Toward a Unified Global Standard for Outdoor Trespass Lighting: Harmonising Design, Metrics, and Environmental Protection Across Jurisdictions

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ABSTRACT

Outdoor Trespass Lighting (OTL) is regulated globally using vertical illuminance limits; however, significant divergence exists across six primary regulatory frameworks that were analysed (IES, CIE, ILP, AS/NZS, IDA, TAC), resulting in regulatory fragmentation and inconsistent environmental protection. This study develops and validates a unified international OTL framework using a minimum-threshold convergence (MTC) methodology, whereby the most restrictive permissible illuminance across standards is adopted for each environmental zone. A systematic comparative review (2010–2025) was conducted using Scopus, Web of Science, and professional standards databases. Regulatory divergence was quantified, and a harmonised four-zone framework (1, 3, 8, 15 lux) was derived. The framework was validated through simulation-based case studies using representative roadway lighting geometries and cross-comparison against IES RP-8 and CIE 150 compliance outcomes. Results demonstrate that the unified thresholds: (i) remain within all major international limits, (ii) reduce regulatory ambiguity, and (iii) do not compromise safety or compliance. Sensitivity analysis confirms that minimum-threshold convergence provides a robust, conservative, and legally defensible harmonisation strategy. The study establishes a scalable model for global lighting governance, identifies the limitations of facade-based photometry, namely that vertical illumination does not fully capture circadian or biological light exposure, and recommends integrating it with eye-level and circadian metrics. This is a governance consequence for municipalities and engineering practitioners.

Keywords: Outdoor Trespass Lighting; Regulatory Harmonisation; Environmental Governance; Vertical Illuminance; Skyglow; Glare; Policy Convergence.

INTRODUCTION

Artificial Light at Night (ALAN) has become an indispensable component of modern society, supporting transportation systems, economic activity, public safety, security, and nighttime mobility. However, a growing body of research demonstrates that excessive, misdirected, or poorly controlled outdoor lighting can generate substantial environmental and societal impacts. These impacts include ecological disruption, degradation of nocturnal habitats, circadian rhythm disturbance, glare-related visual impairment, and increased skyglow, all of which have prompted increasing concern among researchers, policymakers, and lighting professionals (Falchi et al., 2016; Kyba et al., 2017; Boyce, 2014).

One of the principal manifestations of these impacts is Outdoor Trespass Lighting (OTL), which occurs when artificial light extends beyond its intended task area and intrudes upon adjacent properties, sensitive ecological environments, or residential spaces. OTL is widely recognized as a source of visual discomfort, environmental degradation, and community concern, particularly where nighttime illumination affects residential dwellings or environmentally sensitive areas. Consequently, most professional lighting organizations regulate OTL using maximum vertical illuminance limits measured at property boundaries, façades, or other representative locations where light intrusion may occur.

Although there is broad international agreement on using vertical illuminance (Ev) as the primary metric for assessing OTL, substantial divergence exists among the major regulatory frameworks currently in use. Prominent authorities, including the Illuminating Engineering Society (IES), International Commission on Illumination (CIE), Institution of Lighting Professionals (ILP), International Dark-Sky Association (IDA), Standards Australia/Standards New Zealand (AS/NZS), and the Transportation Association of Canada (TAC), employ different environmental zoning systems, vertical illuminance thresholds, curfew provisions, adaptive-lighting considerations, and enforcement approaches. These differences have evolved independently in response to regional priorities and regulatory traditions, resulting in a fragmented international regulatory landscape.

The consequences of this fragmentation extend beyond technical inconsistencies. From a governance perspective, conflicting standards increase regulatory complexity, complicate compliance assessments, create uncertainty for practitioners operating across jurisdictions, and may lead to inconsistent levels of environmental protection. Municipalities, lighting designers, infrastructure owners, and manufacturers are often required to navigate multiple standards that pursue similar objectives yet prescribe different allowable limits. Such divergence can increase transaction costs, reduce regulatory predictability, and hinder the development of coherent international environmental policies. Research on policy harmonization and regulatory convergence has consistently demonstrated that alignment among jurisdictions can improve interoperability, reduce implementation burdens, and strengthen governance effectiveness (Abbott and Snidal, 2001; Vogel, 1995; Holzinger and Knill, 2005; Holzinger et al., 2008; Blind, 2013; Alexandros, 2025).

Beyond governance considerations, concerns regarding ALAN have increasingly expanded into the domain of public health. Although findings from animal studies are not always directly transferable to humans, epidemiological evidence consistently associates nighttime light exposure with disruptions to sleep and circadian health, as well as a range of adverse physiological outcomes (AMA, 2016; Nagai et al., 2019; Kaushik et al., 2022; Phillips et al., 2019; Walker et al., 2021). Additional studies have linked ALAN exposure to inflammatory responses, delayed healing, cardiovascular effects, and other health-related concerns (Boyko et al., 2017; Obayashi et al., 2019; Mindel et al., 2019; Weil et al., 2020). These findings reinforce the importance of establishing effective and enforceable mechanisms to manage intrusive outdoor lighting, particularly in residential environments where occupants may be exposed.

Previous studies have explored methods for reducing light pollution and controlling obtrusive lighting through improvements in luminaire design, lighting calculations, visibility-based approaches, adaptive controls, and intelligent lighting systems (Thurairajah et al., 2021a; Thurairajah et al., 2021b; Thurairajah et al., 2022a; Thurairajah, 2022b; Thurairajah, 2023a; Thurairajah, 2023b; Thurairajah, 2023c). While these contributions have advanced the understanding of OTL mitigation, comparatively little attention has been devoted to harmonizing the regulatory frameworks themselves. Existing literature predominantly focuses on the consequences of ALAN and the technical means of controlling it, whereas the problem of conflicting international OTL standards remains largely unresolved. As a result, a significant gap exists in both the academic literature and professional practice: no unified framework currently reconciles the differing vertical illuminance limits adopted by major international authorities while maintaining compatibility with existing regulatory requirements.

To address this gap, the present study develops a unified global framework for Outdoor Trespass Lighting based on a Minimum-Threshold Convergence (MTC) methodology. The underlying principle is intentionally conservative: for each environmental zone, the lowest maximum vertical illuminance value accepted among the major international standards is selected as the harmonized threshold. Unlike averaging or consensus-based approaches, which may dilute environmental protections, the minimum-threshold approach preserves the most restrictive existing requirement, ensuring compatibility with all reviewed regulatory frameworks while maintaining a precautionary level of environmental protection.

The study employs a systematic comparative review of six principal OTL regulatory frameworks, drawing on peer-reviewed literature, professional standards, and institutional publications from 2010 to 2025. Regulatory divergence is evaluated through comparative analysis of zoning classifications, illuminance limits, and curfew provisions. A harmonized four-zone framework is subsequently derived and validated through simulation-based case studies and analytical calculations of vertical illuminance using representative roadway-lighting scenarios. Sensitivity analyses are performed to evaluate the robustness and reproducibility of the proposed methodology under varying geometric and photometric conditions.

This research makes four principal contributions. First, it introduces a novel application of regulatory convergence theory to outdoor lighting governance. Second, it develops the first unified international OTL framework, systematically derived from the requirements of six major standards organizations. Third, it demonstrates that a harmonized set of thresholds of 1, 3, 8, and 15 lux can satisfy all reviewed frameworks without weakening existing environmental protections. Finally, it provides municipalities, practitioners, and standards organizations with an implementation-ready model to reduce regulatory fragmentation, improve policy coherence, and support future international standardization efforts. In doing so, the study establishes a practical pathway toward global harmonization of OTL regulation while recognizing the need to integrate biologically relevant exposure metrics that go beyond conventional vertical illuminance measurements.

BACKGROUND

Existing outdoor OTL guidelines worldwide

It is essential to have a clear understanding of what constitutes OTL and how to control it to support residents' CH and well-being. Various components are associated with OTL, such as mounting height, improper installation, overlighting, and clutter, which refers to excessive lighting that can cause glare and discomfort (IES RP-8, 2021). For instance, adjusting the mounting height, ensuring proper installation, and using OL controls can help mitigate these issues. Identifying these elements that affect resident well-being is crucial. International literature search tools, databases, and publishers, such as Google Scholar, MetSearch, Scopus, Elsevier, and professional authorities, were used to review all available technical documents on OTL to clearly define the proposed task. Some of the leading authorities contacted on Published Standards are:

1. IES (TM-15, 2021), IES RP-8-25, North America
2. CIE (CIE-150, 2017), Europe
3. IDA (2021), International
4. AIES (AS/NZS 42822019, 2019), Australia
5. ILP (GN01, 2020), U.K.
6. TAC (TAC, 2006), Canada

The author has been familiar with North American-published literature on OTL throughout his professional practice but initiated a comprehensive literature search (from 2019 to 2025) to identify and compile all available publications on OTL. Some of the publications are identified as follows:

1. The CIE, "Guide on the Limitation of the Effects of Obtrusive Light from OL Installations, 2nd Edition" (CIE-150, 2017).
2. The AS/NZS, "Control of the obtrusive effects of OL" (AS/NZS 42822019, 2019).
3. The ILP, "Guidance Note 1 for the reduction of obtrusive light 2020" (ILP GN01, 2020).
4. The IDA, "lighting zone rating and characteristics zones" (IDA, 2021).
5. The IES, "Recommended practice for lighting roadway and parking facilities" (ANSI/IES RP-8, 2021).
6. The TAC, "Guide for the Design of Roadway Lighting" (TAC, 2006).

The published data from these documents were used to establish definitions, design criteria, calculations, and measurement practices, and form a basis for determining limiting values for OTL. This approach will help establish a robust scientific basis for the proposed OTL design criteria. Later, the author conducts a thorough analysis and theoretical exploration of the current design criteria for OTL and their variations. The methodology section aims to address the existing knowledge gap.

Sometimes OL from luminaires falls on or spreads around green spaces and dwellings when the intended area in which they are installed illuminates an outdoor environment, including roadways, parking lots, pathways, and sports fields. Most importantly, the ALAN falls within residential areas, where it can be an unwanted

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OTL, subsequently annoys the public, deprives them of sleep, and may also obstruct the operation of security cameras (ANSI/IES RP-8, 2025). Avoiding high-mast lighting near residential areas, hospitals, hotels, and airports is a more effective way to control OTL. However, it can be validated by OLD.

The limiting values for OTL are influenced by transient adaptation and ambient brightness in the traffic corridor environment (Pothukuchi 2021). For example, a higher OTL limit may be tolerated in an urban environment where ambient and adaptation brightness may be relatively high (compared to a rural setting). Conversely, no OTL may be accepted in an environmentally sensitive area (ANSI/IES RP-8, 2025).

A comparative matrix was developed to facilitate a systematic evaluation of obtrusive light at night (OTL) design criteria adopted by regulatory and professional organizations in North America and internationally. Table 1 presents a consolidated summary of the OTL design requirements and zone classifications established across the reviewed frameworks. While curfew-based lighting restrictions are generally not applied in North American jurisdictions, largely due to liability and public safety considerations, it is noteworthy that European guidance documents, including CIE 150 and ILP GN01, incorporate curfew provisions as a key mechanism for reducing light pollution and mitigating nighttime environmental impacts.

To enhance readability and reduce redundancy, the comparative analysis of the six regulatory frameworks has been consolidated into a single comprehensive matrix that directly juxtaposes environmental zone classifications and corresponding illuminance limits. This unified presentation enables a clearer assessment of similarities, differences, and areas of regulatory convergence among the frameworks. Detailed zone descriptions and illuminance thresholds for each framework are provided in Appendix A, which presents six framework-specific tables for reference. For the purposes of the main text, the zone definitions have been condensed to emphasize the most significant distinctions and commonalities, thereby supporting a more concise and focused comparative analysis.

Table 1: Outdoor OTL design criteria developed by other authorities.

Source: Compiled by the author

No.	Development of OTL Design Criteria	Design Criteria Used or Developed by Other Authorities					
	Organisation and Country	Curfew	OL Zones	Trespass Values for Zones, Vertical Illuminance in Lux			
				LZ1	LZ2	LZ3	LZ4
13a	"Transport Association of Canada" (TAC, 2016)	NO	YES	1	3	8	15
13b	"IES" (ANSI/IES RP-8, 2025)	NO	YES	1	3	8	15
13c	"CIE" (CIE-150, 2017), Europe	YES	YES	2	5	10	25
13d	"ILP" (ILP GN01, 2020), UK	YES	YES	2	5	10	25
13e	"Standards Australia/Standards New Zealand" (AS/NZS 42822019, 2019)	NO	YES	-	10	10	25
13f	"International Dark Sky Association" (IDA/IES MLO, 2020)	NO	YES	1	3	8	15

Key divergence metrics:

- Threshold variance (Δlux)
- Zone equivalence mismatch
- Curfew dependency

OL zones are critical for managing OL to minimise OTL, enhance visibility, and protect the night sky. Various organisations have established guidelines to define these zones, each with specific criteria for OTL limits. OL

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zones are categorised based on the level of artificial light present and their effects on ecological systems and human health. These zones are designed to provide a regulatory framework for controlling OL, to reduce OTL, glare, and skyglow.

The above-noted organisations have proposed OL zones under sections 2.4.1 to 2.4.6, showcasing a collaborative effort with minor variations in the OTL limiting values and description of the OL zones. They all share a common goal: effectively managing OTL to protect human interests and natural ecosystems. Understanding these zones is crucial for municipalities, as it empowers them to develop better policies for urban planning and environmental conservation. It is essential to strike a balance and create a framework for OTL that aligns with international practices and local requirements for OLD.

The conflicting OTL criteria used by different professional organisations worldwide create a gap in knowledge, literature, and professional practice. The contradiction between various standards and practices is not just a matter of concern but an urgent issue that needs immediate resolution. They must be harmonised. This justifies and highlights the critical need for further investigation.

Therefore, the following section will provide the methodology to fill this gap in knowledge to find a unified global standard for the OTL application.

METHODOLOGY: MINIMUM-THRESHOLD CONVERGENCE

The limitations of the current fragmented global standards can be addressed through a unified global framework.

Systematic Comparative Review Protocol

A structured review was conducted using:

- Databases: Scopus, Web of Science, Google Scholar
- Standards repositories : IES, CIE, ILP, IDA, AS/NZS, TAC
- Timeframe: **2010–2025**

Inclusion Criteria:

- Official national or international OTL standards
- Documents specifying **quantitative vertical illuminance thresholds**
- Peer-reviewed or institutional publications

Exclusion Criteria:

- Non-quantitative guidance
- Non-official or non-validated sources

This yielded **6 primary regulatory frameworks** for comparative analysis.

A conservative harmonisation principle was adopted:

For each environmental category, select the lowest maximum vertical illuminance limit currently accepted within major international standards.

This approach:

- Preserves environmental protection
- Ensures compatibility with all reviewed frameworks
- Eliminates threshold conflict
- Reduces interpretive discretion

Unlike averaging or median-based harmonisation, minimum-threshold convergence avoids regulatory dilution.

Conflicting Criteria

All professional organisations have different OTL limiting values. The best way to unify these is to select the 'worst-case scenario' approach, which in this context means the lowest OTL criteria number for each zone provides the worst conditions so that it can satisfy all the organisation's requirements. This justifies and unifies the requirements for a single evaluation criterion and satisfies every standard. The unified criteria are crucial and pivotal in proving the solution. It eventually leads to a more efficient and effective way of evaluating OTL, instilling confidence in the approach. However, it still does not satisfy the residents' impact of OTL.

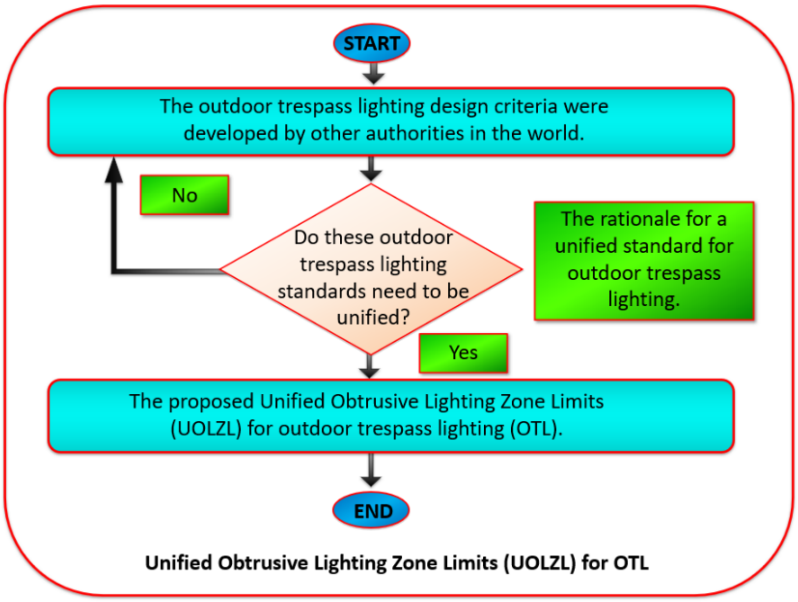
Proposed unified design requirement for OTL based on the current Standard.

The author's proposed OL zone classifications are based on the abutting Municipal Official Land Use Designation and will address conditions unique to Ontario (Ontario Land Use Planning, 2023). The OL zones are classified into four zones, ranging from LZ1, which is the most restrictive, to LZ4, the least restrictive. Various organisations' existing OTL practices are covered under background (TAC, 2006; IES TM-15, 2021; CIE-150, 2017; ILP GN-01, 2020; IDA, 2021; AS/NZS, 2019). All these organisations have similar criteria with minor variations in the description and the OTL values.

Figure 1 shows the flowchart for the proposed OTL, which checks all available standards worldwide and ensures they meet the unified OTL standard for occupants.

Figure 1: The proposed OTL meets the occupant's OTL

(Source: by the author)



Quantitative Regulatory Divergence Analysis

A harmonized obtrusive light at night (OTL) standard may be achievable across the reviewed regulatory frameworks. As illustrated in Figure 2, the OTL limiting values established by the various organizations prior to harmonization exhibit a substantial degree of alignment, with only minor variations observed among the respective standards. This convergence indicates the potential for developing a unified and broadly acceptable framework that accommodates the requirements of multiple professional and regulatory bodies while maintaining consistency in environmental and community protection objectives.

The principal OTL performance metric considered across the reviewed frameworks is vertical illuminance, measured either at the property boundary or at the façade of residential bedroom windows, where light trespass

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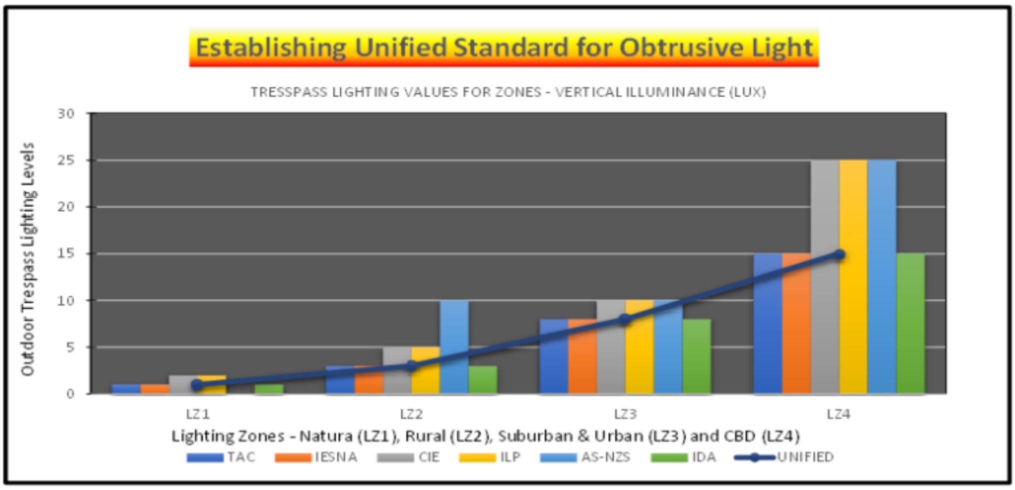
is most likely to affect occupants. By directly comparing these limiting values, Figure 2 provides a quantitative basis for assessing regulatory divergence and identifying common threshold ranges that could support the development of a cohesive international standard for OTL management and mitigation.

Figure 2: The proposed unified standard for outdoor OTL before harmonisation

(Source: by the author)



Harmonisation Model: Minimum-Threshold Convergence (MTC) methodology

The Minimum-Threshold Convergence (MTC) methodology is to harmonise international Outdoor Trespass Lighting (OTL) standards. While individual OTL limits exist across major authorities (IES, CIE, ILP, AS/NZS, IDA, TAC).

Formal Definition

For each lighting zone:

$$E_{\text{Unified},\, i} = \min\left(E_{TAC}, E_{IES}, E_{CIE}, E_{ILP}, E_{AS/NZS}, E_{IDA}\right)$$

Where:

- $i = \{LZ1, LZ2, LZ3, LZ4\}$
- Missing values (e.g., "–") are **excluded**, not treated as zero.

Table 14 shows the minimum threshold selection and the resulting unified threshold limit.

Table 14: Minimum-Threshold Selection

Zone	Values Considered						Minimum Selected	Unified Limit
	TAC	IES	CIE	ILP	AS/NZS	IDA		
LZ1	1	1	2	2	-	1	1	1 lux
LZ2	3	3	5	5	10	3	3	3 lux
LZ3	8	8	10	10	10	8	8	8 lux
LZ4	15	15	25	25	25	15	15	15 lux

The systematic derivation of a single, conservative, universally compliant threshold set (1, 3, 8, 15 lux) is novel. The originality lies not in introducing new photometrics, but in:

- Framing standard harmonisation as a regulatory convergence problem for Universal compliance compatibility

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- Explicitly operationalising a worst-case / non-deterioration principle (no standard weakened).
- Translating fragmented standards into an implementation-ready governance framework.

The unified thresholds are derived using a conservative minimum-selection rule, ensuring that the adopted limits do not exceed any value currently accepted within major international standards. This guarantees full backward compatibility with all regulatory frameworks and prevents any reduction in environmental protection.

Validation

Simulation-Based Case Study

A **representative lighting scenario** was modelled:

Table 15 provides the complete set of framework components together with a reproducible measurement protocol that enables independent verification of the results. The analysis employed Lithonia Lighting LED luminaires with symmetric distribution characteristics to establish a controlled and representative simulation environment. The primary purpose of the simulation was to calculate vertical illuminance and assess the accuracy of the proposed analytical methodology by directly comparing it with model outputs. A sensitivity analysis was subsequently performed at observation points L1, L2, X, R1, and R2 to examine the influence of spatial position on calculated illuminance values. The results demonstrate the approach's reproducibility and provide a basis for evaluating the robustness of the proposed framework under varying measurement conditions.

Table 15. Lighting System Configuration.

Item	Description
Luminaire	Lithonia Lighting
Wattage	149 W
CCT	5000 K
CRI	90
Distribution	Symmetric
Mounting Height	11.4 m
Absolute Lumens	24,000
Protection Rating	IP65
Software (Autolux 2025)	The calculation for the horizontal level at the finished grade. ECI at 1.5m height at the property line and bedroom windows.

Table 15 below shows representative lighting parameters selected based on typical lighting practices described in ANSI/IES RP-8-25.

Table 16: Lighting parameters

Source: by the author

Parameter	Value
Mounting height	10 m
Road Width	12 m
Distance to residence (Setback distance)	25 m
Observer eye height	1.5 m
Luminaire: Lithonia Lighting, 149W, 90CRI, 50K	

Five observation points were evaluated relative to the luminaire location:

- directly opposite the pole

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- 10 m lateral offset
- 20 m lateral offset.

Three evaluation frameworks were applied:

1. IES RP-8, IDA and TAC compliance
2. CIE 150 and ILP compliance
3. AS/NZS 42822019 compliance
4. Proposed unified standard

These locations represent typical viewing geometries encountered in residential environments adjacent to roadways. Figure 3 below shows the computer calculation results for the ECI.

Figure 3: Façade (Vertical) Computer Calculation

Source: Designed by the author

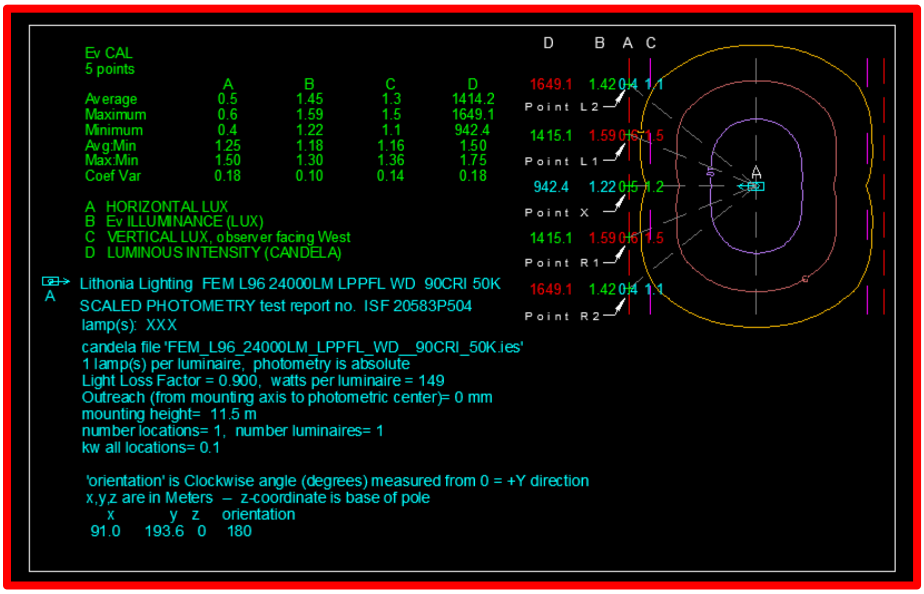
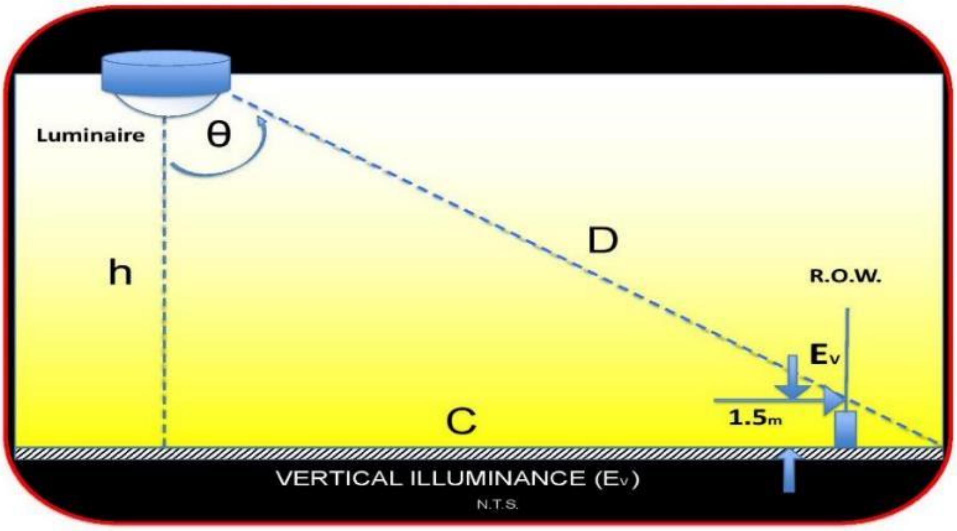


Figure 4 below shows where the vertical illuminance calculation will be performed.

Figure 4: Vertical Illuminance

Designed by the author, adopted from ANSI/IES RP-8 (2025)



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$$\text{Vertical Illuminance } [E_V] = \frac{\text{Intensity * Sine angle } [I_\theta \sin\theta]}{\text{Distance Square } [D^2]} \quad (1)$$

The basic calculation of flux transfer is the inverse square cosine law (ANSI/IES RP-8, 2025). For the particular case in which the surface is normal to the flux, θ = 90 degrees, the equation is simplified to:

$$\text{Horizontal Illuminance } [E_H] = \frac{\text{Intensity } [I_\theta]}{\text{Distance Square } [D^2]} \quad (2)$$

$$\text{Vertical Illuminance } [E_V] = 0 \quad (3)$$

Where: E_H = horizontal illuminance.
I_θ = luminous intensity of an illuminance source.
θ = the angle measured from the vertical to the incident ray.
E_v = vertical illuminance.
h = vertical distance from the source.
D = distance between the source and point P.
D = h/cosθ = C/sinθ

As measured from the OLS, the horizontal and vertical illumination are inversely proportional to the square of the vertical distance. In general, the relationship is expressed as:

$$\text{Horizontal Illuminance } [E_H] = \frac{\text{Intensity * cosine angle } [I_\theta \cos^3\theta]}{\text{Distance Square } [h^2]} \quad (4)$$

$$\text{Vertical Illuminance } [E_V] = \frac{\text{Intensity * sine \& cosine anlges } [I_\theta \cos^2\theta \sin\theta]}{\text{Distance Square } [h^2]} \quad (5)$$

(If cos θ =90°, this formula is not applicable.

These equations form the basis of conventional outdoor lighting calculations.

Table 16 below shows the required manual calculation results for the vertical illuminance.

Table 16: Manual Calculation

Source: by the author

Description	Point L2 is 20m right to Point X	Point L1 is 10m right to Point X	Window opposite to Pole (Point X)	Point R1 is 10m right to Point X	Point R2 is 20m right to Point X
Pole MH from eye (h)	10.00	10.00	10.00	10.00	10.00
Pole to Home window (C)	32.02	26.93	25.00	26.93	32.02
Tan θ	3.20	2.69	2.50	2.69	3.20
Angle θ	72.65	69.61	68.19	69.61	72.65
Intensity(I)	1649.10	1415.10	942.40	1415.10	1649.10
$Cos^2θ$	0.09	0.12	0.14	0.12	0.09
Sin θ	0.95	0.94	0.93	0.94	0.95

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h^2	100	100	100	100	100
Vertical Illuminance (Ev)	1.42	1.59	1.22	1.59	1.42

Note: The intensity values have been taken from the OL computer calculation

The results indicate that the calculated vertical illuminance values ranged from approximately 1.22 lux to 1.59 lux, depending on the observer's position and viewing angle.

Importantly, the manual calculations matched the computer simulation results, confirming the validity of the proposed formula. This agreement demonstrates that the derived equation accurately represents the geometric relationship governing illuminance from outdoor luminaires.

The sensitivity analysis provides a systematic evaluation of how calculated vertical illuminance responds to changes in key geometric and photometric variables, including observation angle, spatial position, and luminous intensity. To maintain a controlled comparison between simulation and analytical methods, roadway-specific and environmental variables—such as roadway classification, depreciation factors, atmospheric effects, and surface reflectance characteristics—were excluded from the analysis. This approach isolates the intrinsic performance of the proposed calculation framework and facilitates direct validation of the analytical model. The results demonstrate strong agreement between simulated and calculated illuminance values across all tested configurations, indicating that the methodology is both reliable and reproducible. Importantly, the analysis confirms that the minimum-threshold framework remains stable under varying conditions and consistently constrains worst-case exposure levels, reinforcing its effectiveness as a precautionary and harmonized regulatory approach. The following section will provide the required results from the above-noted assessments.

RESULTS: PROPOSED UNIFIED GLOBAL FRAMEWORK FOR OTL

Validation Results

The validation results and the findings highlight that the outdoor trespass lighting is well below the required threshold light level of 3 lux for the obtrusive lighting zone LZ2. Table 17 below indicates the criteria if the study location if it is within an obtrusive lighting zone (LZ2).

Table 17: Criteria for the obtrusive lighting zone (LZ2)

Metric	**IES RP-8, IDA and TAC**	**CIE 150 and ILP**	**AS/NZS 42822019**	**Unified**
Compliance achieved	✓	✓	✓	✓
Maximum Ev (lux)	3.0	5.0	10.0	3.0
Over-lighting risk	Medium	High	High	Low

Key Finding:

- Unified thresholds never exceed any existing standard
- Provide the most conservative compliant condition

Unified Obtrusive Lighting Zone Limits (UOLZL)

The harmonised system consolidates international categories into four environmental zones. Therefore, the author proposes a unified standard to test OTL. These zones can be adapted as Unified Obtrusive Lighting Zone Limits (UOLZL) for OTL. Table 18, shows the proposed unified OL zones:

Table 18: The Proposed Unified Obtrusive Lighting Zone Limits (UOLZL)

No.	OL Zones	Unified Limit (Ev)	Ambient Brightness	Locations	Land Use
14a	LZ1	1 Lux	Dark	Environmentally Sensitive Area (ESA)	Natural Park, River, Valley, Sensitive Vegetative Species

14b	LZ2	3 Lux	Low	Rural	Rural, Agricultural or Open Spaces
14c	LZ3	8 Lux	Medium	Urban and Suburban Residential	Low/Medium Density residential or Institutional Facilities & Churches
14d	LZ4	15 Lux	High	Dense Urban with blended Residential, Commercial and Industrial	Commercial, Industrial & high-density residential & recreational mixed-use.

Definition: Maximum allowable vertical illuminance at any point along the vertical plane of the property boundary, measured according to CIE 150:2017 or ANSI/IES RP-8-25 procedures.

Curfew differentiation is intentionally excluded to enhance enforcement clarity and reduce administrative variability.

Proposed design criteria for OTL

The OTL at a height of 1.5m can be calculated using OL design software or measured using a light meter. All measurement and calculation methods must meet IES or CIE standards (ANSI/IES RP-8-25, 2025; CIE-150, 2017). The author presents a unified OTL with limiting values for the maximum levels in Table 19.

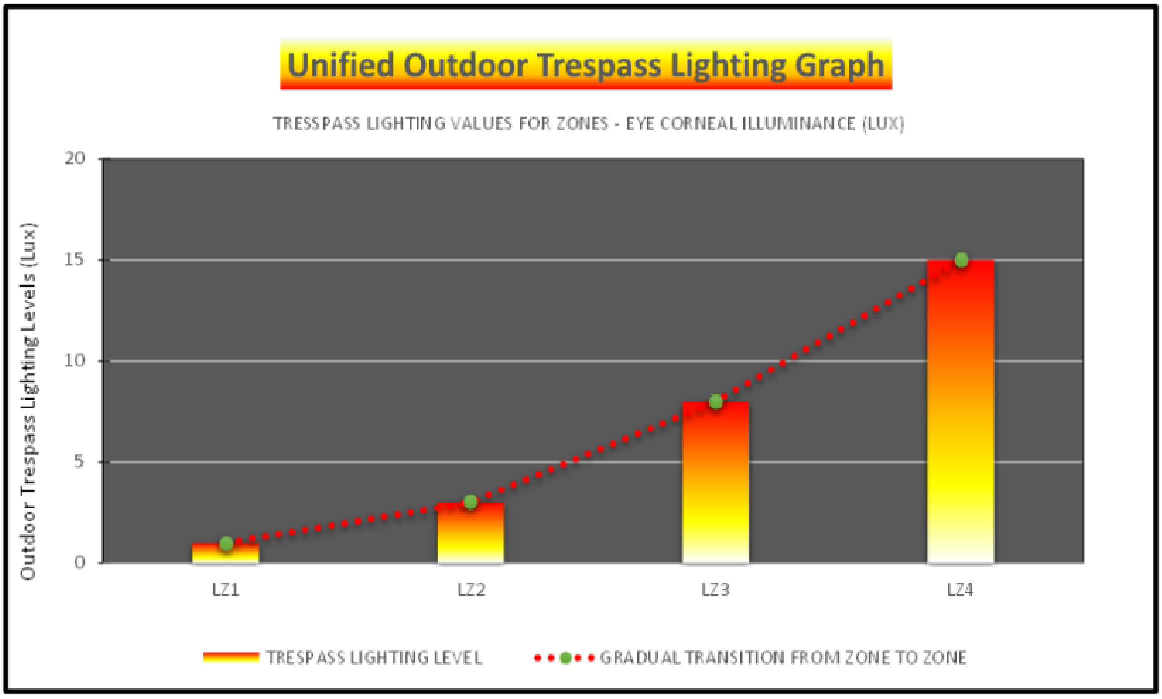
Table 19: Proposed unified outdoor OTL levels

No.	OL Zones	Unified Limit (Ev) (Lum. /Sq. m.)
15a	LZ1	1.0 lux
15b	LZ2	3.0 lux
15c	LZ3	8.0 lux
15d	LZ4	15.0 lux

Figure 5 below shows A graphical representation of OTL levels versus OL zones after harmonisation.

Figure 5: A graphical representation of OTL levels versus OL zones after harmonisation

(Source: by the author)



A minimum-threshold convergence methodology was applied to derive unified obtrusive lighting limits. For each environmental zone, the lowest maximum vertical illuminance value reported across major international standards (IES, CIE, ILP, AS/NZS, IDA, TAC) was selected. Missing values were excluded from the selection process. This approach ensures that the unified thresholds remain within all existing regulatory limits, thereby guaranteeing universal compliance and preserving the most conservative level of environmental protection. The resulting unified limits of 1, 3, 8, and 15 lux for Zones LZ1–LZ4 represent a globally harmonised and legally defensible framework.

The local requirement is equal to or well below the international standard requirement. Therefore, establishing a global standard does not violate the local standard or requirement. Therefore, the following section will discuss the importance of a unified global standard for the OTL applications.

DISCUSSION

Theoretical Contribution

This study introduces:

A conservative convergence framework for environmental standard harmonisation

Distinct from:

- Averaging → weakens protection
- Median → ignores extremes

Minimum threshold ensures:

- Risk minimisation
- Legal defensibility
- Policy interoperability

Scientific Limitation

The study acknowledges:

- Vertical illuminance **does not fully represent ocular or biological exposure**
- Future standards should integrate:
  - Eye-level metrics (e.g., corneal illuminance)
  - Melanopic Weighting

Rationale for a unified standard for outdoor OTL

In this context, OTL is an area that is not to be illuminated. The leading OL professional organisations (TAC, IES, CIE, ILP, AS/NZS, and IDA) reviewed and recommended limitations at the ROW for traffic corridors or resident property line (RPL) for other public OL applications.

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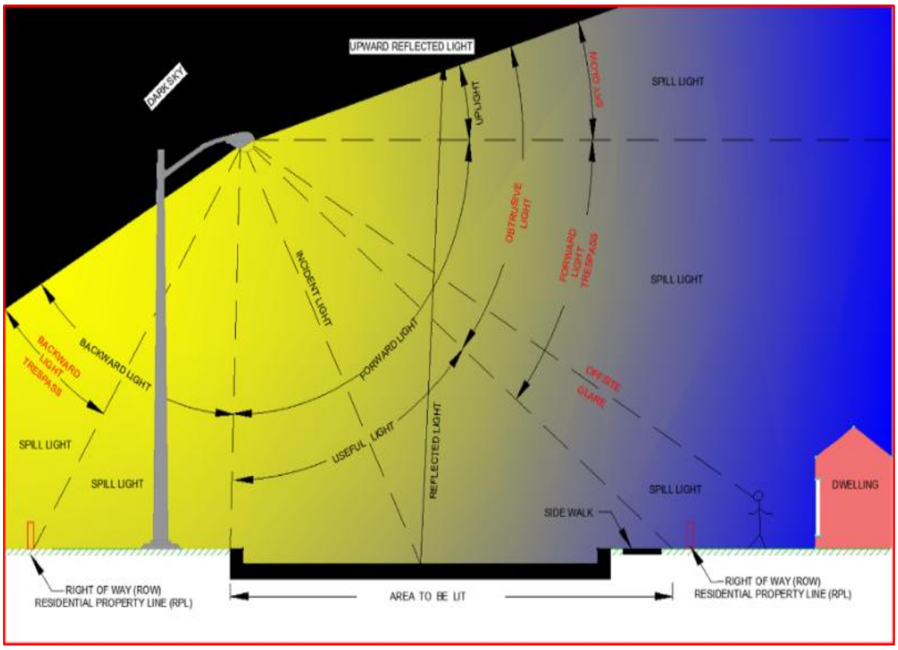
Figure 6 shows OLP, including useful light, obtrusive, and OTL, adopted from the "Recommended practice for lighting roadway and parking facilities" (ANSI/IES RP-8, 2025).

Figure 6: Useful Light and OTL

Source: Adopted from ANSI/IES RP-8-25 and designed by the author



Authorities assigned the ROW or RPL as an OTL limit (ANSI/IES RP-8, 2025; IDA/IES, 2020) for roadway lighting applications. However, European guidelines advise limiting vertical illuminance on RPL, with a focus on dwellings with windows (ILP GN01, 2021; CIE 150, 2017). By collectively addressing OTL in occupant bedroom windows, OL professionals can significantly improve public well-being. This collective effort is a powerful opportunity to improve the living conditions of many.

Traffic density, or the number of vehicles on a given stretch of road at a specific time, can increase the risk of accidents, particularly at night when visibility is reduced. This highlights the significance of implementing suitable OL solutions to improve safety for both drivers and pedestrians. By adjusting light levels based on real-time traffic conditions, adaptive OL systems not only conserve energy when full illumination is unnecessary but also greatly minimize OTL. This promising technology holds a bright future for roadway lighting, inspiring optimism about potential improvements in the overall user experience on roads.

Traffic density is also considered a risk factor when selecting an OL class in North America (IES RP-8, 2025). Traffic density changes during the night, and the OL class also changes (IES RP-8, 2025); ILP PLG08 (ILP PLG08, 2016) is the same in this respect. However, the author of this research employs the 'worst-case scenario', which in this context refers to the most severe or challenging conditions for this project. This approach ensures a thorough evaluation; therefore, higher-density traffic classes were used, instilling confidence in the process's thoroughness.

By following guidelines outlined in authoritative documents like ILP PLG08 and RP-8-21, municipalities can make informed decisions about adjusting their OL infrastructure in response to dynamic traffic conditions. Changes in traffic density during nighttime hours directly influence the selection and adjustment of OL classes, as outlined in the RP-8-21 and ILP PLG08 guidelines. It's crucial that authorities continuously monitor these changes to execute effective OL strategies that improve road safety while being mindful of environmental impacts. This vigilance and commitment, particularly through continuous monitoring, are key to ensuring the ongoing protection of road users.

The CIE (CIE-150, 2017) and Australians (AS/NZS 4282, 2019) have adopted two sets of limiting values to address some potentially conflicting requirements for higher illumination levels for dark-hours activity. The two groups of values are quantified based on the previous illumination levels in the area. The local authorities established higher light levels before a nominated or curfew hour and lower light levels after midnight. All roadway lighting applications were exempt from curfew restrictions because of the safety aspect of roadway lighting in North America (ANSI/IES RP-8, 2025).

European standards frequently employ post-curfew lighting reductions to limit obtrusive light and associated environmental impacts during periods of diminished nighttime activity. In contrast, North American standards have generally refrained from adopting such measures, primarily due to liability, safety, and operational considerations. A unified international framework could reconcile these differing approaches by establishing common baseline thresholds while permitting optional post-curfew requirements as jurisdiction-specific enhancements. Such a model would maintain harmonization of the principal performance criteria, ensuring consistency across jurisdictions, while providing regulatory flexibility for authorities seeking to impose more stringent post-curfew controls to address local environmental, ecological, or community concerns.

The resolution of conflicting criteria among professional organizations marks a critical advancement in this research. Given the variability in OTL limits across jurisdictions and standards, this study adopted a unified 'worst-case scenario' approach—applying the lowest permissible illuminance value across all zones as a benchmark to satisfy the organization's requirements. This methodological decision not only harmonized the evaluation process but also ensured compliance with the most stringent existing standards, thereby satisfying the expectations of all major regulatory bodies. The implementation of this unified criterion provided a robust and defensible foundation for subsequent analyses, reinforcing the reliability and consistency of the proposed evaluation framework. Moreover, it streamlined the comparison of design alternatives and facilitated more precise guidance for practitioners. However, while this resolution effectively standardizes technical assessment, it remains limited in capturing the nuanced health implications of OTL exposure on residents. The need for further integration of health-based OTL thresholds is urgent, as it is necessary to evaluate OL impacts holistically and ensure the well-being of residents.

ENFORCEMENT MECHANISMS

Beyond regulatory and governance considerations, exposure to Artificial Light at Night (ALAN) has emerged as a critical public health concern. Since 2019, health practitioners have increasingly recognised nighttime light exposure as a contributing factor in disease development and delayed physiological recovery (Donker, 2019; Simons et al., 2019; Nagai et al., 2019). Empirical evidence links ALAN exposure to impaired post-stroke recovery (Boyko et al., 2017; Weil et al., 2020), arterial stiffening (Obayashi et al., 2019), delayed skin wound healing (Walker et al., 2019), and systemic inflammation (Mindel et al., 2019).

Taken collectively, these findings elevate ALAN from a technical nuisance to a population-level health risk, reinforcing the urgency of regulatory harmonisation. The absence of consistent, enforceable limits on outdoor light intrusion undermines public health protections and weakens accountability across jurisdictions. In this context, professional bodies such as the Illuminating Engineering Society (IES) and the International Commission on Illumination (CIE) are well-positioned to play a central role in formalising and enforcing a unified framework that translates scientific evidence into coherent, globally applicable guidelines.

Professional organizations such as the IES and CIE are well-positioned to lead the development and institutionalization of a globally harmonized framework for obtrusive-light management. The proposed framework incorporates the most stringent requirements identified across the international standards reviewed and therefore provides a precautionary baseline that meets or exceeds the existing provisions of all six regulatory systems examined. Importantly, the framework does not conflict with current standards; rather, it establishes a more restrictive and environmentally protective set of criteria. By ensuring applicability across diverse jurisdictions and lighting contexts, the framework has the potential to minimize implementation challenges and enhance stakeholder acceptance. A practical pathway to adoption would involve endorsement by international standards organizations, complemented by implementation through model codes and municipal regulations at the local level. Such a dual-scale approach would enable progressive harmonization, allowing jurisdictions to realize the benefits of improved consistency and environmental protection while avoiding the institutional challenges associated with immediate global standardization.

INSTITUTIONAL AND PRACTICE IMPLICATIONS

The unified limits (1, 3, 8, 15 lux):

- Fall within the most restrictive internationally accepted values.
- Require no jurisdiction to weaken existing protections.
- Provide manufacturers with predictable compliance targets.
- Simplify multinational engineering documentation.
- Strengthen the legal defensibility of municipal bylaws.

By aligning photometric science with regulatory harmonisation theory, the framework transforms fragmented guidance into a coherent institutional template.

Importantly, the model avoids introducing biologically weighted or spectral metrics that, while scientifically evolving, lack universal legal codification and would reintroduce interpretive ambiguity.

LIMITATIONS AND FUTURE RESEARCH

A key limitation of the proposed framework is that it relies on a proxy measure of exposure rather than on the biological and health outcomes that ultimately motivate concern about artificial light at night. While the harmonized thresholds presented herein offer a practical mechanism for regulatory convergence, they are not necessarily optimal for health protection. The framework is therefore best viewed as a scientifically informed interim solution that balances current regulatory requirements with the need for international consistency. Importantly, its structure is sufficiently flexible to accommodate future metric developments, including biologically informed measures that may more accurately characterize human health impacts. Accordingly, the framework establishes a pathway for immediate harmonization while recognizing that further metric evolution may be necessary to achieve a more comprehensive and outcome-based regulatory approach. This study focuses on threshold convergence rather than:

- Spectral power distribution controls
- Adaptive lighting integration
- Longitudinal ecological or health outcome monitoring

Future work should include field validation across climatic regions and integration with dynamic lighting control systems.

FIELD MEASUREMENTS AND VALIDATION

Single-epoch field measurements offer limited accuracy because they cannot fully capture the range of operational, temporal, and environmental variables that affect outdoor lighting performance. Variations in lamp output, temperature, surface reflectance, atmospheric conditions, and measurement geometry introduce unavoidable uncertainties that cannot be eliminated through one-time measurements alone.

In this study, manual measurements and computational analyses show deviations within ±10% under controlled conditions, consistent with accepted tolerances in international standards and validation studies (CIE 198, 2011; EN 13201-4, 2015; IES RP-8, 2025; Rusu et al., 2021; University of New Brunswick, 2024). This agreement lies within the combined uncertainty limits associated with instrumentation accuracy, photometric data precision, modeling assumptions, and environmental variability.

Validation against established standards confirms that the adopted simulation tools reliably reproduce real-world lighting behavior under initial conditions (LLF = 1.0). In professional outdoor lighting practice, simulation results within ±10% of field measurements are regarded as functionally equivalent to measured performance.

Additional field validation is therefore unnecessary for the objectives of this research. The study prioritizes developing a harmonized standard using the Minimum-Threshold Convergence (MTC) framework over site-specific compliance verification. The demonstrated consistency with internationally recognized standards and independent field-validated studies provides sufficient confidence in the accuracy, reliability, and applicability of the proposed methodology.

This research concludes the next section based on the above-noted results and discussion.

CONCLUSION

This research critically evaluated existing international standards governing OTL and identified significant inconsistencies in environmental zoning classifications, vertical illuminance thresholds, curfew provisions, and measurement methodologies. Although all major organizations share the objective of reducing obtrusive light, their divergent numerical limits and assessment approaches hinder global harmonization and complicate professional practice.

By adopting a "worst-case scenario" methodology—selecting the lowest permissible vertical illuminance thresholds across established standards—this study developed a unified, conservative framework that satisfies all major regulatory bodies while simplifying implementation. The resulting unified OL zoning system (LZ1–LZ4) provides consistent maximum limits of 1, 3, 8, and 15 lux, respectively, ensuring international compatibility without weakening existing protections.

The framework:

- Maintains compatibility with all major standards
- Preserves environmental protection
- Enhances regulatory clarity
- Reduces institutional fragmentation
- Provides an implementation-ready municipal template

The harmonisation of OTL thresholds represents a substantive advancement in sustainable nighttime environmental governance, demonstrating how technical standard convergence can strengthen both environmental protection and institutional efficiency.

This study contributes to global discourse by:

- Providing a harmonised regulatory framework adaptable across jurisdictions.
- Offering municipalities a defensible, evidence-based OTL evaluation method.

Future research should integrate adaptive lighting technologies. The development of a unified international standard for OTL represents a critical step toward sustainable nighttime lighting—balancing safety, environmental stewardship, and human well-being.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

The author has declared that no competing interests exist.

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APPENDIX

Comprehensive definitions of environmental zones and associated illuminance thresholds for each reviewed framework are presented below. To ensure consistency and facilitate comparative analysis, each framework is documented using two framework-specific tables: one summarizing the environmental zone classifications and their descriptive characteristics, and a second detailing the corresponding maximum permitted vertical illuminance limits for each zone. This approach provides a transparent and reproducible basis for evaluating similarities, differences, and areas of convergence among the various OTL regulatory frameworks.

Transportation Association of Canada (TAC, 2006)

TAC has published a design guide for roadway lighting, which includes OL zones. As shown in Table A1., areas are categorized into four lighting zones (LZ1 to LZ4), with LZ1 being the most restrictive and LZ4 the least.

Table A1. Environmental OL Zones by TAC

Source: Compiled by the author (TAC, 2006)

No.	ZONE	DESCRIPTION
1a	LZ1	These are very rural areas outside a city with little or no ambient OL, no commercial development and no outside public night-time pedestrian activity. Where OL is required in an LZ1 area, the OTL measurements would be taken at the place being inhabited by humans as opposed to the property boundary line or edge of road allowance (TAC, 2006).
1b	LZ2	These are rural areas outside of a city with very low population density, no commercial development, minimal outdoor night-time pedestrian activity and no security issues or concerns. Where OL is required in an LZ2 area, the OTL measurement would be taken at the place being inhabited by humans as opposed to the property boundary line or edge of road allowance (TAC, 2006).
1c	LZ3	These are areas within a city, with low to medium population density, some outdoor pedestrian night-time activity and no security issues or concerns. Potential traffic conflict between vehicles, pedestrians and cyclists is inevitably mild. Such areas include residential subdivisions, town house developments on local and collector roads, as well as highways and freeways. Where OL is required in an LZ3 area, the OTL measurements would be taken at the property boundary line or edge of road allowance (TAC, 2006).
1d	LZ4	These are areas within a city with medium to high population density, or areas intended for heavy public and commercial activity. Potential traffic conflicts between vehicles, pedestrians and cyclists are inevitable and intense. Urban areas with both commercial and residential developments encounter a high level of nighttime vehicular and public activities. Such areas include those with multi-family housing (apartments), those in a downtown core, as well as areas of commercial and industrial development on local, collector and arterial roads, as well as highways and freeways. Where OL is required in an LZ4 area, the OTL measurements would be taken at the property boundary line or edge of road allowance (TAC, 2006).

The recommended acceptable maximum OL level value for the OTL limit is "vertical illuminance on properties" (TAC, 2006). The TAC values serve a critical role in determining the proposed highest values of vertical illuminance at the residence or at the boundary line/edge of the road allowance, as defined. Limitations on OTL extend to nearby or prospective dwellings, especially concerning the surfaces of those properties exposed to OL. The values consider the summary of all the OL installations (TAC, 2006). Table

A2 below gives the proposed highest vertical illuminance levels at property lines.

Table A2. The proposed maximum vertical illuminance on the ROW

Source: Compiled by the author (TAC, 2006)

OL Technical Parameter	Application Conditions	Environmental Zones				
		E0 (Lux)	E1 (Lux)	E2 (Lux)	E3 (Lux)	E4 (Lux)
Illuminance in Vertical Plane (E_v)	Pre-Curfew Post-Curfew not applicable	N/A	1	3	8	15
Note: Maximum allowable light level anywhere along the vertical surface of the RPL.						

Illuminating Engineering Society (ANSI/IES RP-8, 2025)

The IES published a document proposing introducing OL zones in all OL systems (ANSI/IES RP-8, 2025). Table 3 below provides the proposed OL zones and brief descriptions.

Table A3. Environmental OL Zones by IES

Source: Compiled by the author (ANSI/IES RP-8, 2025).

No.	ZONE	DESCRIPTION
2.3a	LZ0	OL Zone 0 applies to areas where permanent outdoor lighting is not expected. When used, lighting must be minimal in intensity and duration. Typical locations include wilderness parks, observatories, and protected dark-sky areas. Permanent lighting requires special review. Some rural communities may adopt Zone 0 for residential preservation.
2.3b	LZ1	OL Zone 1 applies to areas requiring low ambient lighting, such as single-family homes, rural centers, business parks, and low-activity commercial or industrial zones. It may also include developed sections of parks or natural areas with limited nighttime use.
2.3c	LZ2	OL Zone 2 applies to areas with moderate ambient lighting, including multifamily housing, schools, hospitals, mixed-use zones with residential focus, and community recreation areas. It may also accommodate outdoor sales or industry within otherwise LZ-1 designated areas.
2.3d	LZ3	OL Zone 3 applies to areas with moderately high lighting needs, including commercial corridors, town centers, mixed-use zones, industrial areas, rail yards, active recreation fields, malls, car dealerships, gas stations, and other exterior retail spaces with significant nighttime activity.
2.3e	LZ4	OL Zone 4 applies to areas with very high ambient lighting and is reserved for exceptional cases, such as high-density entertainment districts or heavy industrial zones. It is generally unsuitable for typical urban or suburban settings.

The recommended maximum OL level value for the OTL limit is "vertical illuminance on properties" (ANSI/IES RP-8, 2025). The OTL limitations "apply to nearby dwellings or potential dwellings, especially to their relevant surface or surfaces on properties." The values consider the summary of all the OL installations (ANSI/IES RP-8, 2025). Table A6 below gives the proposed highest values of vertical illuminance on property lines.

Table A4. The proposed maximum vertical illuminance on the ROW

Source: Compiled by the author (ANSI/IES RP-8, 2025).

OL Technical Parameter	Application Conditions	Environmental Zones				
		E0 (Lux)	E1 (Lux)	E2 (Lux)	E3 (Lux)	E4 (Lux)
Illuminance in Vertical Plane (E_v)	No curfew	0.5	1	3	8	15

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Note: Maximum allowable light level anywhere along the vertical surface of the RPL.

International Commission on Illumination (CIE-150, 2017)

The CIE has introduced OL zones in a latest publication titled "Guide on the Limitation of the Effects of Obtrusive Light from OL Installations, 2nd Edition" (CIE-150, 2017). Table A5 below indicates the proposed OL zones and provides brief descriptions.

Table A5 Environmental OL Zones by CIE

Source: Compiled by the author (CIE-150, 2017)

No.	OL Zones	OL Environment	Examples
2.5a	E0	"Intrinsically dark"	"IDA-designated Dark Sky Parks, UNESCO Starlight Reserves, and major optical observatories" (CIE-150, 2017).
2.5b	E1	Dark	"Relatively uninhabited rural areas" (CIE-150, 2017).
2.5c	E2	"Low district brightness"	"Sparsely inhabited rural areas" (CIE-150, 2017).
2.5d	E3	"Medium district brightness"	"Well-inhabited rural and urban settlements" (CIE-150, 2017).
2.5e	E4	"High district brightness"	"Town and city centres and other commercial areas" (CIE-150, 2017).

The recommended maximum OL level value for the OTL limit is applies to nearby dwellings, specifically their relevant surfaces, especially where windows are (CIE-150, 2017). OTL restrictions apply to adjacent existing or future dwellings, with specific focus on the impacted surfaces of those properties. The values consider the summary of all the OL installations (CIE-150, 2017). Table A6 below gives the proposed highest values of vertical illuminance on property lines.

Table A6 The proposed maximum vertical illuminance on the ROW

Source: Compiled by the author (CIE-150, 2017)

OL Technical Parameter	Application Conditions	**Environmental Zones**				
		E0 (Lux)	E1 (Lux)	E2 (Lux)	E3 (Lux)	E4 (Lux)
Illuminance in Vertical Plane (E_v)	"Pre-curfew"	N/A	2	5	10	25
	"Post-curfew"	N/A	<0.1*	1	2	5
*If the installation is for public OL, then this value may be up to 1 Lux						

Institution of Lighting Professionals (ILP GN01, 2021)

The ILP has introduced an OL zones publication titled "Guidance Note 1 for reducing obtrusive light" (ILP GN01, 2021), based on the published CIE standard, but it indicates some minor deviations from the CIE standard. Table A7 below gives the proposed OL zones and brief descriptions.

Table A7 Environmental Zones by ILP

Source: Compiled by the author (ILP GN01, 2021)

No.	Surrounding	OL Zones	OL Environment	Examples
7a	Protected	E0	"Dark" (SQM 20.5+)	"Astronomical observable dark skies, UNESCO Starlight Reserves, IDA Dark Sky Places" (ILP

				GN01, 2021).
7b	Natural	E1	"Dark" (SQM20 to 20.5)	"Relatively uninhabited rural areas, National Parks, Areas of Outstanding Natural Beauty, IDA buffer zones, etc." (ILP GN01, 2021).
7c	Rural	E2	"Low district brightness"	"Sparsely inhabited rural areas, village or relatively dark outer suburban locations" (ILP GN01, 2021).
7d	Suburban	E3	(SQM 15 to 20) "Medium district brightness"	"Well-inhabited rural and urban settlements, small town centres of suburban locations" (ILP GN01, 2021).
7e	Urban	E4	"High district brightness"	"Town/city centres with high levels of night-time activity" (ILP GN01, 2021).

The IDA refers to the Sky Quality Meter (SQM), a device that measures the night sky luminance. Astronomers typically use it to quantify the brightness of skyglow, measured in magnitudes per square arcsecond. This practical scale ranges from 16.00, indicating a bright night sky, to 22.00, representing minimal OTL, facilitating the measurement and evaluation of OTL levels.

The highest light level of vertical illuminance on property lines needs to be determined. These thresholds are enforced for surrounding residential properties, primarily where the windows are situated. The OL levels are the sum of all the ALAN installations. TableA8 below shows the proposed highest vertical illuminance on property lines:

TableA8 The proposed maximum vertical illuminance on ROW

Source: Compiled by the author (ILP GN01, 2021)

OL Technical Parameter	Application Conditions	**Environmental Zones**				
		E0 (Lux)	E1 (Lux)	E2 (Lux)	E3 (Lux)	E4 (Lux)
Illuminance in Vertical Plane (E_v)	Pre-curfew	N/A	2	5	10	25
	Post-curfew	N/A	<0.1*	1 x	2	5
*If the installation is for public OL, then this value may be up to 1 Lux						

The Council of Standards Australia/Standards New Zealand (AS/NZS, 2019)

The Council of Standards AS/NZS has introduced OL zones to manage the obtrusive effects of OL (AS/NZS 4282, 2019). This document is based on the published CIE standard (CIE-150, 2017) but there are some minor deviations from this standard. Table A9 below provides the proposed OL zones and brief descriptions.

Table A9 Environmental Zones by AS/NZS

Source: Compiled by the author (AS/NZS 4282, 2019)

No.	OL Zones	OL Environment	Examples
9a	A0	"Intrinsically dark"	"UNESCO Starlight Reserves, IDA Dark Sky Parks, Major optical observatories, no road lighting - unless specifically required by the road control authority" (AS/NZS 4282-2019, 2019).
9b	A1	"Dark"	"Relatively uninhabited rural areas, no road lighting - unless specifically required by the road control authority" (AS/NZS 4282-2019, 2019).
9c	A2	"Low district brightness"	"Sparsely inhabited rural areas and semi-rural areas" (AS/NZS 4282-2019, 2019).
9d	A3	"Medium district brightness"	"Suburban areas in towns and cities" (AS/NZS 4282-2019, 2019).

9e	A4	“High district brightness”	“Town and city centres and other commercial areas, residential areas abutting commercial areas” (AS/NZS 4282-2019, 2019).

The recommended maximum value of light technical parameters for obtrusive light control is vertical illuminance (AS/NZS 4282, 2019). The vertical illuminance is the summation of all the ALAN coming towards the measurement location. Table A10 indicates the proposed highest vertical illuminance on property lines:

Table A10 The proposed maximum vertical illuminance on the ROW

Source: Compiled by the author (AS/NZS 4282, 2019

OL Technical Parameter	Application Conditions	**Environmental Zones**				
		A0 (Lux)	A1 (Lux)	A2 (Lux)	A3 (Lux)	A4 (Lux)
Illuminance in Vertical Plane (E_v)	“Pre-curfew”	N/A	2	5	10	25
	“Post-curfew”	N/A	<0.1*	1	2	5
*If the installation is for public OL, then this value may be up to 1 Lux						

International Dark-Sky Association (IDA, 2021)

IDA is an advocacy group formed by astronomers, and its primary focus is on reducing direct sky glow and reflected light (IDA, 2021). OL Zone (LZ) Ratings and Characteristics are shown in Table A11 below:

Table A11 Environmental OL Zones by IDA

Source: Compiled by the author (IDA, 2021)

No.	ZONE	AMBIENT ILLUM.	CRITERIA
11a	LZ0	Very Dark	“Critical dark environments, such as especially sensitive wildlife preserves, national parks, and major astronomical observatories” (IDA, 2021).
11b	LZ1	Dark	“Developed areas in state and national parks, recreation areas, wetlands and wildlife preserves; developed areas in natural settings; areas near astronomical observatories; sensitive night environments; zoos; areas where residents have expressed the desire to conserve natural illumination levels” (IDA, 2021).
11c	LZ2	Low	“Rural areas, low-density urban neighbourhoods and districts, residential historic districts. This zone is intended to be the default condition if a zone has not been established” (IDA, 2021).
11d	LZ3	Medium	“Medium- to high-density urban neighbourhoods, urban shopping and commercial districts, industrial parks and districts. This zone is intended to be the default condition for commercial and industrial districts in urban areas” (IDA, 2021).
11e	LZ4	High	“Reserved for very limited applications such as major city centres, urban districts with especially high security requirements, thematic attractions and entertainment districts, regional malls, and major auto sales districts” (IDA, 2021).

The OTL limits the recommended maximum allowable light level anywhere along the vertical surface of the RPL (IDA/IES MLO, 2020). The OTL limitations, which significantly impact nearby dwellings, require that

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vertical illuminance on property line surfaces remain below the permitted maximum (IDA/IES MLO, 2020). Table A12 gives the proposed highest values of vertical illuminance on property lines.

Table A12 The proposed maximum vertical illuminance on the ROW

Source: Compiled by the author (IDA/IES MLO, 2020).

OL Technical Parameter	Application Conditions	**Environmental Zones**				
		E0 (Lux)	E1 (Lux)	E2 (Lux)	E3 (Lux)	E4 (Lux)
Illuminance in Vertical Plane (E_v)	No curfew	0.5	1	3	8	15
Note: Maximum allowable illuminance at any location along the vertical plane of the property boundary.						