thresholds determine the usefulness of daylight and address issues of underlit and over-lit spaces.

UDI & DA & CDA

Compared to DA and CDA, UDI offers more detailed information on visual and thermal discomfort but can be more complex due to its three metrics per calculation point.

USEFUL DAYLIGHT ILLUMINANCE RANGES

- Achieved: 100 -2000 lx
- Fell-short: < 100 lx
- Exceeded: > 2000 lx

Ranges founded on reported occupant preferences in daylit offices.

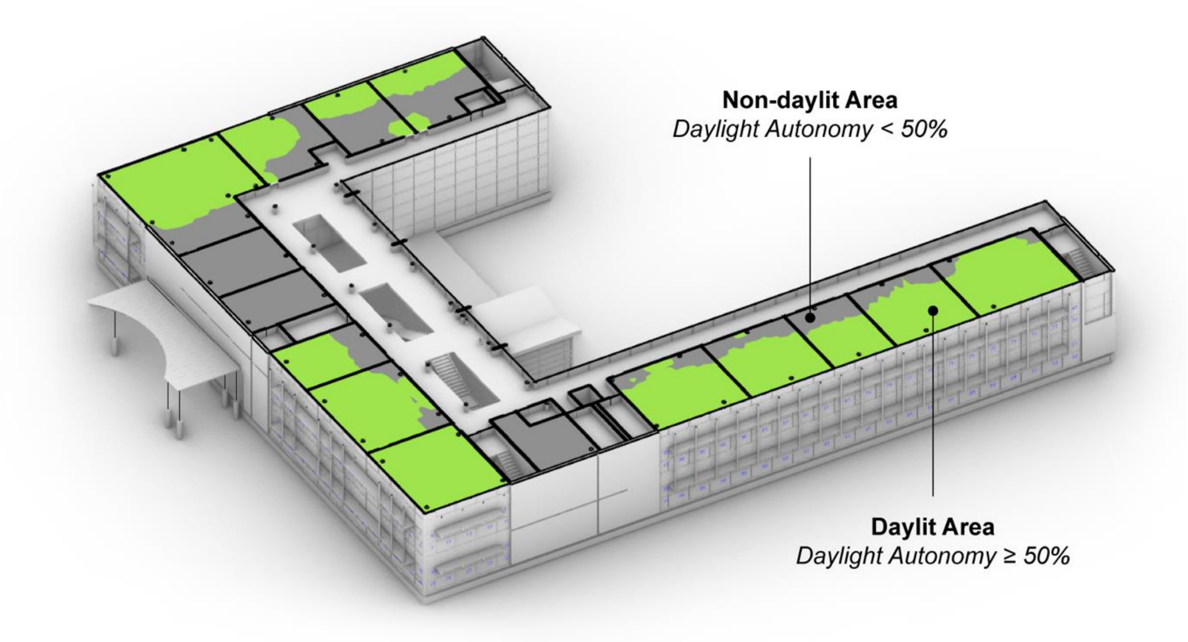
SPATIAL DAYLIGHT AUTONOMY (sDA)

Background

In 2012, IES LM 83 expanded former temporal metrics with spatial consideration, introducing sDA and ASE.

Definition

Spatial Daylight Autonomy or **sDA300/50%** measures the percentage of space receiving 300 lx for 50% of annual occupied hours.



ANNUAL SOLAR EXPOSURE (ASE)

Background

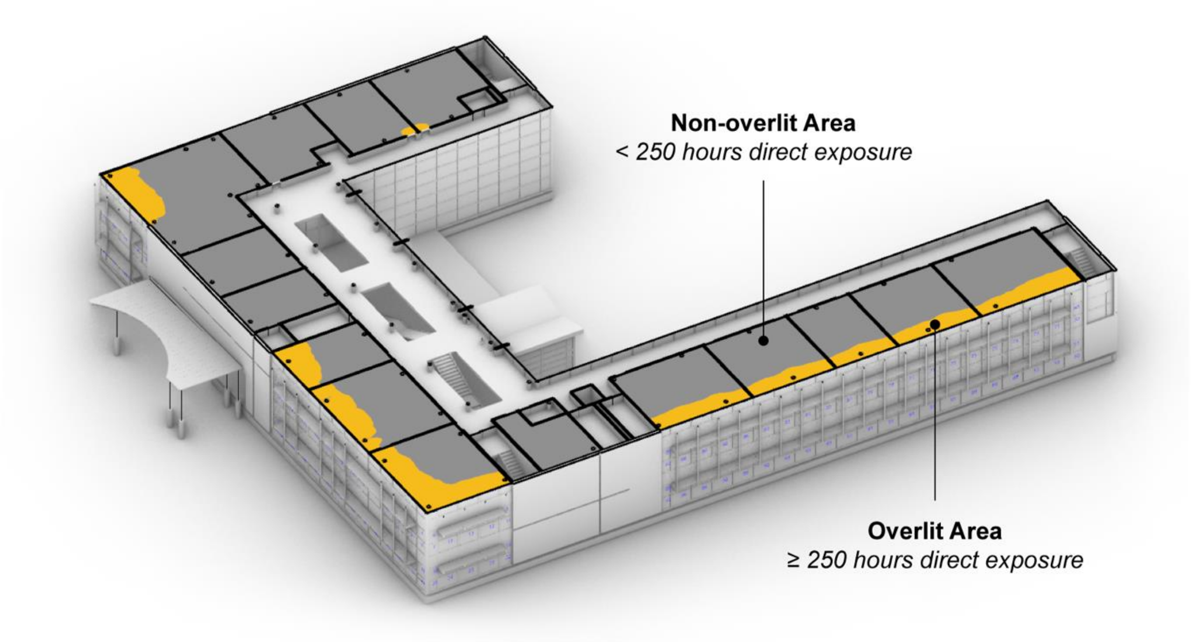
In 2012, IES LM 83 expanded former temporal metrics with spatial consideration, introducing sDA and ASE.

Definition

Annual Solar Exposure or ASE1000/250h measures the percentage of space receiving 1000 lx for 250 hours annually.

Application

Both ASE and sDA are based on field research and are used in standards like LEED v4 and WELL Building Standards for daylight credits.



DAYLIGHT METRIC REQUIREMENTS

1

Assessment Period

Daylight metrics typically consider two types of assessment periods: Daylit hours during the year and Occupied times of the year.

2

Daylight Requirements

Daylight requirements in metrics are typically defined by three criteria: illuminance, time, and spatial thresholds.

3

Employment of Dynamic Blinds

Daylight requirements in metrics usually consider two types of shading devices: static and dynamic

DAYLIGHT ASSESSMENT PERIODS

1

Daylight Hours

Daylight hours are directly linked to the building site and remain constant. However, they don't account for changing occupancy patterns or building use.

2

Occupied Hours

Occupied hours reflect the interplay between natural light and occupant needs. Daylighting needs witnesses to be appreciated.

DAYLIGHT REQUIREMENTS

1. **Illuminance Threshold**
   Illuminance thresholds typically include target, minimum and maximum levels.

2. **Time Threshold**
   Time thresholds determine the percentage of time that the space mees these illuminance criteria.

3. **Spatial Threshold**
   Occupied Spatial thresholds, like those used in sDA and ASE metrics, assess the percentage of space that meets both illuminance and time criteria.

DYNAMIC SHADES

1

Static Shading Devices

Static shading devices, such as light shelves, are often included in daylight assessments without further attention.

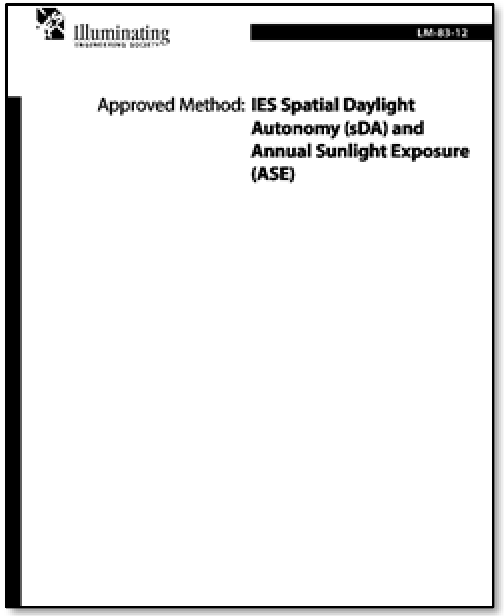
2

Dynamic Shading Devices

Dynamic devices, like venetian blinds, are handled differently across metrics. Some metrics exclude them, especially for glare assessments, while others include them for a realistic depiction of daylight conditions. Additionally, some metrics require annual illuminance profiles for different shading settings to assess their impact.

METRICS COMPARISON

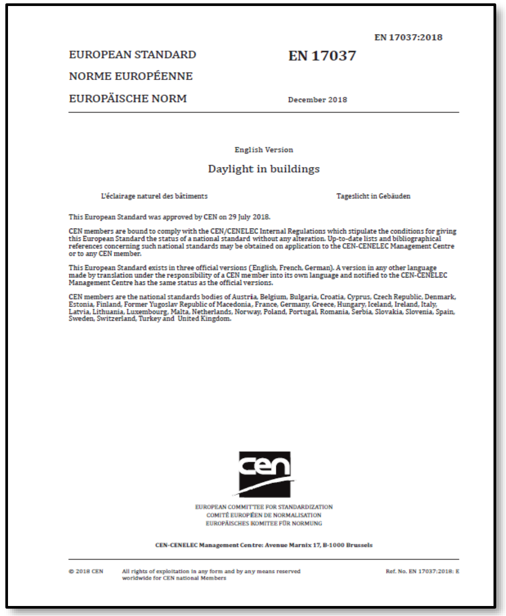
1


Illuminating
LM-83-12
Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)

IES – LM 83 - 2012

Spatial daylight autonomy and annual solar exposure.

2


EN 17037:2018
EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM
EN 17037
December 2018
English Version
Daylight in buildings
L'éclairage naturel des bâtiments
Tageslicht in Gebäuden
This European Standard was approved by CEN on 29 July 2018.

CEN – EN 17037 - 2018

Minimum, medium and high recommendation system for daylight.

Comparison Categories

- Assessment Periods
- Daylight Requirements
- Shades Employment

METRICS COMPARISON – ASSESSMENT PERIOD

EN 17037

EN 17037 adapts its analysis period to climatic variations by selecting **the 4,380 hours with the greatest diffuse horizontal illuminance**.

LM 83

LM 83 uses a consistent analysis period from **8 am to 6 pm every day of the year.**

METRICS COMPARISON – DAYLIGHT REQUIREMENT

EN 17037

	Minimum	Medium	High
Target Illuminance (lx)	300	500	750
Fraction of space for target level (%)	50	50	50
Minimum target Illuminance (lx)	100	300	500
Fraction of space for minimum target level (%)	95	95	95
Fraction of daylight hours (%)	50	50	50

EN 17037 minimum, medium and high recommendations for interior daylight illuminance.

LM 83 - sDA & ASE

- sDA300/50% evaluates the percentage of space achieving a minimum of 300 lux from daylight for at least 50% of the analysis period.
- The daylight performance is categorized as "preferred" if 75% of the space meets sDA300/50% and "nominally acceptable" at a 55% threshold.
- ASE1000,250h measures the potential for visual discomfort by identifying areas exposed to over 1,000 lux from direct sunlight for more than 250 hours annually.

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METRICS COMPARISON – BLINDS EMPLOYMENT

Example of dynamic blinds in an office building (Enviroscreen).

EN 17037

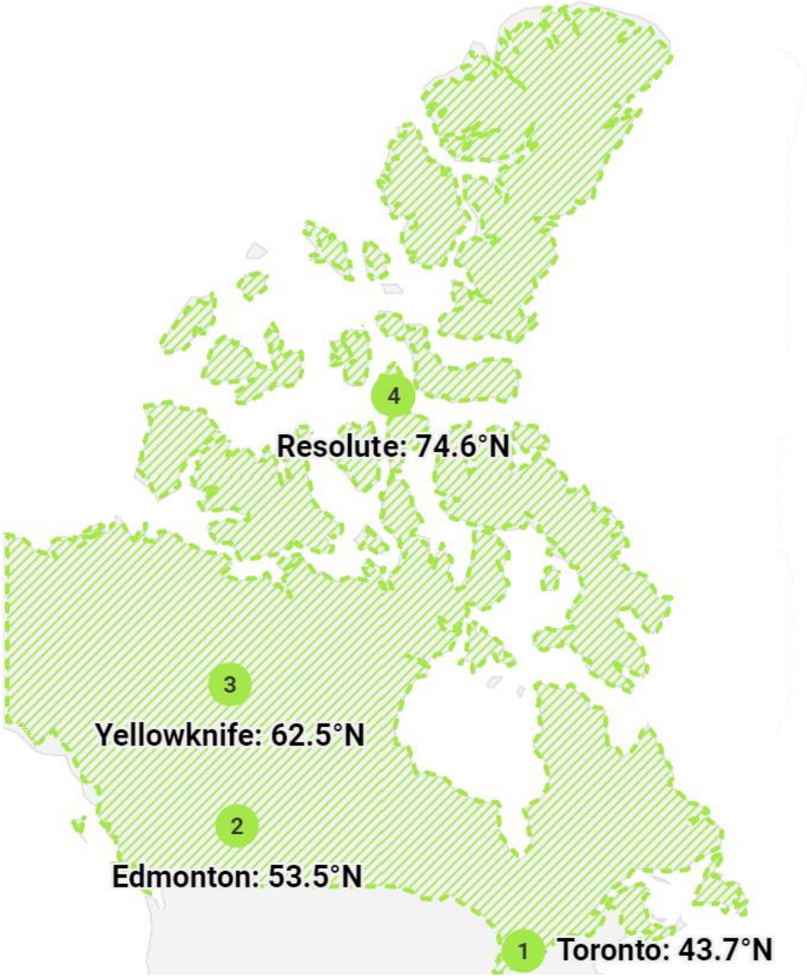
EN 17037 does not factor in the use of dynamic shades or blinds in its daylight assessment, focusing on natural daylight levels achieved.

LM 83

LM 83 incorporates the operation of blinds and shades, adjusting them hourly to manage direct daylight for sDA calculations. For ASE calculations, shading devices are not considered to assess potential discomfort from unmitigated direct sunlight.

COMPLICATIONS OF METRICS

Latitude: EN 17037 The variation in daylight is influenced by latitude. It determines sunlight duration and elevation. Locations further away from the equator receive daylight at a more oblique angle with shorter duration.



Example of Canada's latitude diversity.

AVERAGE DAYLIGHT HOURS IN JANUARY

9 hours
TORONTO

8 hours
EDMONTON

0 hours
RESOLUTE

AVERAGE DAYLIGHT HOURS IN JUNE

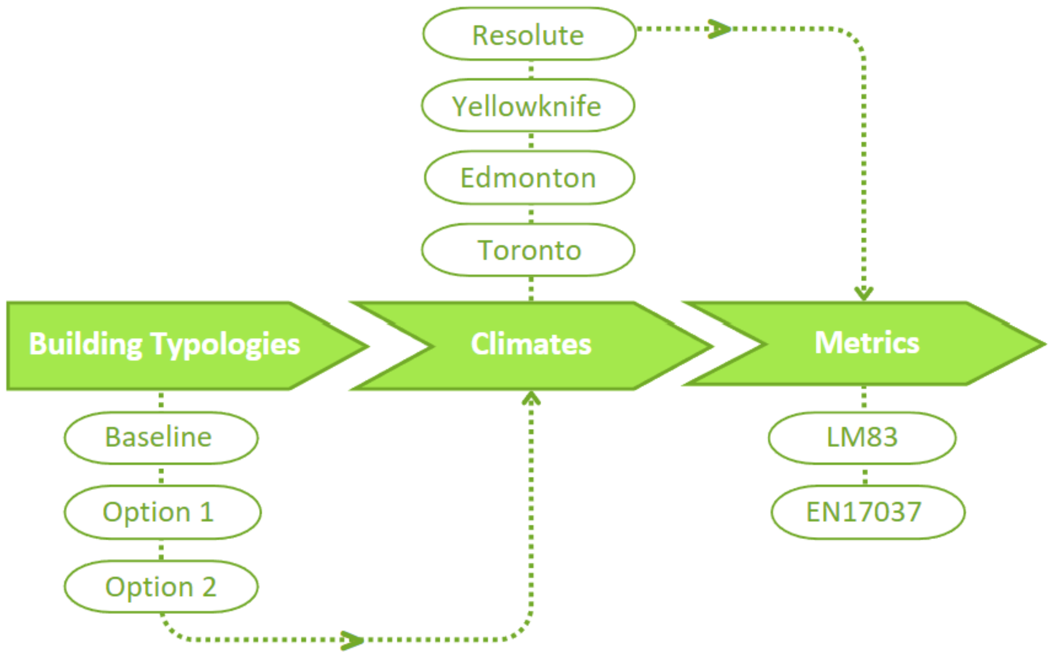
15 hours
TORONTO

16 hours
EDMONTON

24 hours
RESOLUTE

RESEARCH CASE STUDY

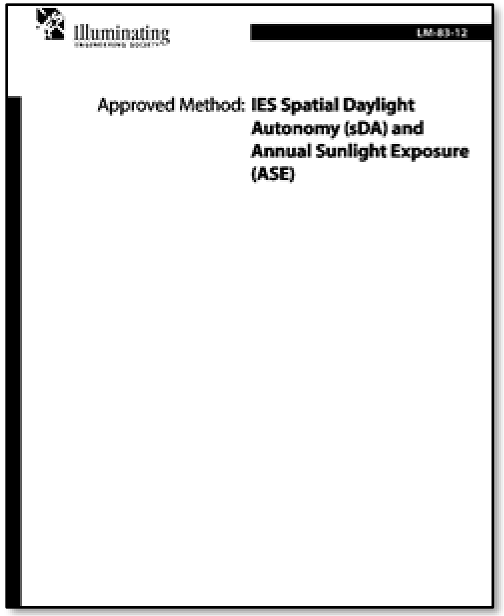
Research Case Study: Research evaluates the appropriateness of global daylight metrics in the Canadian context. The methodology is structured into several key components: daylight metrics, building designs, climate locations, simulation tools, and analysis process.



Workflow diagram for the example case study.

RESEARCH CASE STUDY - METRICS

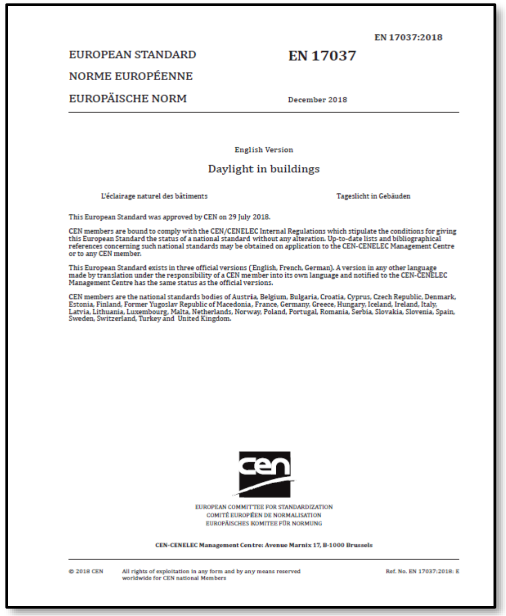
1


Illuminating
LM-83-12
Approved Method: **IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)**

IES – LM 83 - 2012

Spatial daylight autonomy and annual solar exposure.

2


EN 17037:2018

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 17037

December 2018

English Version

Daylight in buildings

L'éclairage naturel des bâtiments — Tageslicht in Gebäuden

This European Standard was approved by CEN on 29 July 2018.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

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CEN – EN 17037 - 2018

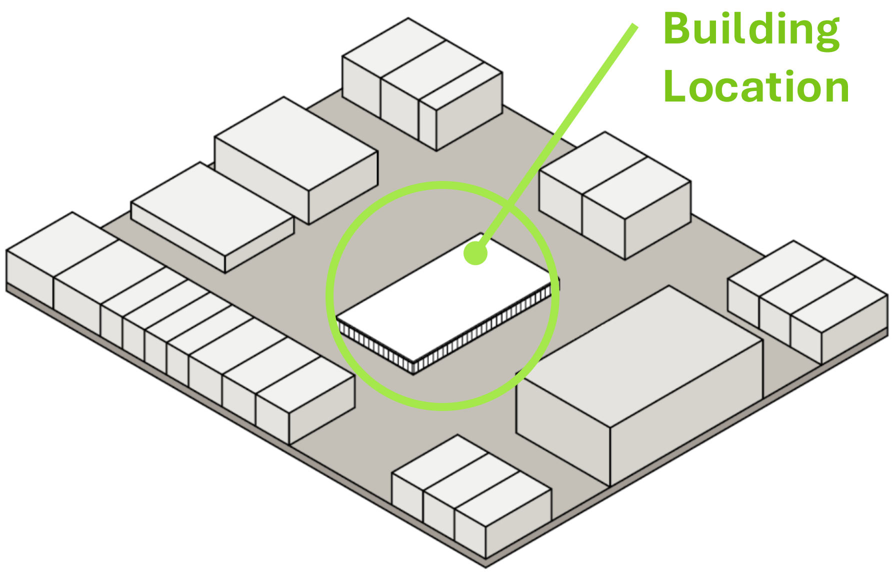
Minimum, medium and high recommendation system for daylight.

Selection For:

- International recognition.
- Differing approaches to daylight evaluation.

RESEARCH CASE STUDY – BUILDING SITE

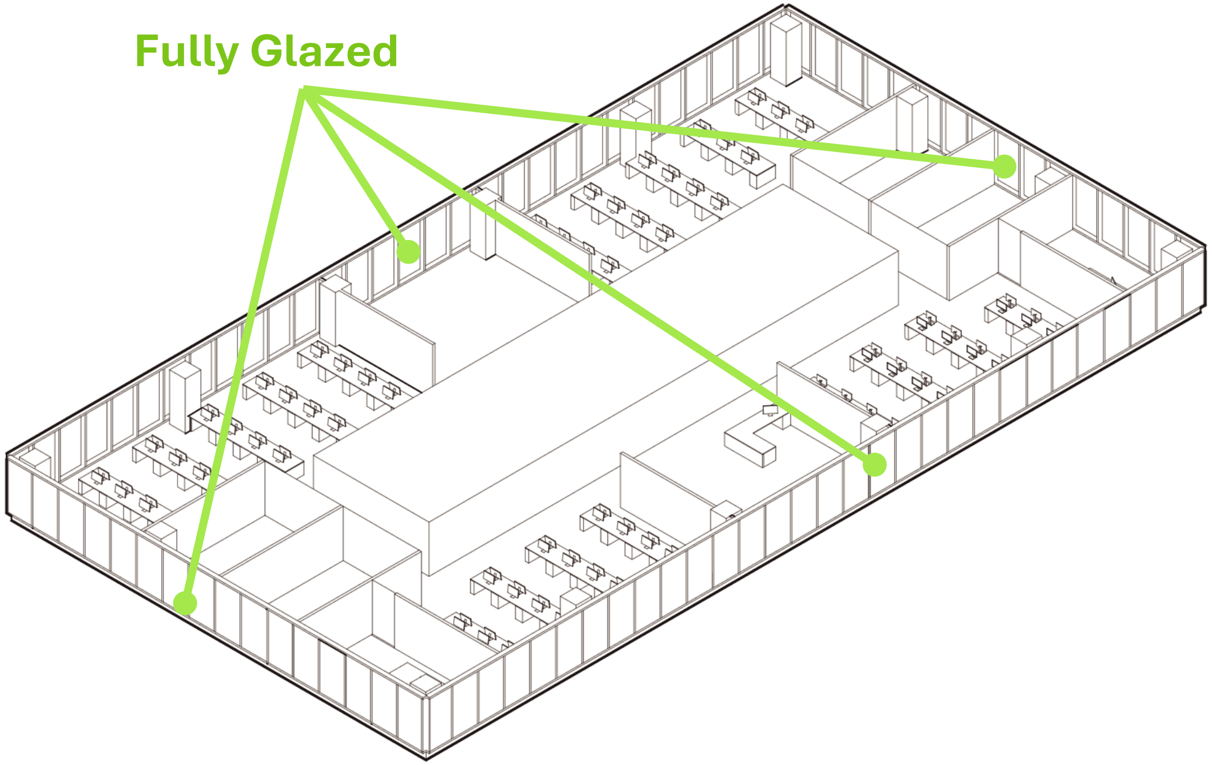
Building Designs: Three building designs were selected to cover a wide range of office building types in Canada, with a particular focus on façade design and its impact on daylighting.



URBAN CONTEXT

Building site context and location.

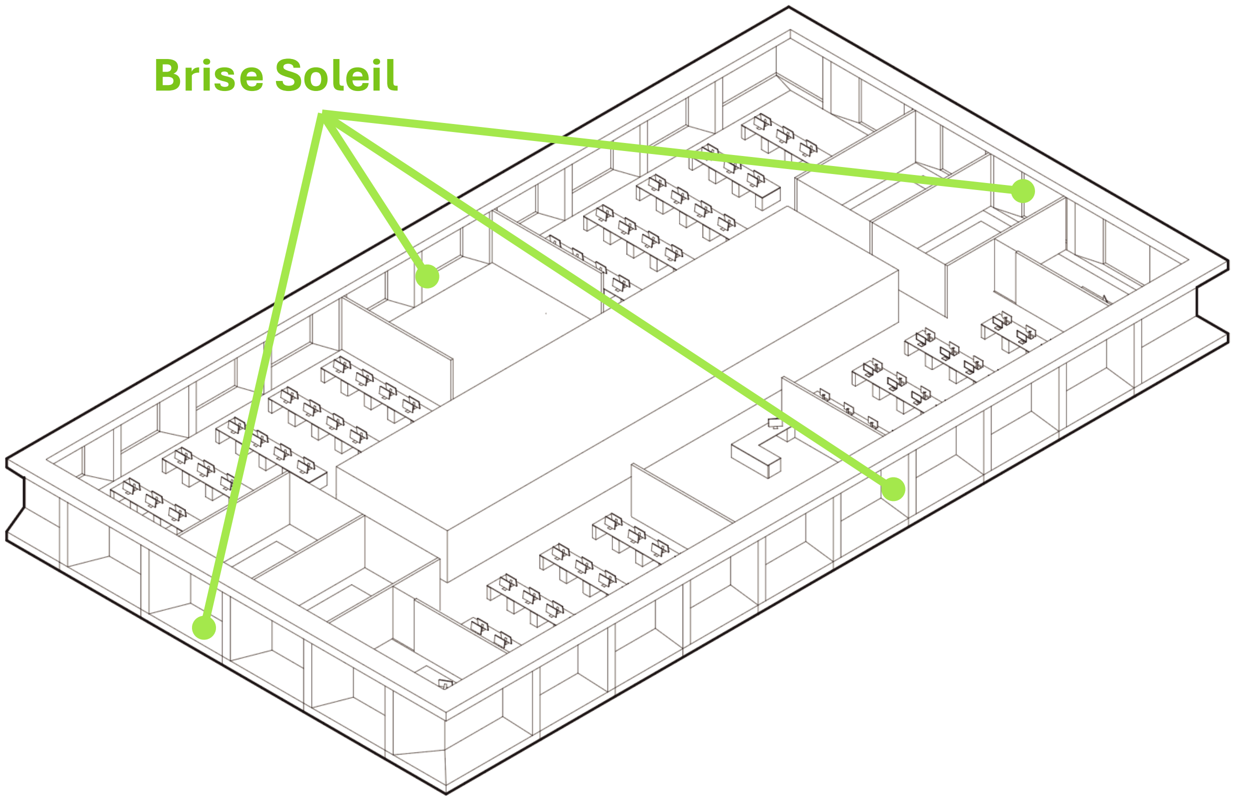
RESEARCH CASE STUDY – BASE CASE DESIGN



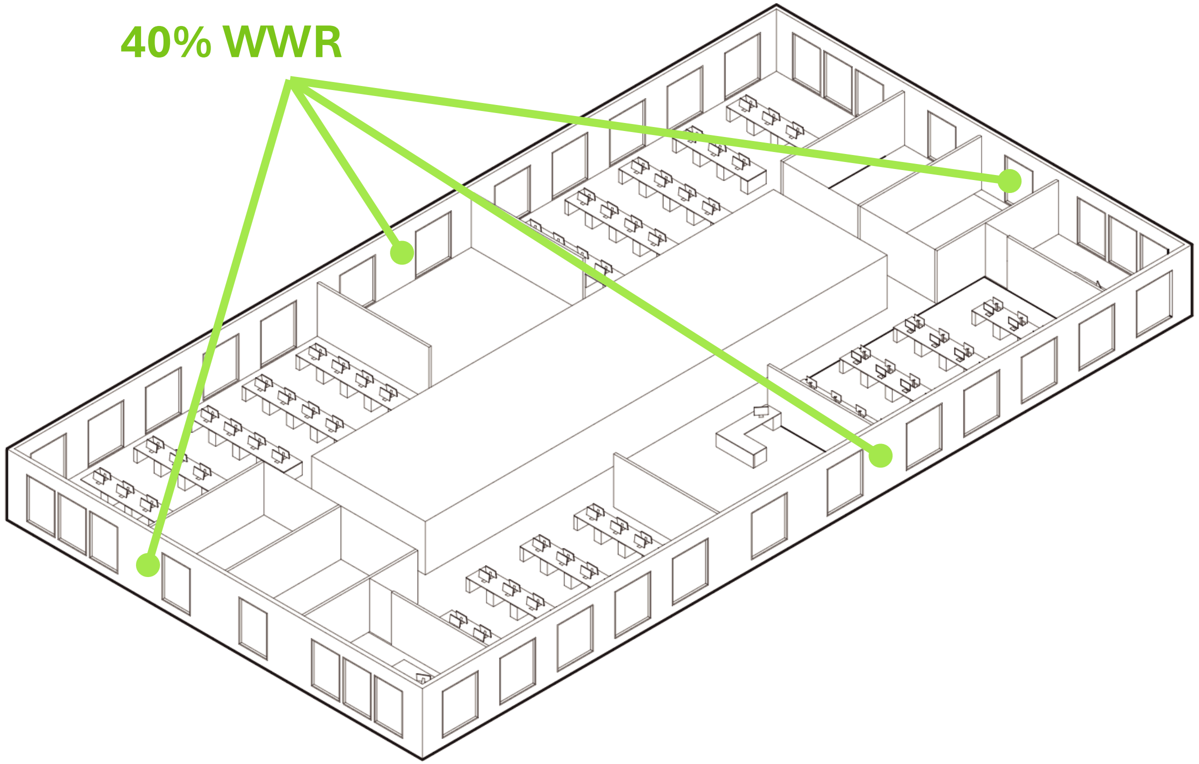
Base Case Design: The fully glazed design presents challenges related to daylight, such as glare and excessive blind closure.

RESEARCH CASE STUDY – OPTION 1 DESIGN

Option 1 Design: The brise soleil façade is designed to enhance daylight diffusion and reduce glare potential.



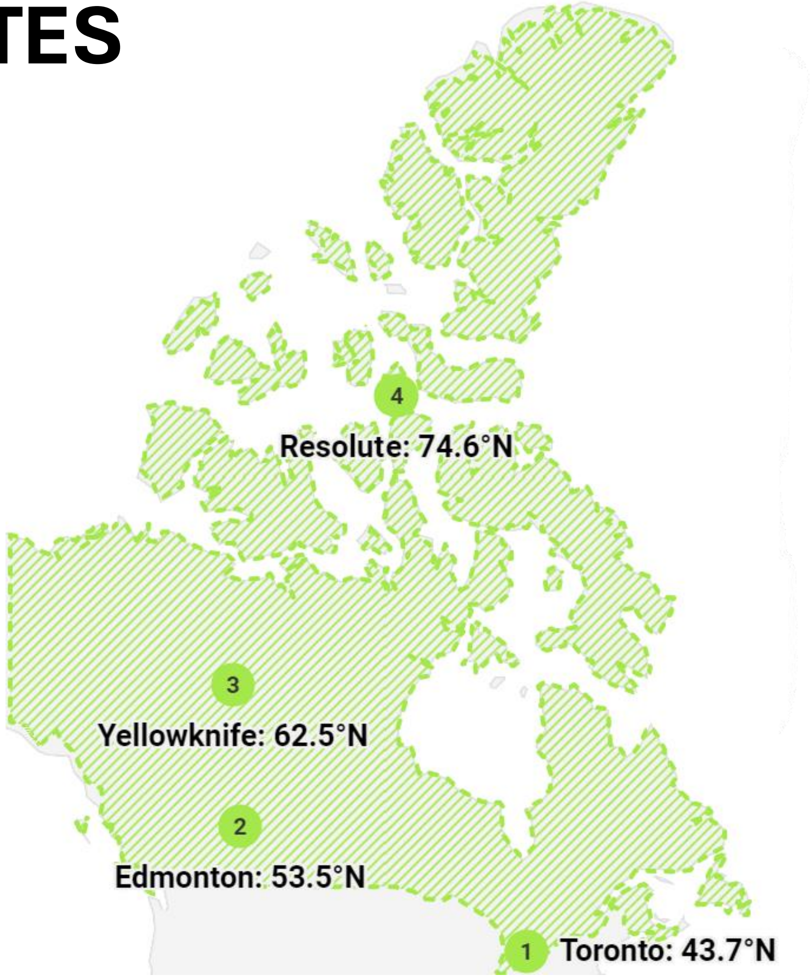
RESEARCH CASE STUDY – OPTION 2 DESIGN



Option 2 Design: Option 2 design reflects the characteristics of a typical 1980s office building with a WWR of approximately 40%.

RESEARCH CASE STUDY – CLIMATES

Climates: The climates studied include Toronto, Edmonton, Yellowknife and Resolute. These climates were chosen to illustrate Canada's latitude diversity.



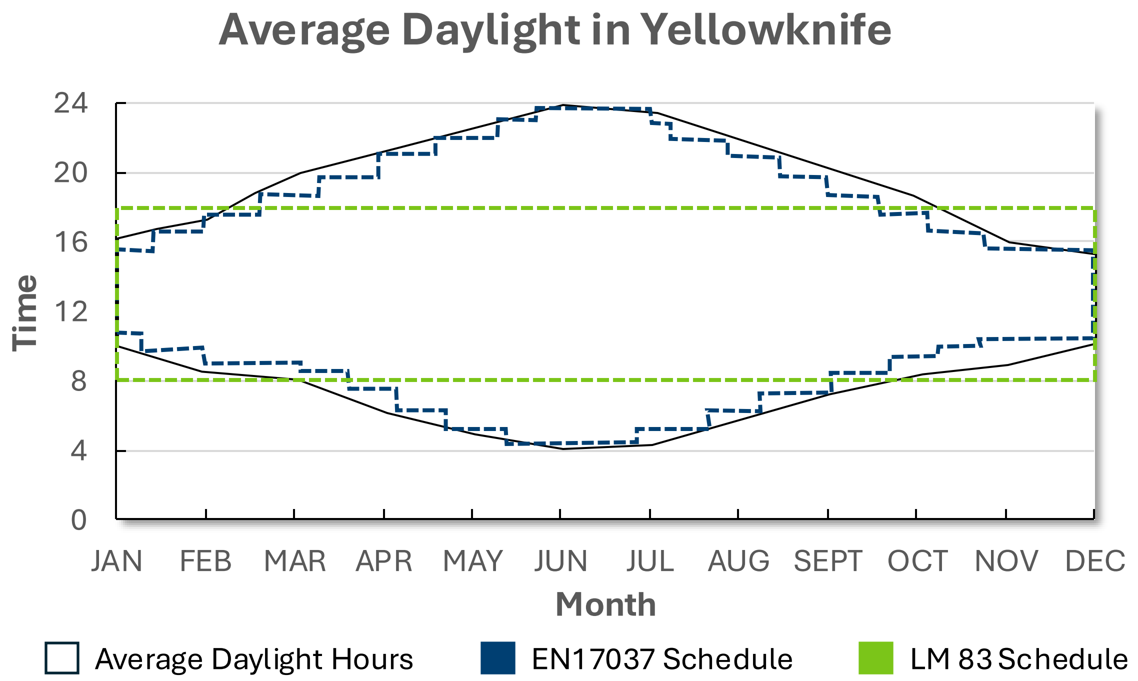
Climates studies in research.

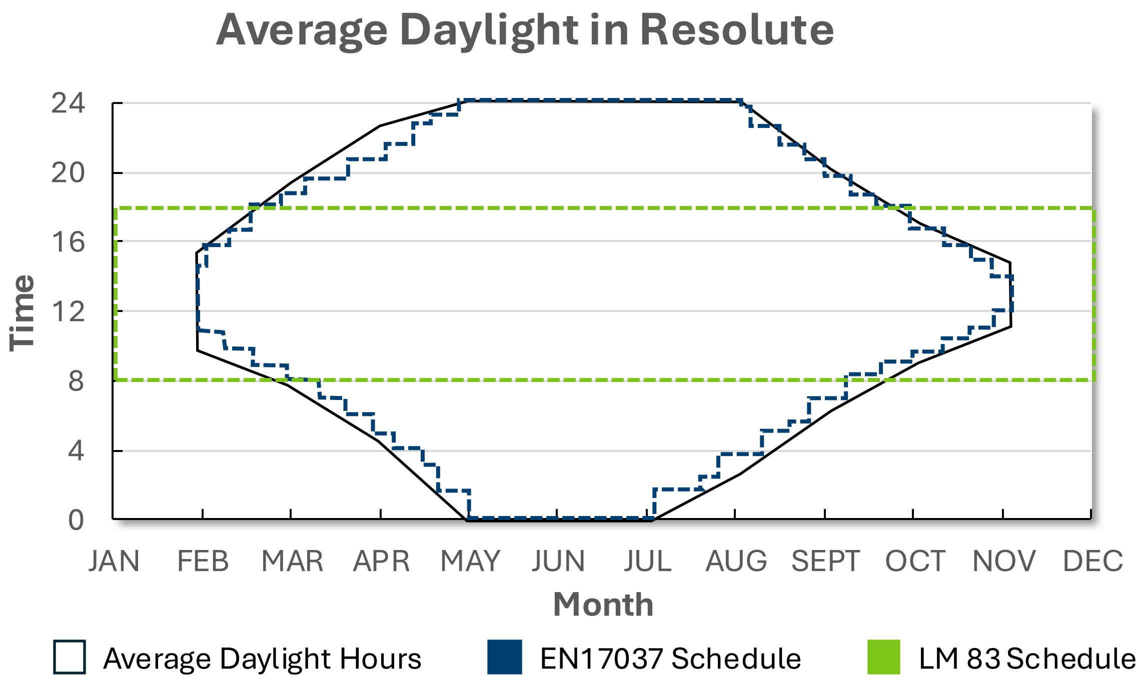
RESEARCH CASE STUDY – ASSESSMENT TOOLS

ClimateStudio: Daylight simulations were performed using ClimateStudio using a six ambient bounce calculation in a method approximating the Radiance 5-phase annual calculation.
Python: Python script was developed to calculate metrics with the goal of adding more daylight metrics to automate future analysis.

ClimateStudio (left) and Python (right) used as assessment tools in research.

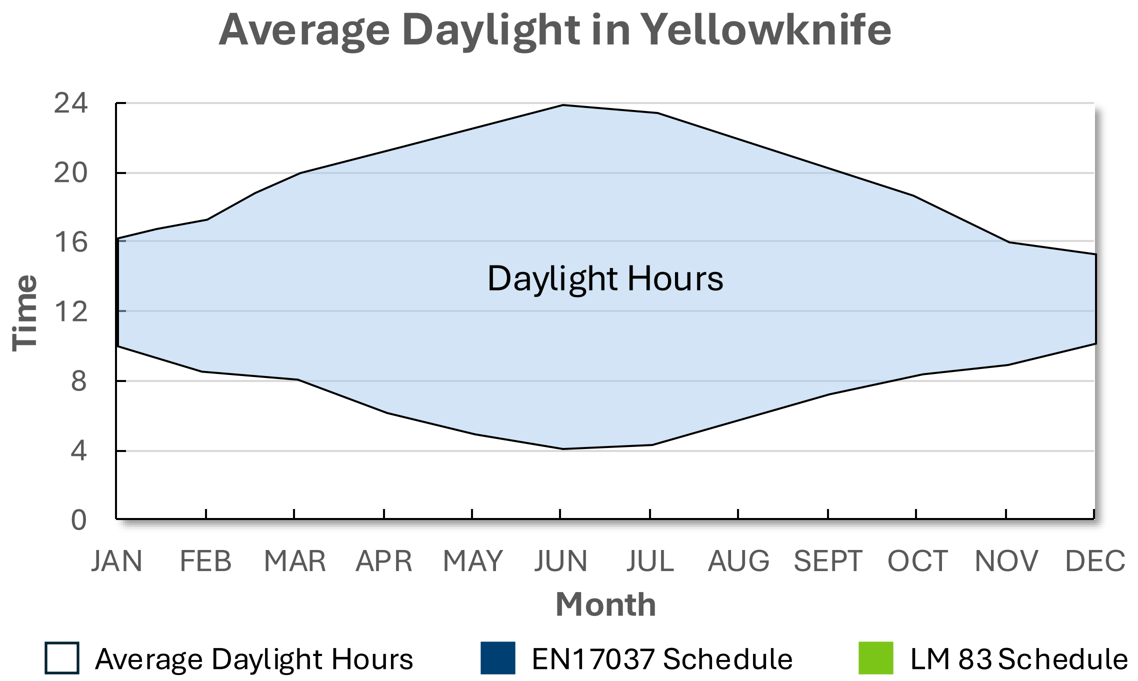
RESEARCH FINDINGS – ASSESSMENT PERIOD

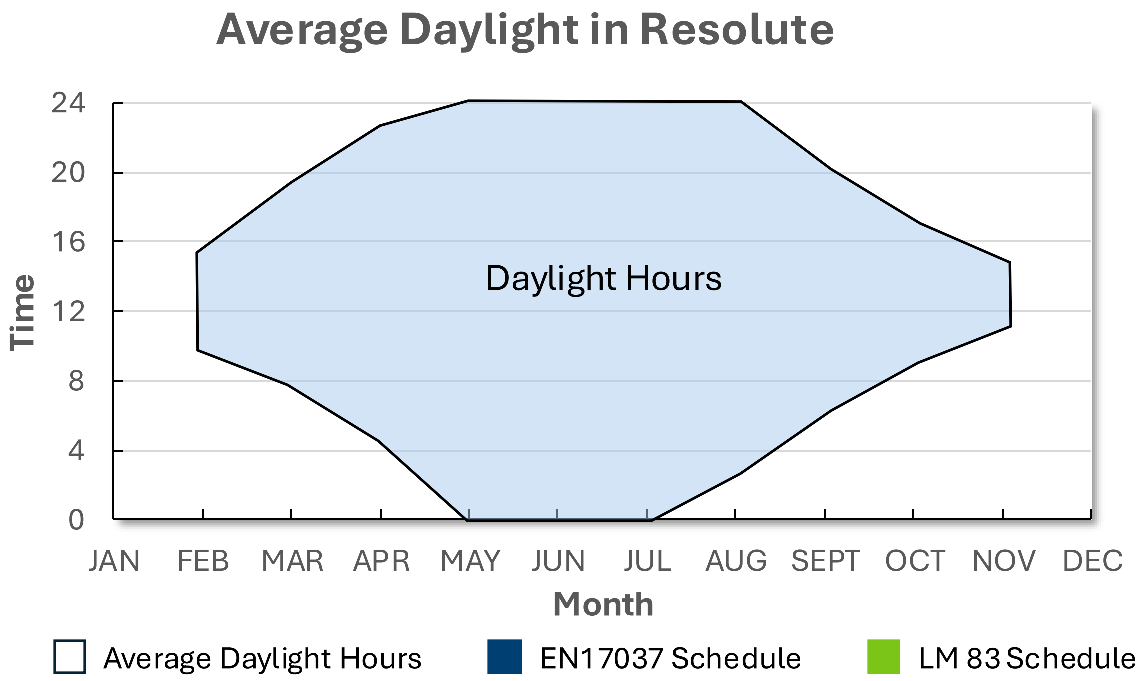




Comparison of actual daylight hours to recommended schedules from LM 83 & EN 17037.

RESEARCH FINDINGS – ASSESSMENT PERIOD





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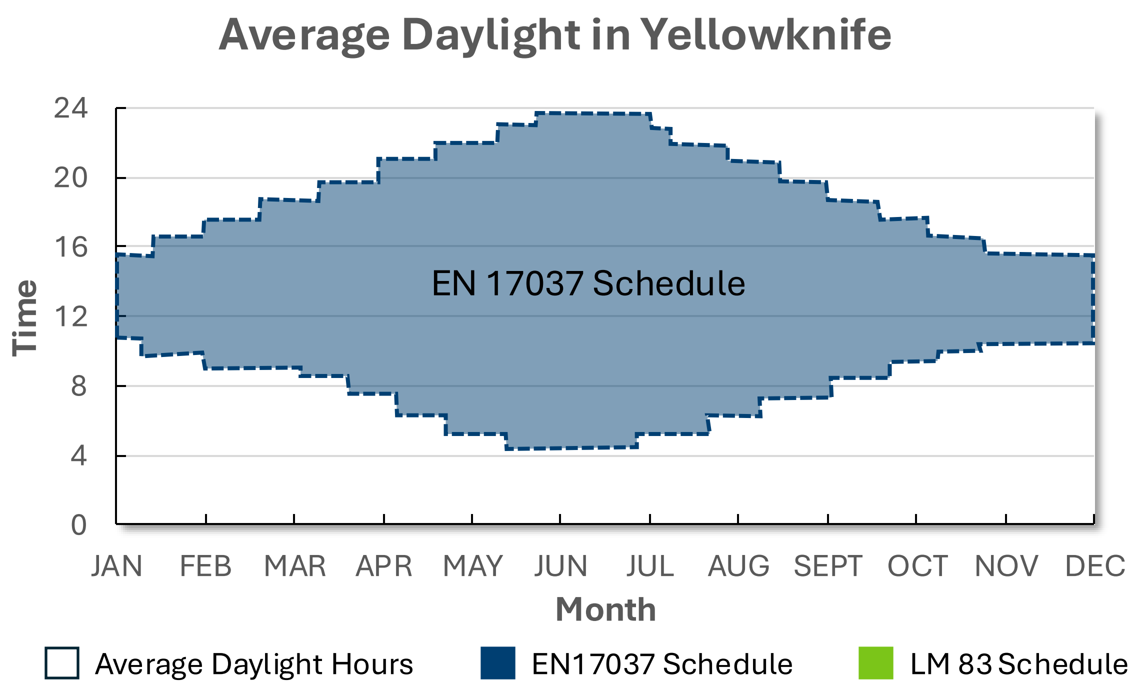
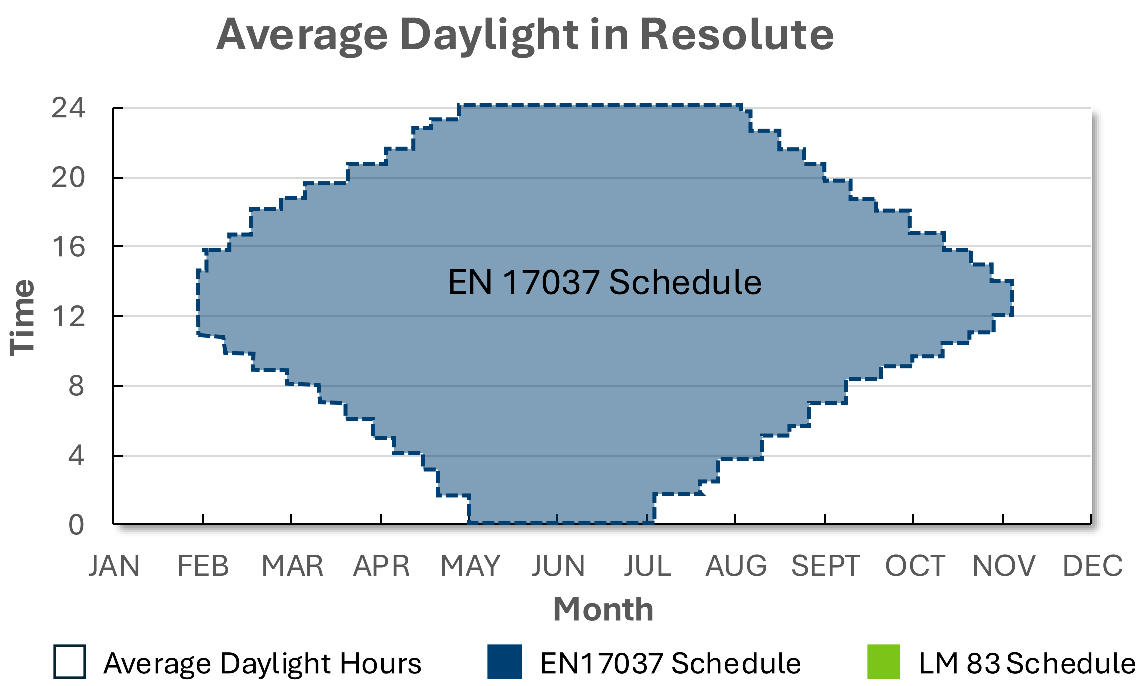
RESEARCH FINDINGS – ASSESSMENT PERIOD





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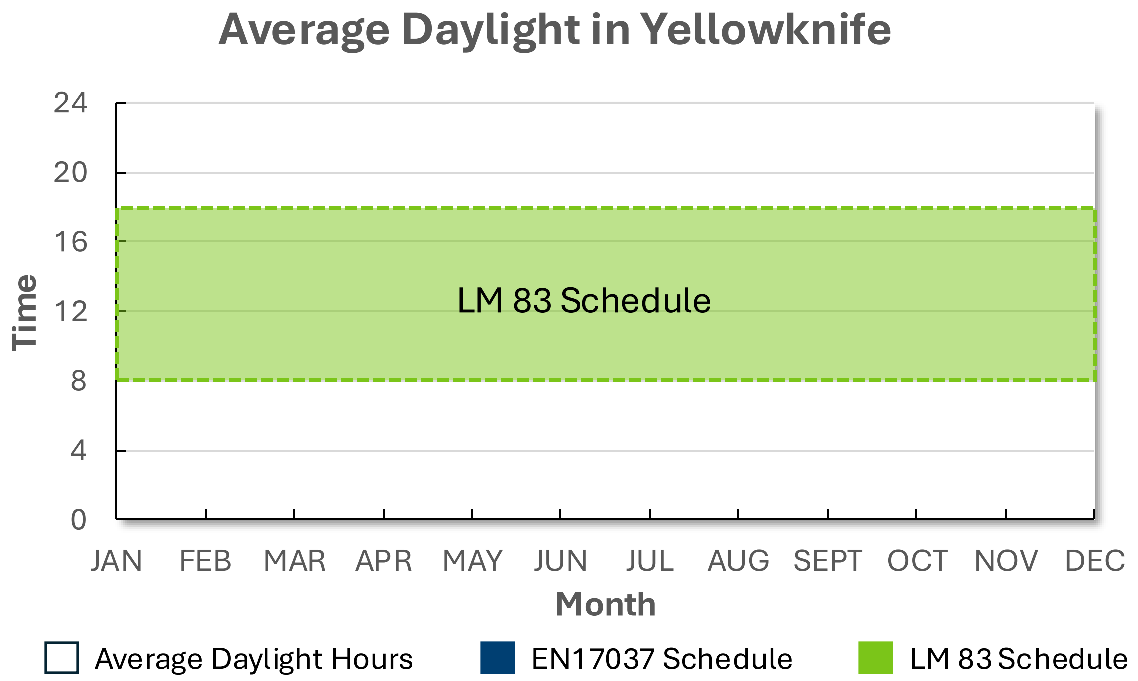

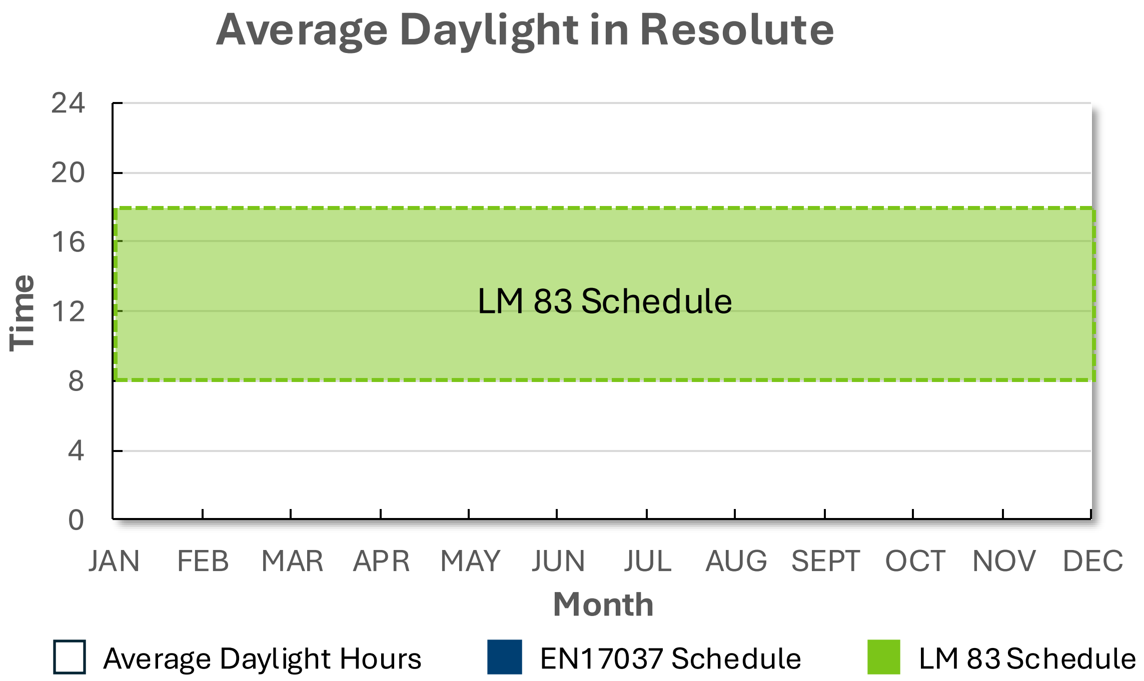

Comparison of actual daylight hours to recommended schedules from LM 83 & EN 17037.

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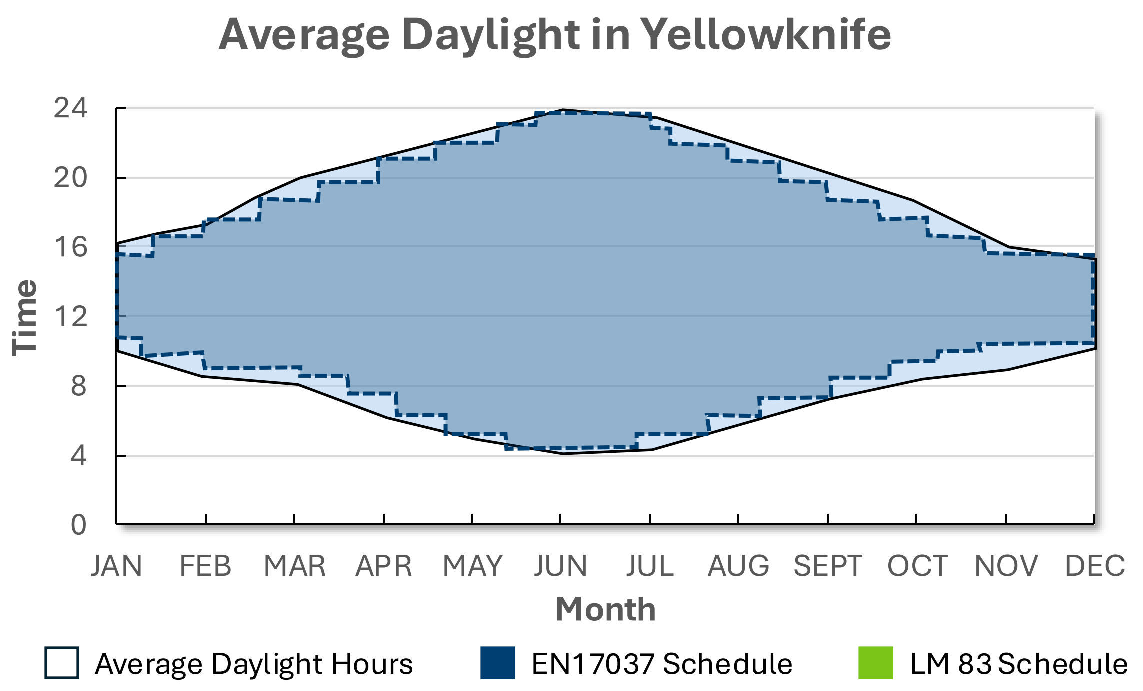
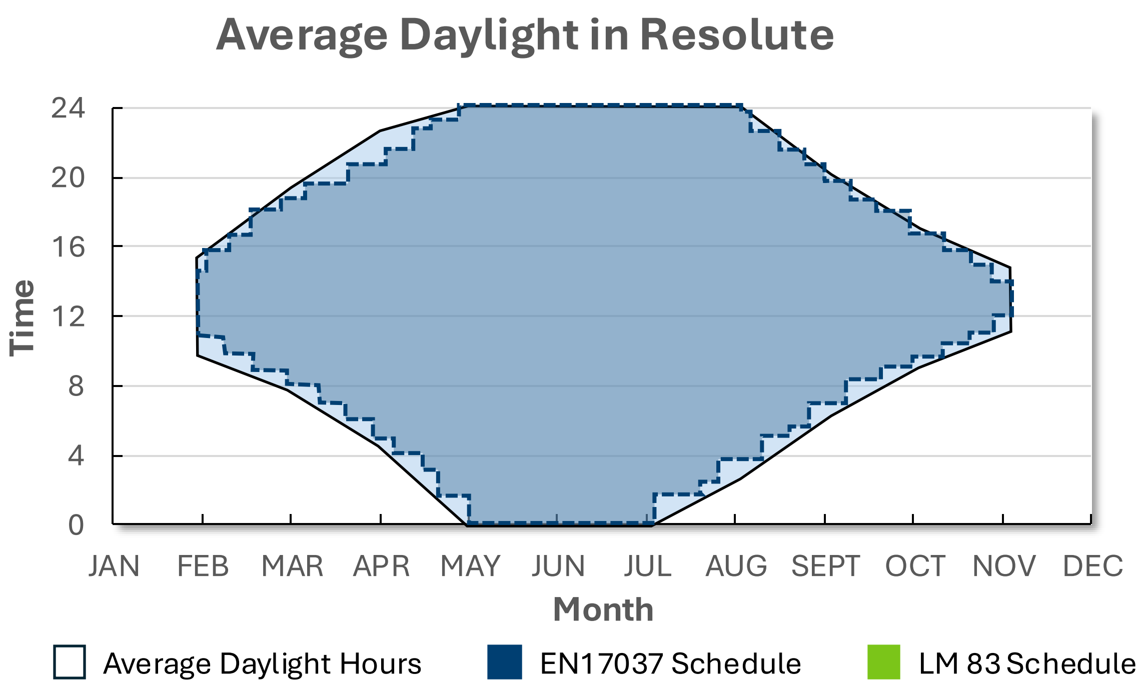
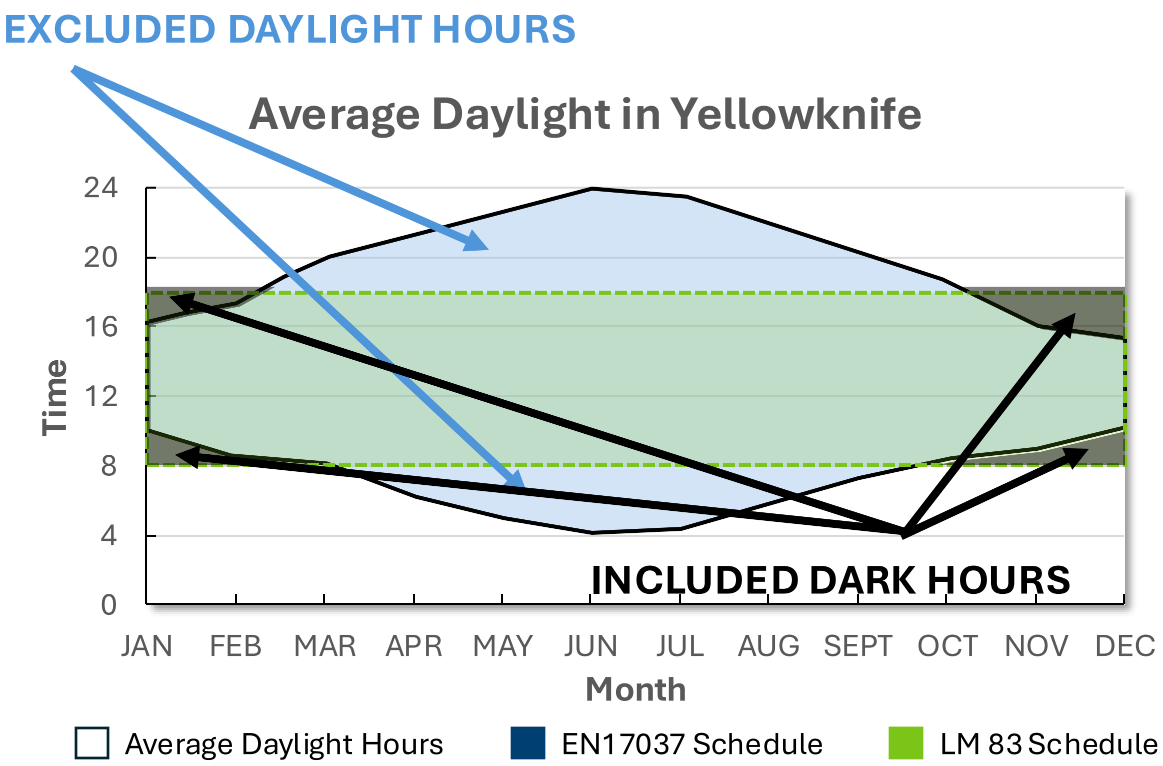
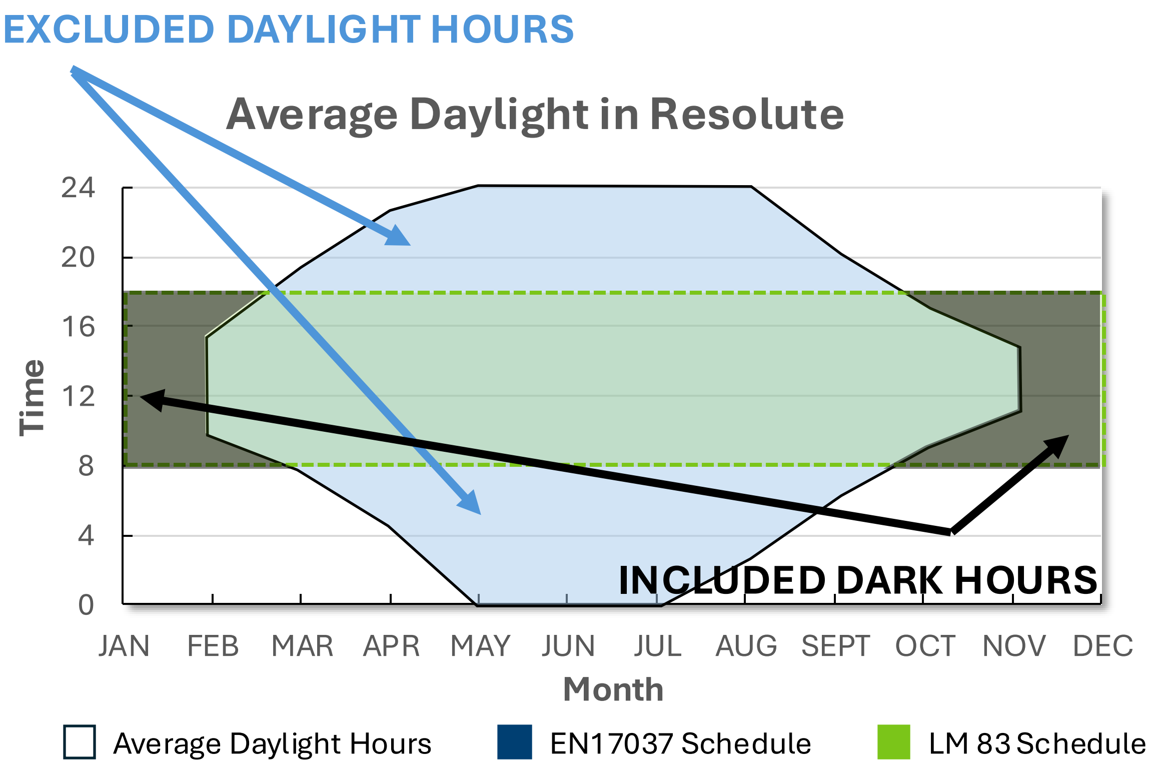




Comparison of actual daylight hours to recommended schedules from LM 83 & EN 17037.

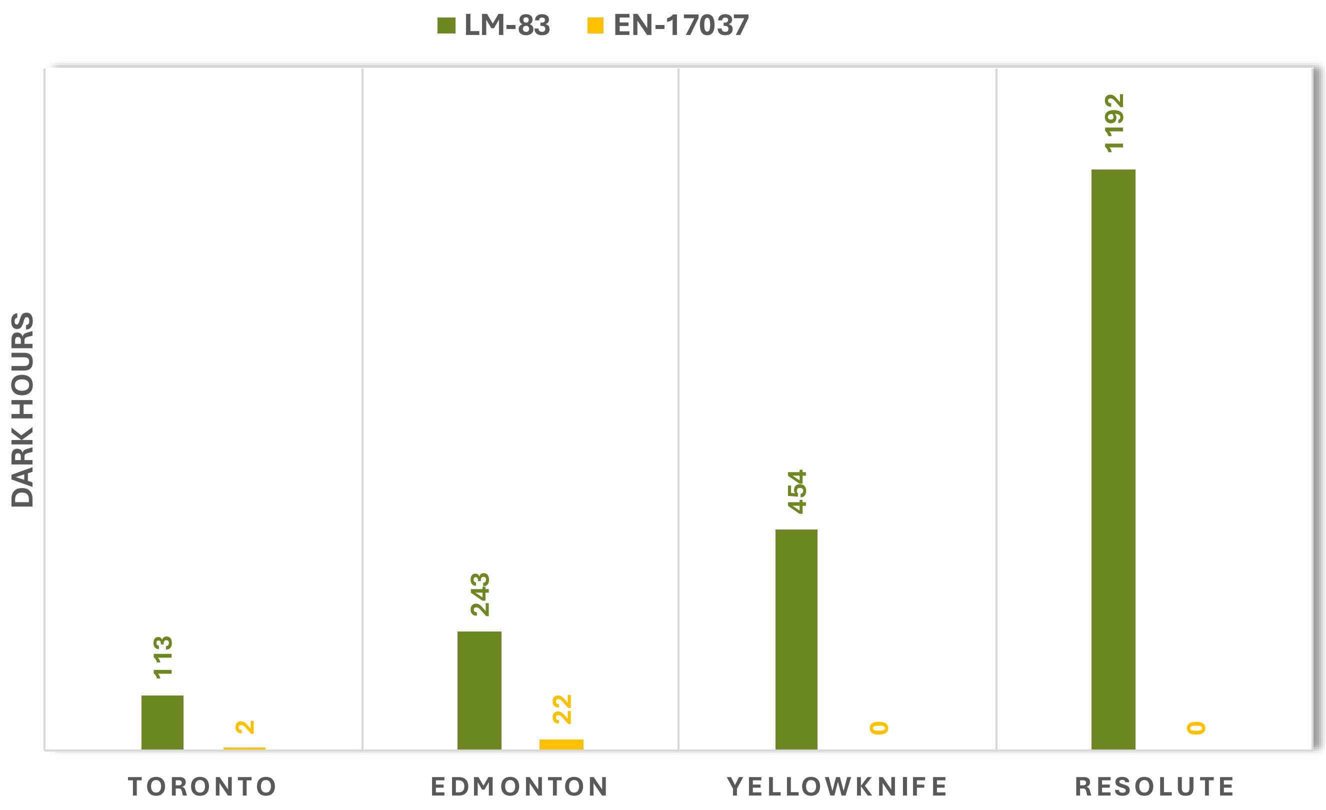
RESEARCH FINDINGS – ASSESSMENT PERIOD





Comparison of actual daylight hours to recommended schedules from LM 83 & EN 17037.

FINDINGS – ASSESSMENT PERIOD



Dark Hours

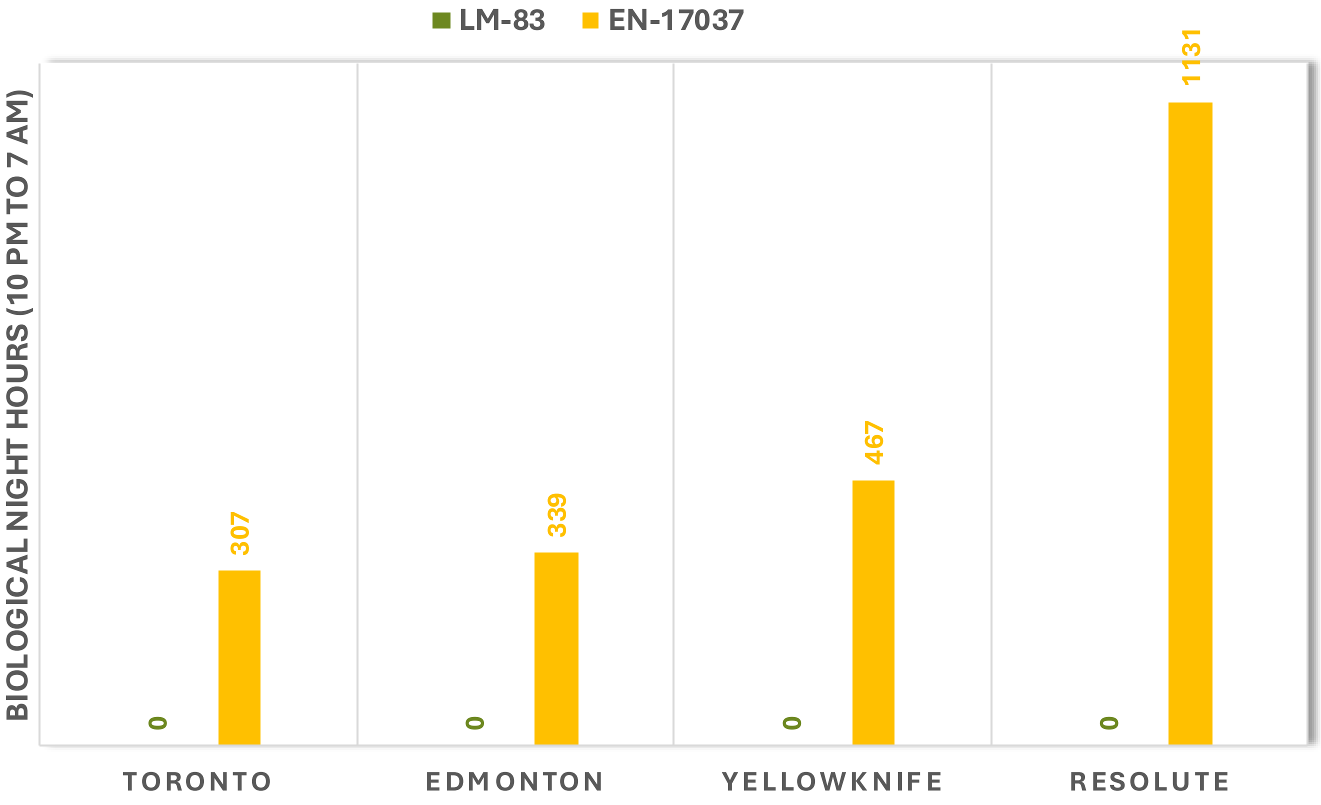
EN 17037

Fewer dark hours within its daylight schedule.

LM 83

Distinctively higher dark hours during the analysis period, **especially in Northern climates**.

FINDINGS – ASSESSMENT PERIOD



Biological Night

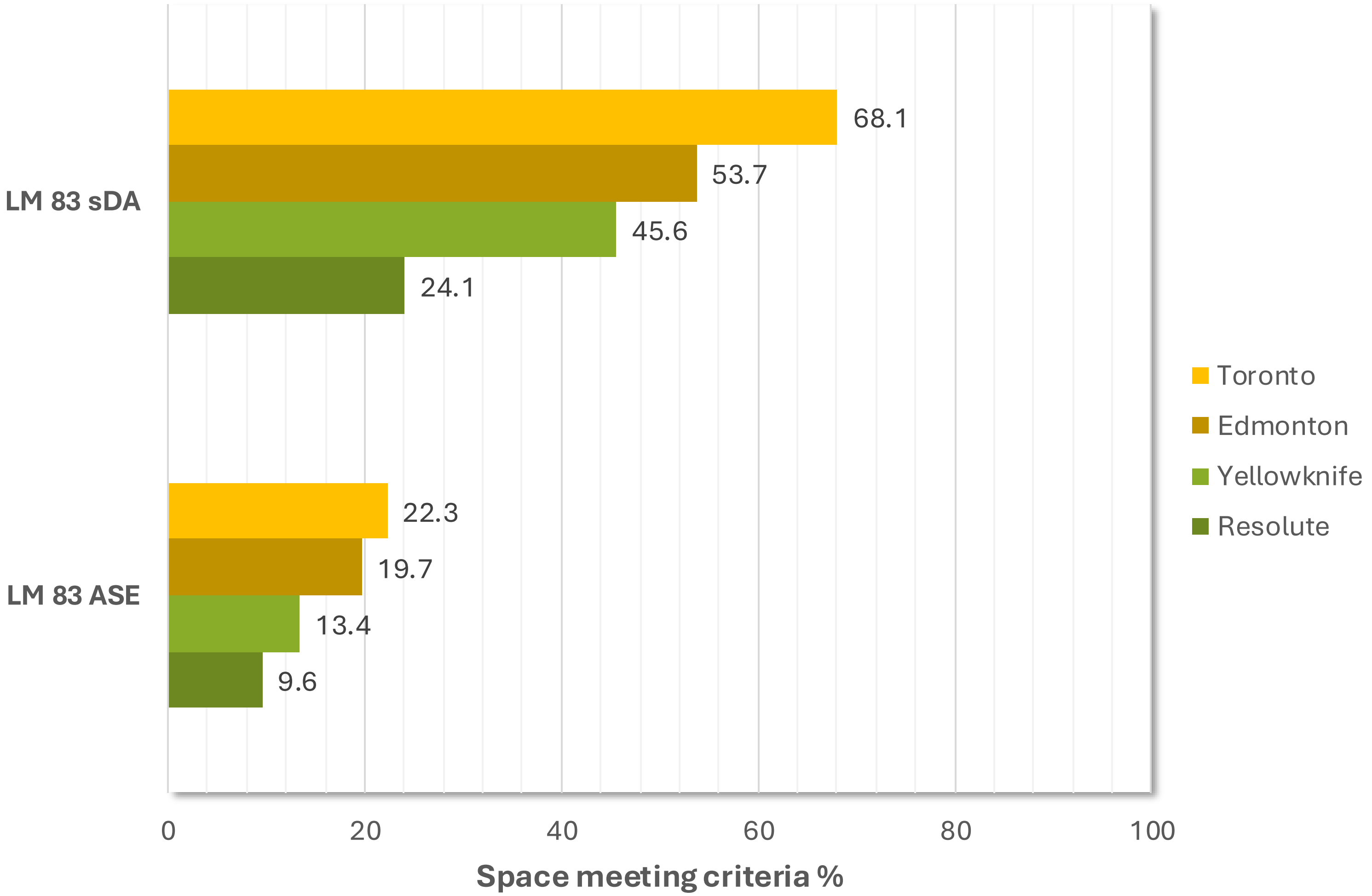
EN 17037

The analysis period **includes an extensive amount** of biological night hours.

LM 83

The analysis period **does not include any** biological night hours.

FINDINGS (BASE CASE MODEL) – LM 83 COMPLIANCE



LM 83

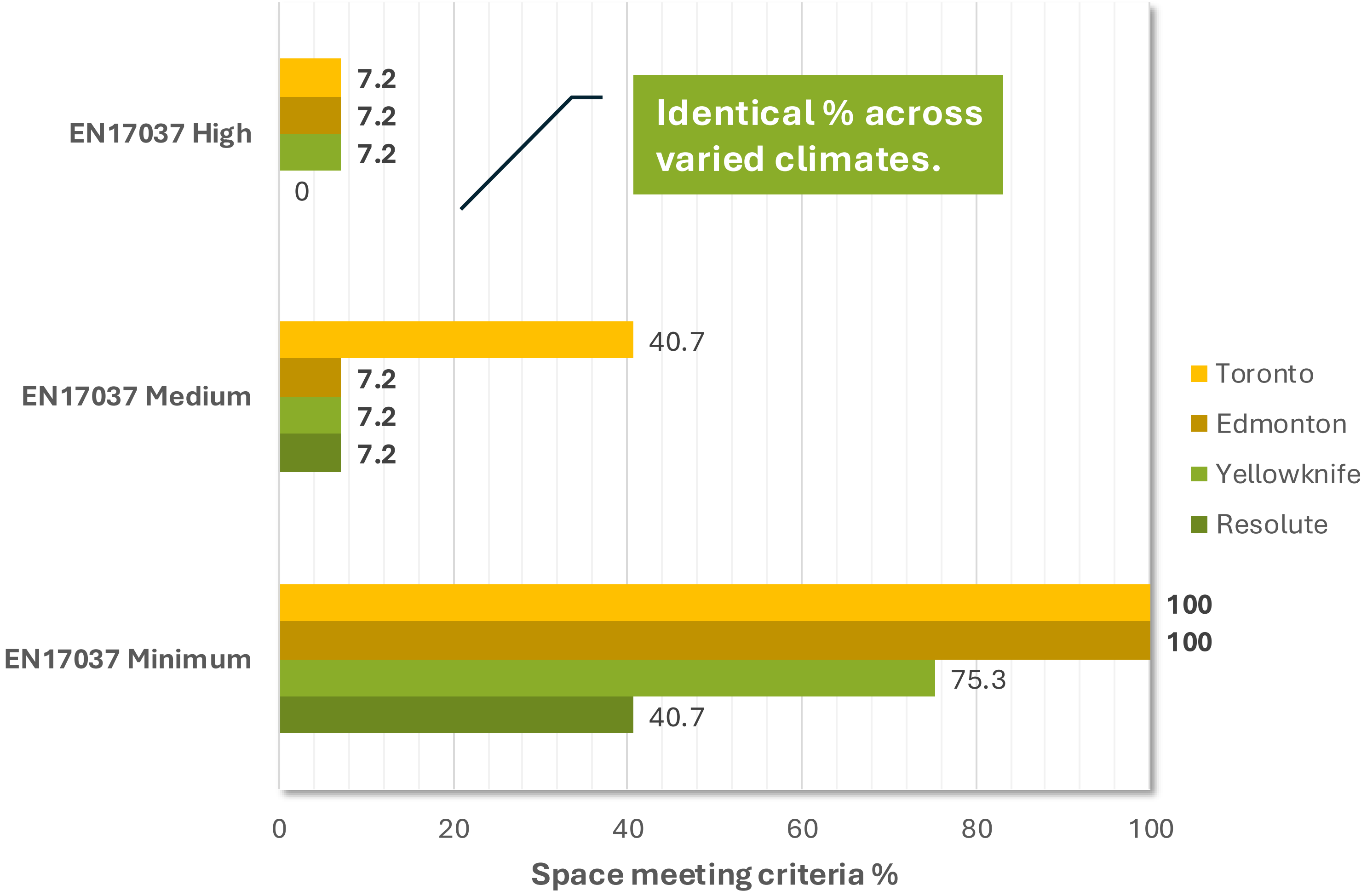
sDA

Decrease in compliance as climate moves northward.

LM 83

Decrease in glare issues as climate moves northward.

FINDINGS – EN 17037 COMPLIANCE



EN 17037

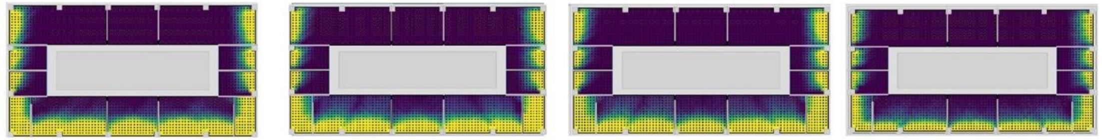
Consistency in achieving min, med, and high levels of daylighting criteria.

Identical percentage in meeting criteria is attributed to **its analysis schedule and rigid daylight assessment.**

FINDINGS – SPATIAL DAYLIGHT PERFORMANCE

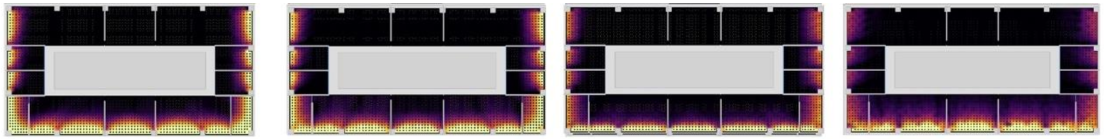
LM 83 Annual Sunlight Exposure

Toronto Edmonton Yellowknife Resolute



LM 83 Mean Annual Illuminance

Toronto Edmonton Yellowknife Resolute



0 250 hours

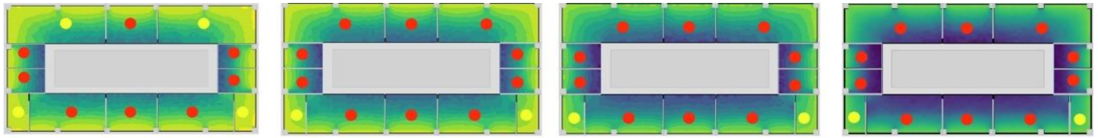
Sunlight Exposure (hours)

0 500 lux

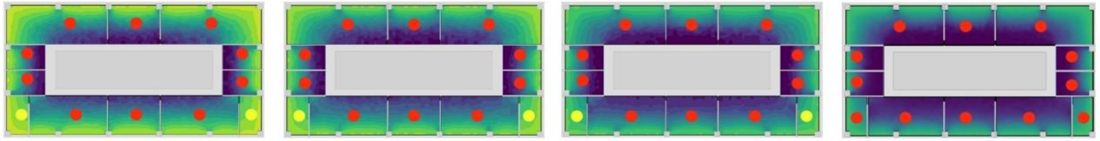
Mean Illuminance (lux)

EN 17037 DAYLIGHT AUTONOMY

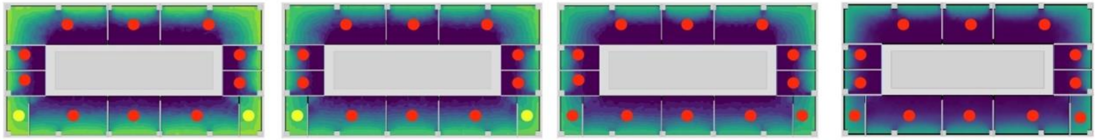
Toronto Edmonton Yellowknife Resolute



300 lux



500 lux



750 lux

0 50 100 %

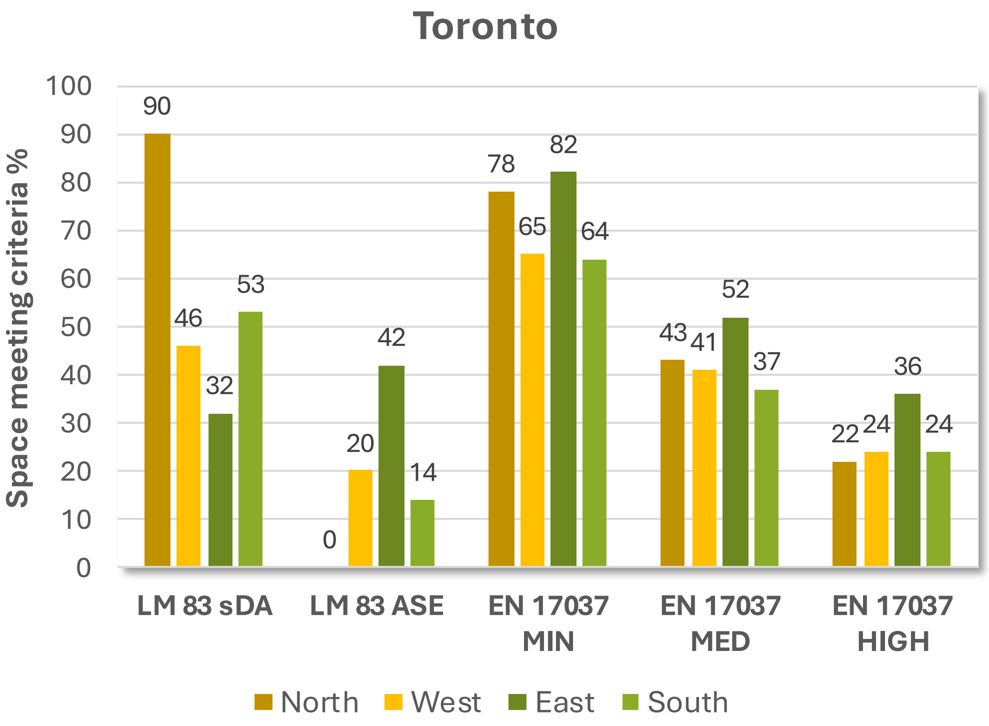
sDA/DA (Percentage of occupied time)

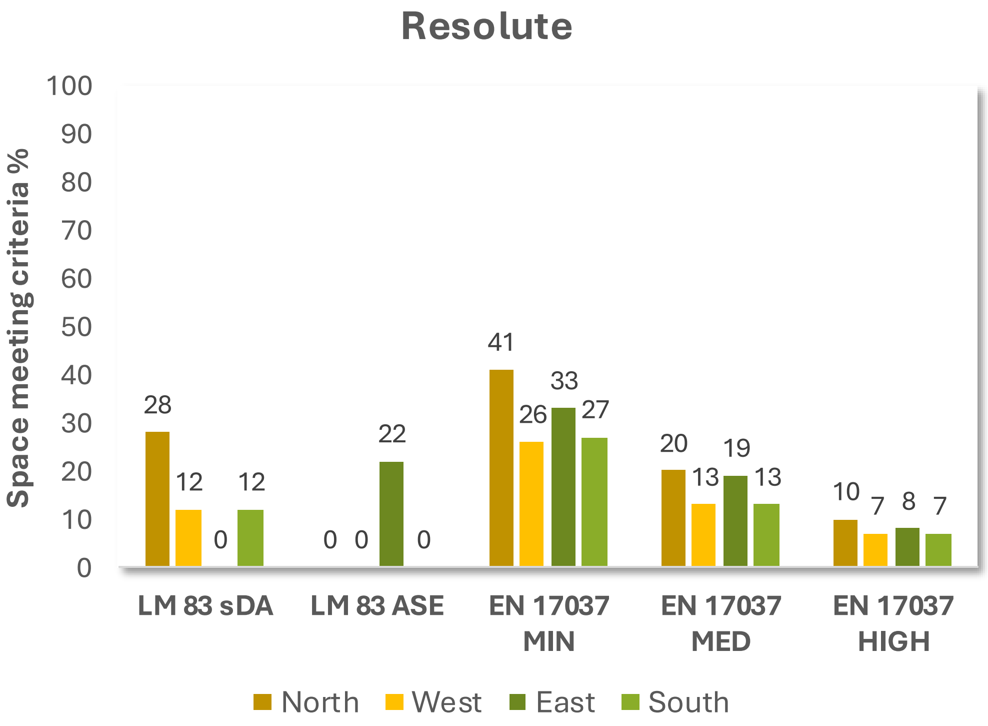
Meets EN 17037 Compliance

Does Not Meet EN 17037 Compliance

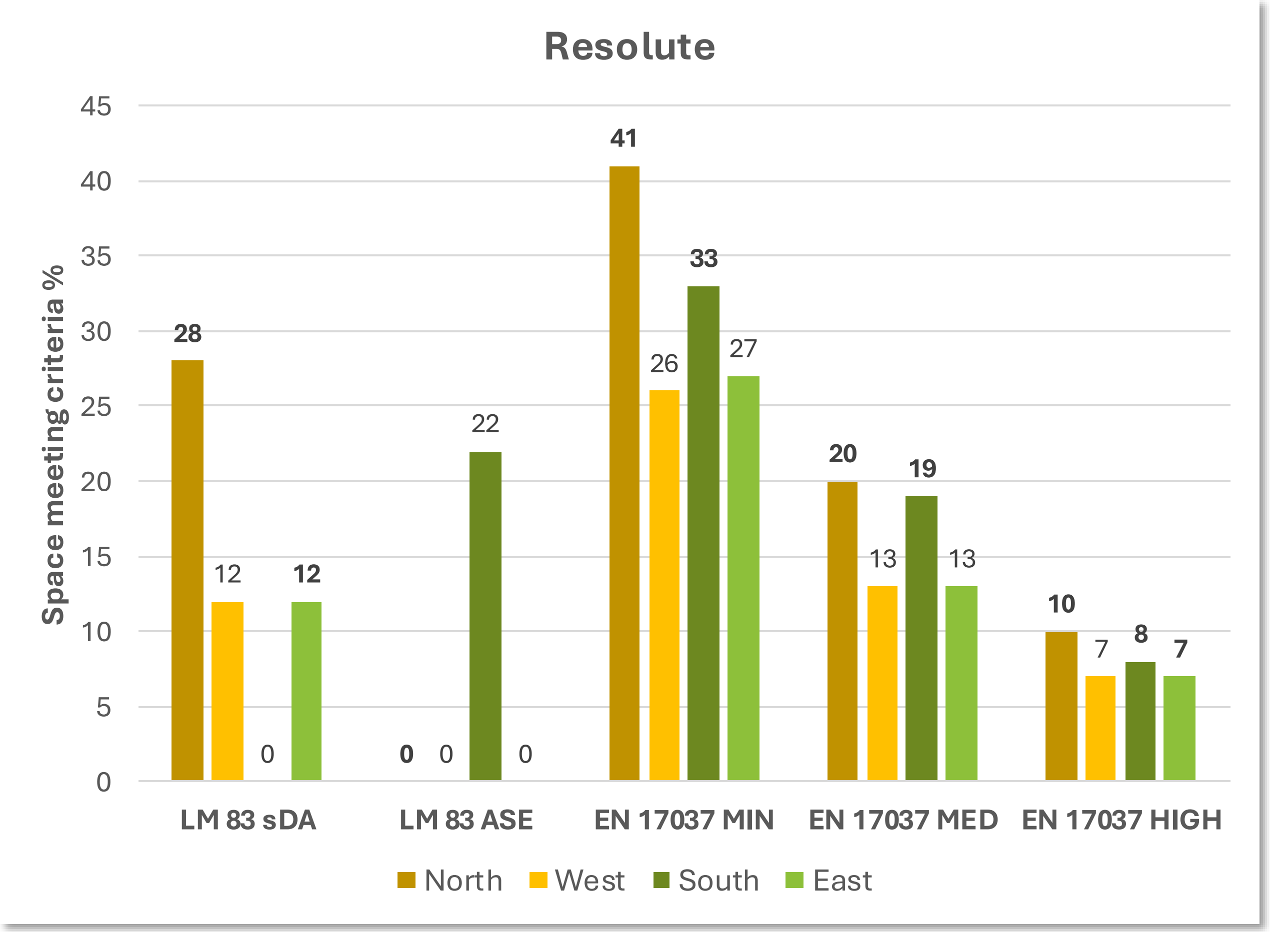
RESEARCH FINDINGS – ORIENTATION ANALYSIS

Decrease in compliance levels as the location shifts northward.





RESEARCH FINDINGS – ORIENTATION ANALYSIS



Orientation Performance

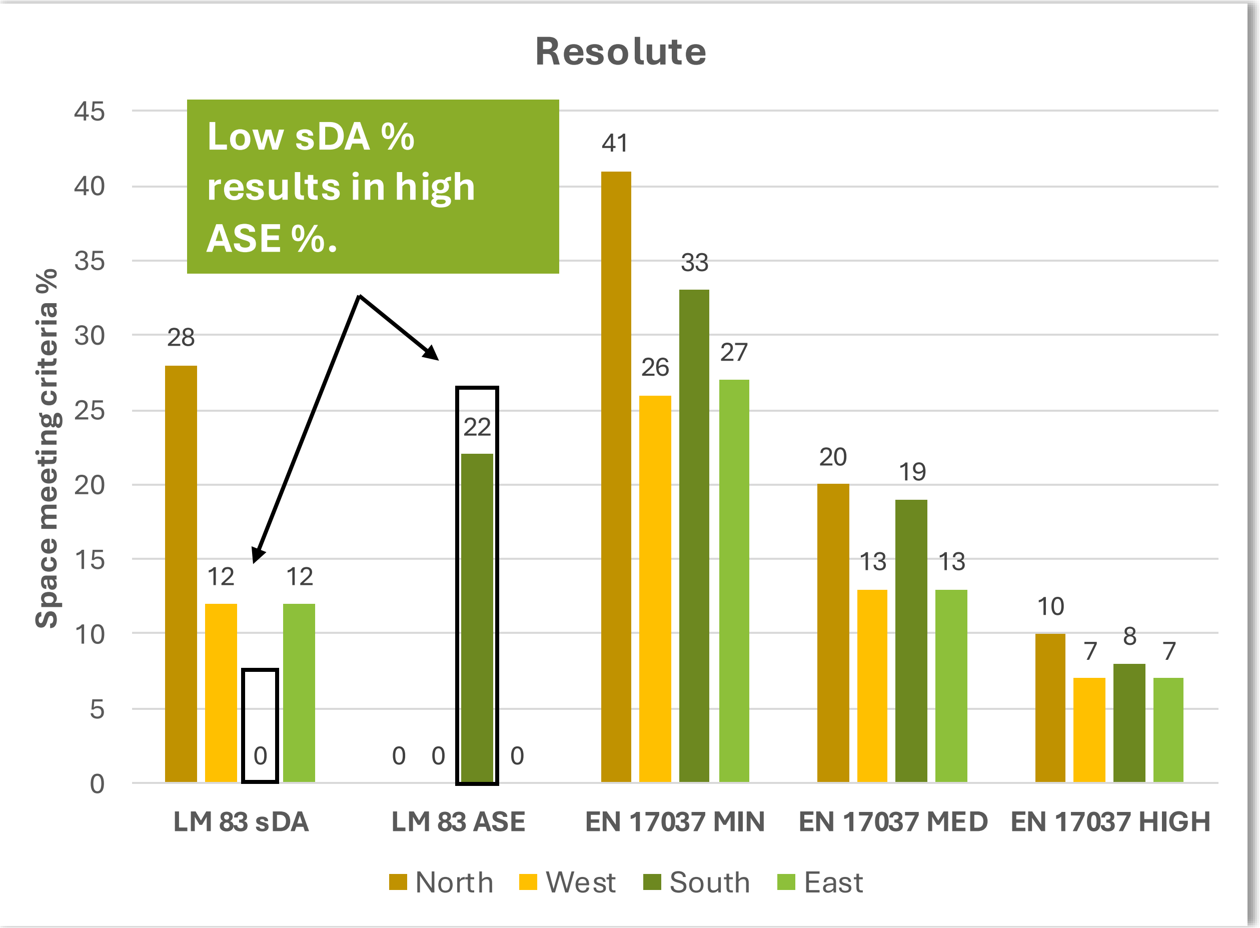
EN 17037

North and South are the best performing orientations.

LM 83

North and East are the best performing orientations.

RESEARCH FINDINGS – ORIENTATION ANALYSIS



LM 83

Low sDA percentage results in high ASE percentage.

ASE does not account for blind use criteria in its daylight performance assessment.

RESEARCH FINDINGS – DISCUSSION

1

EN 17037 vs LM 83

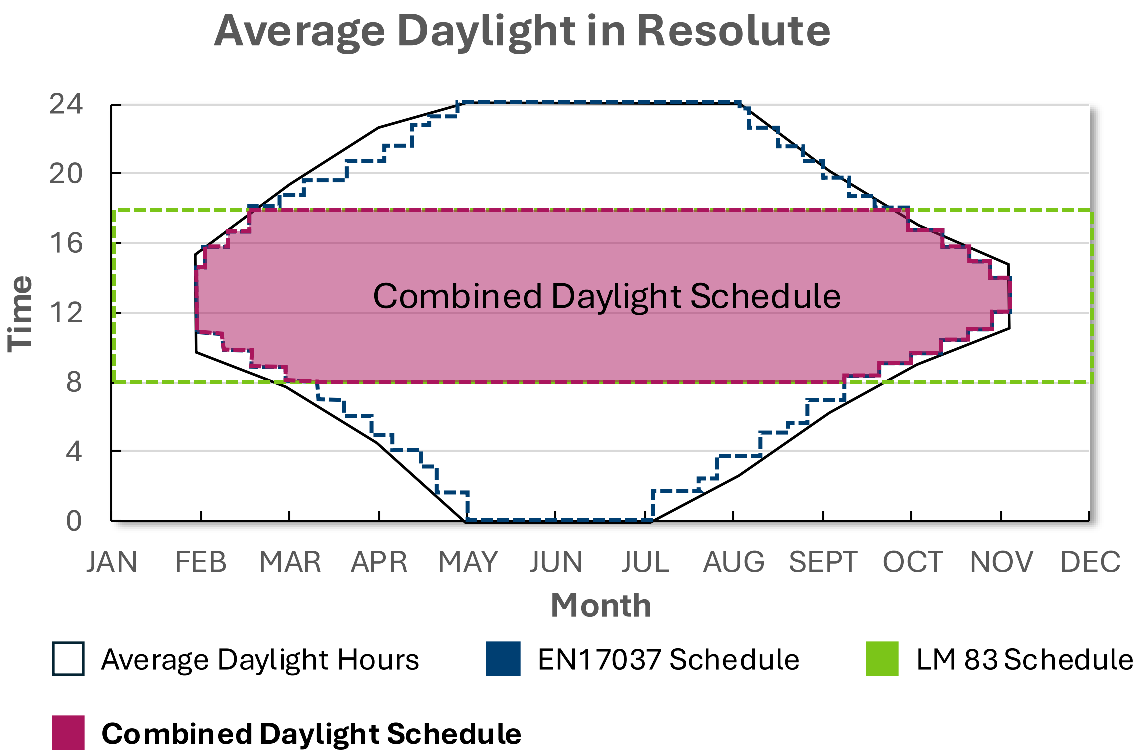
- EN-17037 aligns closely with actual daylight hours, reducing dark hours.
- EN-17037 includes biological night hours, questioning practicality in northern contexts.
- LM-83 aligns with typical occupant hours and includes shading for visual comfort.

2

Challenges

- Meeting higher daylight recommendations is stringent in both metrics.
- EN-17037’s room-based compliance vs. LM-83’s sensor-based evaluation.

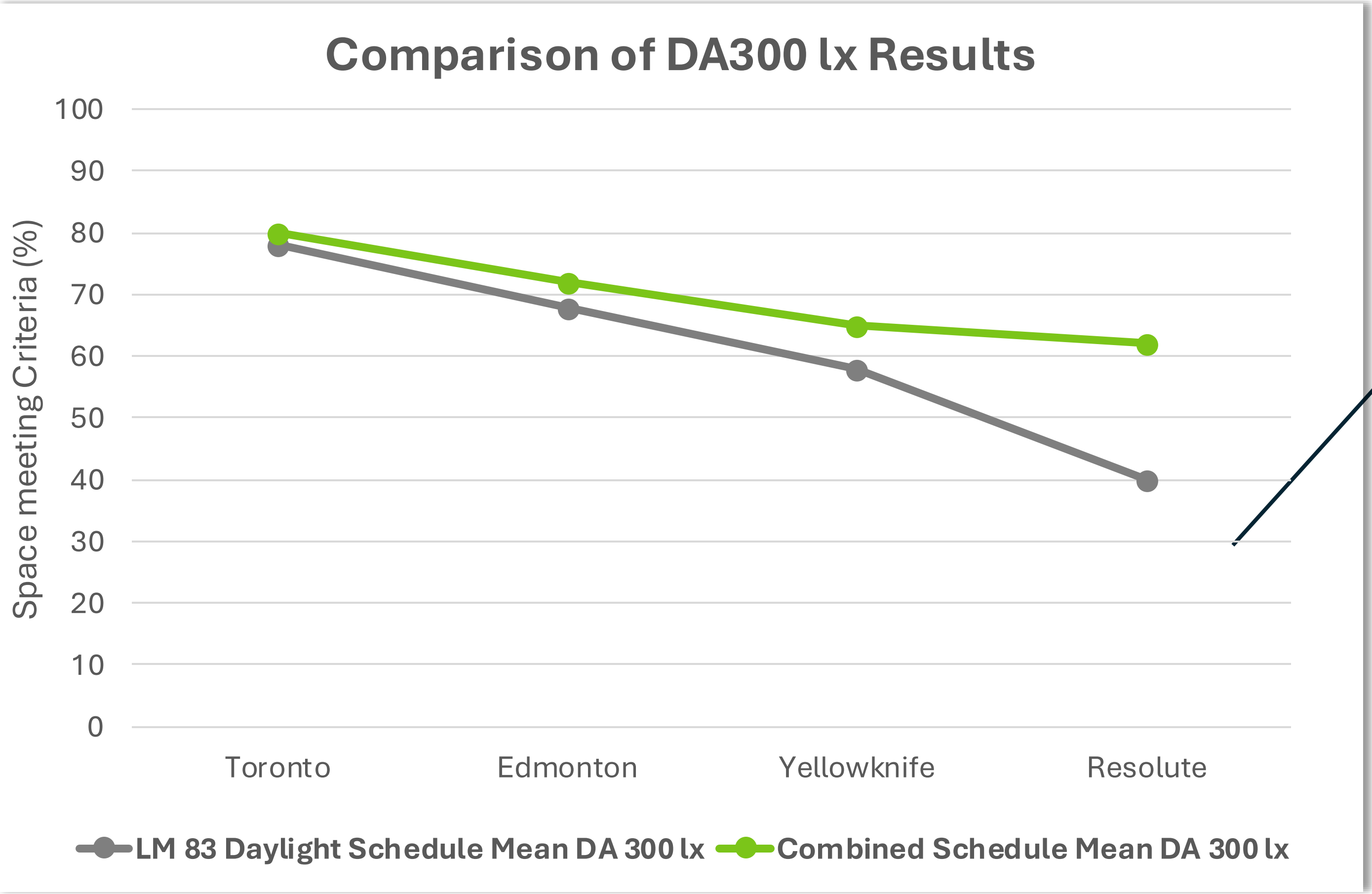
RESEARCH FINDINGS – DISCUSSION



Need for Improved Metric:

- Combine daylight availability with actual occupancy.
- Integrate aspects of both EN-17037 and LM-83.
- Flexible schedule adjusting to seasonal variations and occupancy patterns.

RESEARCH FINDINGS – DISCUSSION



More consistency in daylight results across various climates.

LIMITATIONS AND FUTURE WORK

1

Limitations

- Model specificity: relied on specific architectural models and materials.
- Blinds usage: operational frequency of blinds.

2

Future Work

- Global metrics: more needed to enhance the study.
- Diverse programs: is essential to daylight studies.

FUTURE WORK

Daylight Autonomy (DA), EN 17037 Minimum / medium / high recommendations for daylight provision in a space, Northeast Collaborative for High Performance Schools Criteria (NE-CHPS) v3.2, WELL Healthy Sunlight Exposure, Daylight Factor, Continuous Daylight Autonomy (CDA or DA_con), Green Mark Non-Residential Buildings, Northeast Collaborative for High Performance Schools Criteria (NE-CHPS) v4.0, RDS: RDA + DLA (Residential Daylight Score: Residential Daylight Autonomy + Direct Light Access), Partial Daylight Autonomy (DAp), Useful Daylight Illuminance (UDI) v1, Green Mark Residential Buildings, Various LEED versions from 1.0 - 4.0 NC, Median programmatic illuminance, Daylight Availability (DAvail), Useful Daylight Illuminance (UDI) v2, BREEAM International, UK Daylighting Standards for Schools, Daylight Uniformity, Diffuse daylight (DiffDL), Daylight Satisfaction, Mean Illuminance, Median Illuminance / Vertical and Horizontal illuminance, BREEAM-NOR, Green Star Buildings - Light Quality, Contrast-driven excitement, Continuous overcast daylight autonomy (DAo.con), Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE), BREEAM-UK BS 8206-2:2008 Lighting for buildings, Minimum daylight autonomy, MICI (mean indirect cubic illuminance), Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE), CASBEE, EN 15193 Energy requirements for lighting, Directivity metrics and more...

University of Toronto
John H. Daniels Faculty of
Architecture, Landscape, and Design

Thank you!

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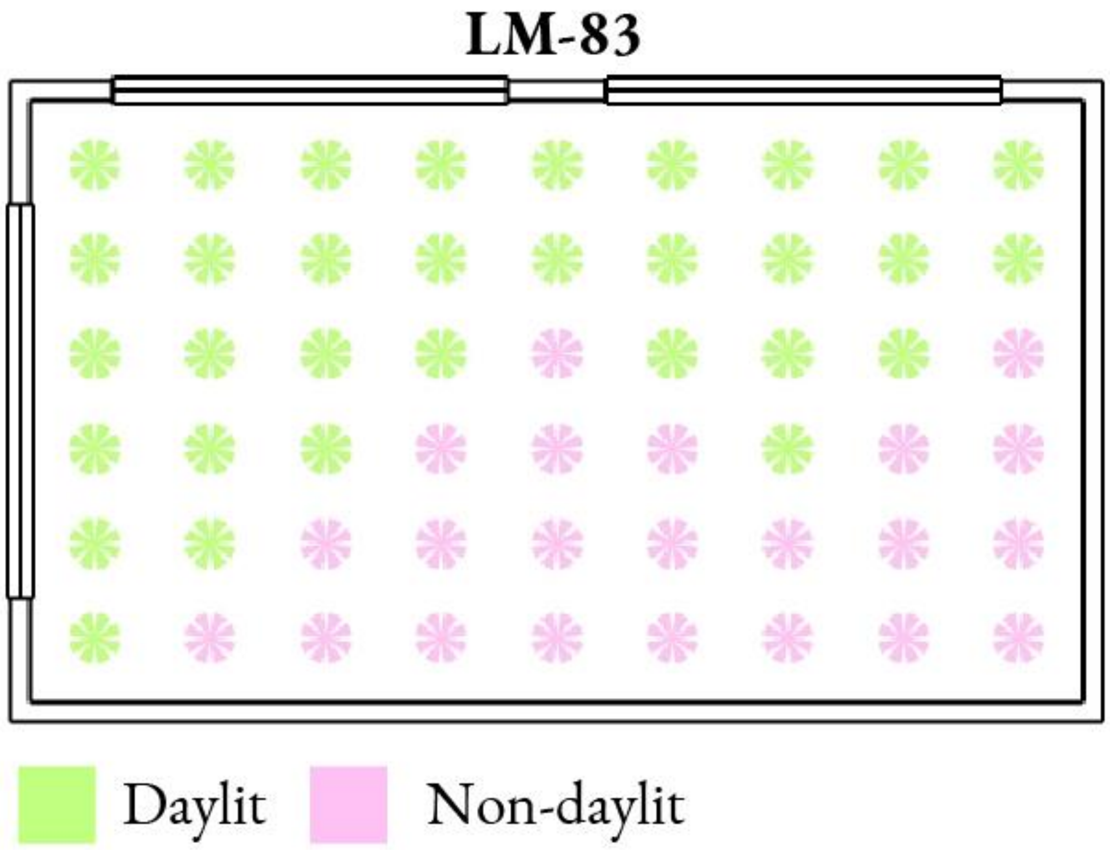
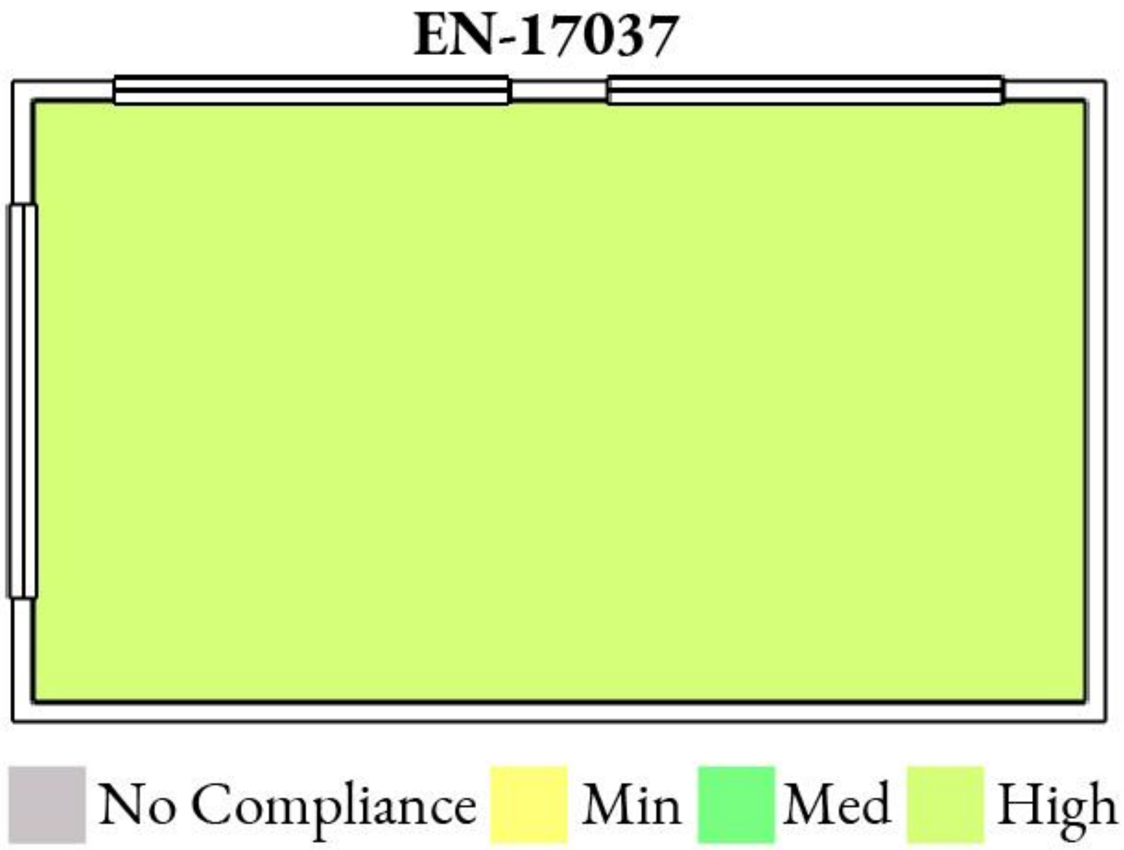


Percentage of Daylit Space: 59.3



Daylight compliance: Medium