

Review

Environmental Light, Screen Exposure, and Green Health in Technology-Rich K–12 Classrooms: A Scoping Review of Modifiable Conditions

Christopher Morales 

School of Pure and Applied Sciences, Florida SouthWestern State College, Fort Myers, FL 33919, USA; christopher.morales@fsw.edu

Abstract

Technology-rich K–12 classrooms are simultaneously learning environments, exposure environments, and resource-use environments. Students encounter daylight, electric light, digital displays, prolonged near work, and screen-mediated cognitive demands. In this review, green health refers to evaluating student health and educational functioning together with environmental performance, including energy demand, daylight utilization, system durability, maintenance, and life-cycle considerations. The scoping review was informed by PRISMA-ScR and JBI guidance. Database searches conducted from May through September 2026 included PubMed, ERIC, Scopus, and Web of Science, supplemented by targeted searching of standards organizations, professional and consensus sources, publisher platforms, relevant disciplinary literature, and citation chaining. Sources were assessed using a population–concept–context eligibility framework and classified by evidence role, directness, and primary evidence domain. The searches identified 3008 records. After deduplication and screening, 78 substantive publications were included in the evidence map; four methodological references were retained separately for review design and reporting. The 78 substantive publications were mapped across seven evidence domains. Green health practice in schools should jointly evaluate student health, instructional function, environmental sustainability, and equity/accessibility. Practical priorities include usable daylight and shading, low-flicker controllable lighting, balanced luminance, purposeful screen use, mode variation, outdoor time, accessible accommodations, commissioning, maintenance, and life-cycle-aware procurement.

Keywords: circadian health; classroom lighting; digital eye strain; green health; myopia; outdoor time; school design; screen exposure; sleep; student attention



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1. Introduction

Digital devices are now embedded in the ordinary infrastructure of K–12 education. Students read from laptops and tablets, view projected or interactive displays, navigate learning management systems, and complete extended near-work tasks under a combination of daylight and electric lighting. These conditions are often managed separately: lighting falls within facilities, screen use within technology, and attention within instruction or student behavior. From a green health perspective, however, they form a shared classroom exposure and resource-use environment. Lighting and display conditions can affect visual comfort [1–3], daytime light exposure can influence alertness [4,5], evening screen use is associated with sleep timing and duration [6–8], and classroom design and digital task structure can shape students' capacity to sustain cognitively demanding work [9–15].

In this review, green health is operationalized as the joint consideration of human health, educational functioning, environmental sustainability, and equity/accessibility when schools design, procure, operate, and evaluate lighting and digital systems. This framing is broader than daylight exposure alone. It includes energy use, daylight harvesting, controls, maintenance, durability, material and life-cycle implications, and the possibility that an environmentally efficient intervention may still create glare, poor visibility, inaccessible controls, or instructional problems. CIE integrative lighting guidance explicitly calls for human well-being to be balanced with energy, environmental, and architectural considerations [16], while current IES sustainability guidance defines sustainable lighting in relation to meeting visual needs with reduced impact on the natural environment and emphasizes life cycle and material health considerations [17].

This distinction is important because school lighting and technology decisions can produce both benefits and trade-offs. Daylight may reduce electric light demand while increasing glare or display reflections if shading and orientation are poorly managed [18]. LED retrofits may reduce connected load but do not guarantee comparable visual comfort or realized energy savings under occupied conditions [19,20]. Accordingly, the green dimension in this review is treated as an integrative interpretation of mapped health, learning, building performance, and technical evidence rather than as a claim that every included publication measures sustainability directly.

The broad label blue light can obscure the distinctions needed for responsible school decision-making. Light must be characterized by spectrum, intensity, timing, duration, spatial distribution, and retinal exposure rather than wavelength labels alone [21,22]. Integrative lighting guidance similarly emphasizes providing appropriate light at appropriate times instead of treating short-wavelength content as uniformly harmful [16,23]. Retinal photochemical hazard is also different from circadian stimulation and visual discomfort. Technical reviews and position statements do not identify ordinary white-light sources or classroom displays as a blue-light retinal hazard under normal use conditions [24,25].

The more immediate concerns associated with technology-rich classrooms are broader and more modifiable. Digital eye strain includes dryness, blurred vision, headache, accommodative stress, and musculoskeletal discomfort, with symptoms shaped by viewing distance, text size, glare, blink behavior, task duration, refractive status, and workstation design [1,2]. Screen use may also affect sleep when it extends into the evening through a combination of light exposure, cognitive arousal, notifications, social interaction, and displacement of bedtime [6,7]. Recent syntheses additionally reinforce the need to distinguish screen exposure itself from the near-work and outdoor-time patterns associated with myopia [26] and to consider both the quantity and quality of digital exposure in guidance for children and adolescents [27].

Prior reviews have generally treated these outcomes as separate areas of inquiry, focusing on sleep [6,7], digital eye strain [2,28–30], myopia [26,31–33], or the cognitive effects of light and screen use [4,5,34,35]. School leaders, by contrast, make decisions across these domains simultaneously. A district may replace fluorescent fixtures with LEDs for energy efficiency, increase one-to-one device use, alter recess time, and consolidate or expand digital platforms within the same period. The practical evidence problem is therefore not simply whether one form of exposure is harmful; it is which classroom conditions have been studied, how outcomes have been measured, where the evidence converges, and which modifications can be implemented without reducing access or instructional value.

This scoping review addressed the following questions: (1) What is known about environmental light and screen-related exposures in K–12 learning environments in relation to students' visual, ocular, circadian, sleep, cognitive, behavioral, learning, and related well-

being outcomes? (2) What environmental performance considerations arise from lighting and technology systems? (3) Which modifiable conditions are identified for classroom and system-level action? This review aims to map the breadth, directness, and limits of the literature rather than estimate a single pooled effect.

2. Materials and Methods

2.1. Review Design, Question, and Methodological Chronology

The review followed the staged approach described in foundational scoping review methodology and subsequent refinements [36,37], with reporting organized with reference to PRISMA-ScR and updated JBI guidance [38,39]. No protocol was prospectively registered or published; accordingly, the review should be understood as an iterative scoping process rather than a preregistered systematic review.

The review was developed through a sequential series of methodological stages. First, an initial narrative evidence scan was undertaken to establish the breadth of the literature, identify terminology used across the relevant disciplines, and refine the scope of the review question. Sources identified during this preliminary stage were not automatically included in the evidence map. Second, the review question and population–concept–context (PCC) eligibility framework presented in Table 1 were formalized for the structured review phase. Candidate sources identified through database and supplementary searching were subsequently assessed against these eligibility criteria.

Table 1. Population–concept–context eligibility criteria.

Element	Included	Excluded
Population	K–12 students; school-aged children and adolescents; educators or school settings when student exposure was central	Studies limited to adult occupational settings unless needed for measurement, mechanism, or implementation context
Concept	Daylight, electric lighting, spectrum, illuminance, luminance, luminance contrast, glare, flicker, display use, digital eye strain, near work, outdoor exposure, sleep timing, attention, learning, mood/depressive symptoms linked to school visual conditions, or environmental performance measures directly tied to school lighting/technology systems	General screen-time research without a visual, sleep, ocular, cognitive, school-environment, or directly relevant environmental performance connection
Context	Classrooms, schools, school-day routines, school technology systems, and school-related evening device use	Clinical treatment studies without environmental or educational relevance
Evidence type	Empirical studies, systematic or scoping reviews, meta-analyses, consensus statements, standards, and foundational mechanistic studies	Commercial claims, unsourced guidance, opinion pieces without an evidentiary basis
Language and date	English-language sources available through 15 September 2026; searches conducted from May through September 2026; no lower publication-date limit.	Sources unavailable in English or without sufficient information for charting

Note. Adult studies were eligible only when they provided foundational measurement, mechanistic, or implementation evidence unavailable in pediatric research; their findings were not treated as direct recommendations for children or adolescents.

Third, sources meeting the eligibility criteria were entered into the data-charting process described in Section 2.4. Charting captured study and publication characteristics, exposures and outcomes, principal findings, reported limitations, and practical control considerations. Evidence role classifications and primary evidence-domain assignments

were applied during this evidence-mapping stage rather than being used as criteria for study inclusion. The seven primary evidence domains therefore functioned as descriptive organizational categories for synthesis; publications could address more than one exposure or outcome area but were assigned to one primary domain for descriptive counting.

Finally, the evidence map was synthesized by domain and evidence role. Practical classroom- and system-level implications were developed only after completion of the evidence map and synthesis and therefore did not determine source eligibility or domain assignment. Search terminology was refined iteratively to accommodate disciplinary differences in terminology, but eligibility remained anchored to the PCC framework reported in Table 1. Meta-analysis was not planned because the purpose of the review was to map heterogeneous exposures, outcomes, study designs, and evidence types rather than estimate a pooled effect.

2.2. Eligibility Criteria

Eligibility was structured using the population–concept–context approach. As summarized in Table 1, the population comprised children and adolescents enrolled in K–12 or comparable primary and secondary education. The central concept was modifiable exposure to classroom lighting, daylight, luminance and contrast conditions, glare, flicker, digital displays, screen-mediated near work, and instructional conditions directly associated with those exposures. Eligible health and functioning outcomes included visual or ocular symptoms, refractive outcomes, circadian and sleep outcomes, attention, behavior, learning, mood or depressive symptoms when linked to the school visual environment, and student-reported comfort or functioning. Environmental performance evidence was eligible when it directly evaluated school lighting or technology decisions, including daylight utilization, energy demand, controls, maintenance, or implementation trade-offs. Adult and higher-education studies were included only when they provided foundational evidence on measurement, mechanism, cognition, or implementation that was not available in pediatric research; such findings were used to inform interpretation rather than as direct K–12 recommendations.

2.3. Information Sources and Search Strategy

PubMed and ERIC database searching was completed on 29 July 2026, with the original targeted supplementary searching continuing through 5 September 2026. Additional database searches in Scopus and Web of Science were completed on 15 September 2026. Full database-specific and supplementary search strategies, search dates, retrieval counts, and screening disposition are provided in Supplementary Table S1.

Supplementary searching was particularly important for lighting engineering, building science, architecture, visual environment research, and sustainability. Sources included CIE, IEEE, IES/ANSI, relevant professional and consensus organization websites, publisher platforms, and the reference lists of major reviews. Google Scholar was used for citation chaining and document retrieval rather than as a primary bibliographic database. Search terminology was adapted iteratively because the included disciplines use different terminology for related exposures and outcomes. Supplementary searches used terms including school indoor visual environment, classroom visual environment, luminance, luminance contrast, glare, daylighting, educational facilities, lighting energy, daylight harvesting, sustainable lighting, life cycle, and material health.

To strengthen multidisciplinary coverage and assess whether the original search strategy had omitted relevant literature indexed outside PubMed and ERIC, additional searches were conducted in Scopus and Web of Science. These multidisciplinary databases were selected to extend coverage across health, psychology, education, environmental

science, engineering, architecture, and building science. Search concepts were aligned with the established PCC eligibility criteria and addressed school and classroom settings in combination with lighting, daylight, luminance, glare, flicker, digital display exposure, digital eye strain, near work, myopia, circadian and sleep outcomes, attention and learning, and environmental performance concepts.

Complete result sets from the Scopus and Web of Science searches were exported and compared with the existing review record set. Duplicate records were removed, and all unique records underwent title and abstract screening using the same eligibility criteria applied in the original review. Records considered potentially eligible proceeded to full-text assessment. These additional searches identified no additional publications meeting the inclusion criteria.

2.4. Source Selection and Data Charting

Records were deduplicated before title and abstract screening. Titles and abstracts were assessed against the eligibility criteria summarized in Table 1, and potentially relevant records proceeded to full-text review. Full-text exclusions were assigned one primary exclusion reason corresponding to the categories reported in Figure 1. The subsequent Scopus and Web of Science searches were incorporated into the same selection process: retrieved records were deduplicated against the existing record set, unique records underwent title and abstract screening, and potentially eligible records were assessed at full text using the same PCC criteria. No additional eligible publications were identified through these expanded database searches; consequently, the substantive evidence map remained unchanged at 78 publications.

For included publications, data were charted by publication year and region, population and school level, study design, exposure and outcome domains, principal findings, reported limitations, and level of practical control. Each substantive publication was additionally classified into one of four evidence role categories: direct K–12 empirical evidence, indirect adult or higher-education empirical evidence, evidence synthesis, or technical/foundational source. Each publication was assigned to one primary evidence domain for descriptive mapping, although publications could contribute to more than one exposure or outcome area. Supplementary Table S2 reports the source-level characteristics, evidence role classifications, primary evidence-domain assignments, and green health relevance of the included publications. Methodological references used to guide scoping-review design and reporting were retained separately and were not charted as substantive evidence.

Initial title and abstract screening, full-text eligibility assessment, and data charting were conducted by a single reviewer. Following completion of the initial screening and charting process, an independent reviewer verified all 78 substantive publications included in the evidence map. The reviewer assessed each publication against the established PCC eligibility criteria and independently checked the charted study characteristics, evidence role classification, primary evidence-domain assignment, and green health relevance coding. No discrepancies in eligibility status, charted characteristics, or classifications were identified during independent verification. Because this verification occurred after completion of the initial review process, it represents independent verification of the included evidence set and its charted classifications rather than prospective duplicate screening of all identified records.

The searches identified 3008 records, including 2784 records from PubMed, ERIC, Scopus, and Web of Science and 224 records identified through supplementary searching. After 1194 duplicate records were removed, 1814 records underwent title and abstract screening, of which 1592 were excluded. Full texts were assessed for 222 potentially

eligible sources. Of these, 140 were excluded: 44 because the population or context did not meet the K–12/youth criteria; 54 because the source was not directly relevant to the eligible light, screen-exposure, environmental performance, or mapped-outcome concepts; 27 because the publication did not meet the eligible evidence-type criteria; and 15 because the publication was duplicate or superseded. A total of 82 sources were retained after full-text assessment, comprising 78 substantive publications included in the evidence map and 4 methodological references retained separately for review design and reporting. The final substantive evidence map therefore remained at 78 publications organized across 7 primary evidence domains.

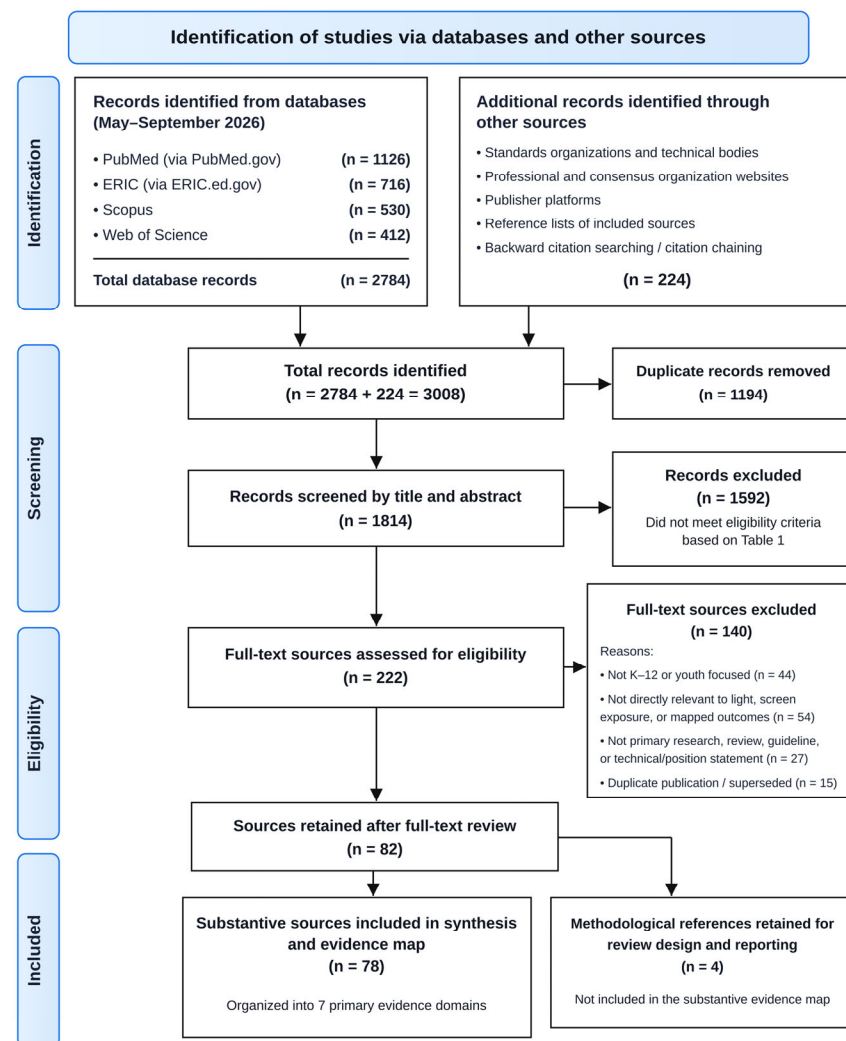


Figure 1. PRISMA-ScR flow diagram of source identification, deduplication, title and abstract screening, full-text eligibility assessment, exclusion reasons, and final inclusion in the substantive evidence map.

When more than one exclusion criterion could apply, the reason most directly responsible for ineligibility under the established PCC framework was recorded as the primary reason. A source-level roster of the original 132 full-text exclusions was not retained; accordingly, those exclusions are reported at the preserved category level rather than being retrospectively reconstructed. The eight additional full-text exclusions identified during the subsequent Scopus and Web of Science searches were documented using the same exclusion framework and incorporated into the updated category totals. Supplementary Table S3 provides the operational definition and final count for each exclusion category together with an audit note describing the extent of the retained exclusion documentation.

2.5. Synthesis

A descriptive thematic synthesis was used. Evidence was grouped by primary exposure and outcome domain and interpreted according to evidence role and directness. Within each domain, evidence role and directness informed interpretation, associations were distinguished from intervention findings, and recurring measurement limitations were identified. Technical standards were treated as measurement or implementation guidance rather than empirical effect estimates. No formal risk-of-bias or certainty-of-evidence assessment was conducted because the purpose was to map the range and distribution of evidence rather than estimate pooled effects or rank interventions. Accordingly, the synthesis emphasizes recurring findings and mapped patterns without assigning formal evidence-strength rankings. Practical implications were developed after completion of the evidence map and are presented separately in Section 4.

3. Results

3.1. Characteristics of the Evidence Map

Supplementary Table S2 classifies each publication by evidence role/directness. Table 2 summarizes the distribution across seven primary evidence domains; counts represent publications rather than independent datasets or evidence strength scores.

Table 2. Distribution of included sources by primary evidence domain.

Primary Domain	Publications, <i>n</i> = 78	Predominant Evidence	Principal Outcomes Mapped
Light measurement, circadian response, and alertness	12	Metrology standards, action spectrum studies, consensus recommendations, systematic reviews, and current IES daytime-light guidance [4,5,8,16,21–23,40–44]	Retinal exposure, melatonin response, circadian timing, alertness, simple cognitive performance
Classroom lighting, daylight, and physical design	22	School field studies, lighting interventions, observational school studies, visual environment reviews, daylight/building studies, and educational facility guidance [3,9,10,18,20,45–61]	Reading, concentration, behavior, comfort, performance, mood, daylight metrics, glare, classroom experience
Blue-light hazard and visual ergonomics	12	Technical statements, reviews, ocular surface evidence, screen-comparison studies [1,2,24,25,28–30,62–66]	Retinal hazard, discomfort, dryness, blur, headache, visual fatigue
Near work, myopia, and outdoor exposure	11	Systematic reviews, cohort studies, randomized and cluster-randomized school trials [26,31–33,67–73]	Myopia onset, progression, axial growth, outdoor time, light intensity
Screen timing, sleep, and exposure guidance	4	Systematic reviews, meta-analytic evidence, controlled evening exposure, recommendation synthesis [6,7,27,74]	Sleep duration, sleep timing, next-day alertness, age-based guidance
Attention, learning, and restoration	12	Learning science reviews, predominantly higher-education classroom studies, digital-reading research, and cognitive/environmental psychology [11–15,34,35,75–79]	Multitasking, comprehension, cognitive load, executive control, sustained attention, restoration
Procurement and implementation	5	Technical guidance, school energy/daylight-harvesting evidence, workplace field evidence, and educational-technology synthesis [17,19,80–82]	Flicker control, exposure assessment, energy use, daylight harvesting, life-cycle and purposeful technology selection

Note. Each publication was assigned to one primary domain for descriptive counting; several contributed to secondary domains.

3.2. Classroom Lighting, Daylight, and Time of Exposure

Lighting evidence separated into related but methodologically distinct lines of inquiry: physiological sensitivity to light [8,41–44], short-term alerting effects [4,5], school-based changes in performance or behavior [46,50–56], school visual environment and daylighting research [3,9,10,18,45,47,48,57–61], and engineering or implementation studies that evaluated lighting quality together with energy or system performance [17,19,20,40,49]. Action spectrum studies established that human circadian responses are especially sensitive to short-wavelength light [41–43], while later recommendations translated this work into receptor-based measures and time-of-day guidance [8,40]. Pubertal development may alter evening light sensitivity [44], making adolescent timing especially relevant. Reviews of daytime exposure found improvements in subjective alertness and selected reaction time outcomes under some conditions, but effects on complex cognition were inconsistent and depended on dose, timing, prior light history, sleep pressure, and task demands [4,5].

School-based lighting studies produced favorable, null, and context-dependent findings [20,46,50–56]. Dynamic or spectral lighting interventions were associated with selected changes in reading, concentration, behavior, attention, sleep, or mood, but effects varied across study conditions and outcomes [50–56]. A seven-week field study of 79 boarding high-school students found that periods of higher light exposure increased acute alertness during the exposure window but did not produce a general improvement in sleep or mood; timing-related differences between morning and evening conditions further illustrated that intensity and clock time cannot be collapsed into correlated color temperature alone [46]. In a year-long Swedish upper-secondary comparison involving 72 students, fluorescent and experimental LED classrooms produced only marginal differences in measured student outcomes and realized energy savings were small because of parasitic system losses [20]. These findings caution against interpreting LED adoption itself as evidence of either health benefit or environmental performance.

Classroom discomfort has been associated with glare and poor lighting conditions [3], and early work comparing classrooms with and without windows suggested possible differences in student health and behavior [57]. A multicounty study of 2670 European schoolchildren linked daylight-related classroom characteristics with mathematics and logical performance measures while illustrating the difficulty of isolating light from other building variables [58]. A large prospective study in eastern China associated higher blackboard illumination and other visual environment characteristics with lower risk of depressive symptoms, but the observational design does not establish causation [59]. The systematic review by Meng et al. synthesized 32 studies across five school visual environment themes—lighting, access to nature, window characteristics, aesthetics, and spatial arrangement—and found a larger evidence base for lighting and access to nature than for several other visual environment features [45]. This broader review helps situate classroom lighting within the building and visual environment literature rather than treating illuminance as the only relevant exposure.

Whole-classroom and building science studies further showed why quantitative lighting variables require contextual interpretation. Multilevel analyses indicate that lighting, temperature, air quality, flexibility, visual complexity, and student ownership jointly explained variation in learning progress [9,10], while classroom-design reviews treat light as one component of an integrated learning environment [60]. In a longitudinal daylighting study using 947 student questionnaires from six classrooms across three middle schools, sDA500, 50% was strongly correlated with daylight comfort, satisfaction, and perceived productivity. UDI300–3000 showed moderate correlations, and melanopic equivalent daylight illuminance was associated with health-perception measures [47]. These are associations with subjective outcomes rather than universal school thresholds. A Cypriot

field/simulation study found generally sufficient daylight but persistent glare concerns, particularly in east- and west-oriented classrooms [18], illustrating that greater daylight availability can coexist with luminance imbalance and visual discomfort. Spectral measurements in educational spaces also show that daylight and electric light integration, surface reflectance, and the spectrum reaching the eye matter for visual and non-visual interpretation [48].

Engineering Quantities and Green Health Interpretation

Illuminance, luminance, spectral characterization, glare, and temporal modulation describe different properties and should not be treated as interchangeable. Illuminance quantifies incident light on a surface, whereas luminance describes light leaving or being emitted from a surface toward the observer and is therefore relevant to perceived brightness, contrast, reflections, and glare. A classroom may satisfy an illuminance target while still presenting uncomfortable luminance ratios or poor display visibility. Correlated color temperature (CCT) describes the chromatic appearance of nominally white light but does not uniquely specify its spectrum; when non-visual responses are of interest, eye-level exposure and receptor-based measures such as melanopic EDI are more informative [16,21,22,40,47,48].

The sustainability dimension is likewise quantitative and conditional. In a modeled Greek public school classroom, Doulos et al. estimated that annual lighting primary-energy use could decline from 90.5 to 0.55 kWhp/m² under the most aggressive LED/daylight-harvesting scenario, with a modeled maximum CO₂ reduction of 32.44 kg/m² of classroom area [19]. That result demonstrates potential rather than a transferable performance guarantee. The Swedish field study described above found only small realized energy savings for its experimental LED system because parasitic losses reduced the expected benefit [20]. Read together, these studies show why green health evaluation should pair lighting quality, student experience, energy use, controls, commissioning, and post-occupancy verification rather than assuming that a lower-wattage or newer technology is automatically the healthier or greener option.

3.3. Blue-Light Hazard, Glare, Flicker, and Digital Eye Strain

Blue-light hazard is a technical photobiological exposure concept, and evaluations of common lamps, computers, and tablets have found ordinary use conditions well below established hazard limits [24,25]. This conclusion does not imply that screens or lighting systems are symptom-free. Routine discomfort is more plausibly associated with visual ergonomics, ocular surface stress, refractive or binocular factors, prolonged task demands, glare, and luminance imbalance than with retinal injury from display spectrum [1–3,28–30,62–64]. Glare and poor contrast therefore warrant direct measurement and environmental correction rather than being subsumed under the label blue light.

Digital eye strain encompasses ocular symptoms such as dryness, irritation, blur, and difficulty refocusing, as well as headache and neck or shoulder discomfort [1,28–30]. Prolonged screen concentration can reduce blink rate and increase incomplete blinking, affecting tear film stability [62]. Symptoms also vary with uncorrected refractive error, binocular vision demand, text legibility, viewing distance, posture, glare, contrast, and continuous task duration. A systematic review focused on young users confirmed substantial heterogeneity in symptom definitions and measurement, which limits prevalence comparisons and intervention claims [2].

Evidence for blue-filtering products was weak. A Cochrane review found no convincing short-term advantage of blue-light-filtering spectacle lenses for visual performance or eye strain symptoms in adults [65], and an experimental study found that blue-blocking

filters did not alleviate digital eye strain signs and symptoms [66]. Direct comparison of screen and hard-copy reading also suggested that symptoms are shaped by task and display conditions rather than spectrum alone [63]. Pediatric observational work linked video display use with dry eye disease in schoolchildren, but the design could not separate device use from blinking, exposure duration, and other behavioral factors [64].

Flicker and temporal light modulation represented a separate exposure pathway [80]. Some LED drivers and dimming systems produce modulation that may be visible or may contribute to discomfort among sensitive users even when not consciously perceived. Because school-based evidence was limited, applicable guidance came primarily from technical standards and procurement literature. Flicker should therefore be measured and managed as an engineering property of the lighting system rather than inferred from the LED label or correlated color temperature [80].

3.4. Near Work, Myopia, and Outdoor Exposure

Myopia research shifted the emphasis from screen spectrum to visual behavior and environmental exposure. Global projections indicate a substantial rise in myopia and high myopia [67], and established reviews describe the condition as the product of genetic susceptibility interacting with educational and environmental patterns [68]. A meta-analysis found an association between near-work activity and childhood myopia, although the underlying studies varied in how reading, studying, and device use were measured [31]. A 2026 European review similarly reported associations among screen-related behavior, near work, reduced outdoor exposure, and myopia-related outcomes while emphasizing heterogeneity and the limits of causal inference [26].

Evidence for outdoor exposure was more consistent than evidence for any specific screen device. Systematic review and meta-analysis linked greater outdoor time with prevention of myopia onset [32]. Observational evidence found lower myopia prevalence among children spending more time outdoors [69], and school-based randomized trials demonstrated that scheduled outdoor time could reduce incident myopia [70]. Cluster-randomized studies further examined outdoor light intensity and objectively monitored exposure, supporting the value of school-day opportunities outside [71,72]. Reviews of randomized trials reached similar conclusions for prevention, while noting that effects on progression among children who were already myopic were less certain [33,73].

Taken together, these findings place screen use within a broader pattern of near work, blinking, posture, and outdoor opportunity. Exposure assessment should therefore emphasize continuous near-work structure and outdoor opportunity rather than a simple paper-versus-screen distinction.

3.5. Screen Timing, Circadian Health, and Sleep

Evening exposure differed from daytime classroom use because circadian effects of light [74] and the displacement of sleep by device use [6,7] became central concerns. Controlled e-reader exposure in adults suppressed melatonin, delayed circadian timing, reduced evening sleepiness, and impaired next-morning alertness [74]. Among school-aged populations, systematic reviews and meta-analyses have associated portable screen access or use with shorter sleep, delayed bedtime, and poorer sleep outcomes [6,7]. These findings are consistent at the level of association, but the literature does not isolate light from content, social engagement, notifications, homework load, and voluntary bedtime delay.

The 2025 synthesis of recommendations for children and adolescents demonstrated broad agreement that digital exposure should be age-appropriate and that quality, context, and timing matter in addition to total duration [27]. For schools, timing and context are more informative than a uniform daily screen-time limit. Homework, late-night notifi-

cations, and device-based assignments may extend exposure into the evening, whereas daytime classroom use occurs under different circadian and instructional conditions [27].

3.6. Screen-Mediated Attention, Reading, and Learning

Direct K–12 evidence in this domain was limited; much of the mapped literature came from broader learning science, higher-education, and adult cognitive research and was therefore used to inform interpretation rather than establish K–12-specific effects. Learning outcomes depended on how technology organized attention. Multimedia learning research shows that digital representation can support understanding when words, images, signaling, and pacing are aligned with the learning objective [11]. Cognitive load theory likewise distinguishes necessary task complexity from avoidable demands that consume limited working-memory resources [12], and later work has extended extraneous load to environmental and contextual conditions surrounding instruction [13]. These perspectives suggest that a screen can either reduce or increase cognitive competition depending on the task architecture.

Classroom and observational research identified specific risks associated with divided attention. Laptop multitasking impaired learning for both users and nearby peers in a classroom experiment [14], and non-academic internet use during class was negatively associated with performance [15]. The methodological importance of these findings is not the unsurprising observation that distraction can impair performance; rather, they demonstrate that screen exposure is not a unitary dose. Task-relevant reading, simulation, collaborative analysis, off-task browsing, and notification-driven switching create different cognitive exposure profiles even when device time is identical. Digital reading research also reported a small comprehension advantage for print under some conditions, particularly when time pressure and informational complexity were high [34], while experimental comparison of linear text on paper and screen found processing differences [75]. These findings do not establish that print is universally superior; they indicate that navigation, scrolling, divided attention, task purpose, and reader expectations must be measured explicitly. Broader cognitive and environmental psychology evidence supports examining interruption, mode switching, and opportunities for recovery alongside total screen exposure [35,76–79]. Within schools, these conditions may be more informative than device time alone when evaluating sustained attention and self-regulation.

4. Discussion and Implications for Green Health Practice

4.1. Principal Findings

Across the seven evidence domains, the most consistent findings concerned modifiable classroom conditions: visual ergonomics, glare and luminance management, continuous near work, outdoor opportunity, evening timing, digital task organization, and system implementation. School lighting studies produced favorable, null, and context-dependent findings, while building science evidence showed that daylight, visual comfort, energy performance, controls, and occupied system performance do not necessarily move together. No single spectrum, CCT, screen use limit, classroom configuration, or retrofit emerged as universally optimal across K–12 settings.

The practical emphasis therefore shifts from product-centered mitigation toward environmental, instructional, and systems design. Because the review did not conduct a formal certainty assessment, the following recommendations are presented according to the source and directness of supporting evidence rather than as ranked interventions.

4.2. Green Health as an Integrative Framework

The green health contribution of this review is an integrative framework rather than a claim that all mapped studies measured sustainability. Four dimensions are considered together: (1) student health and comfort; (2) educational functioning and participation; (3) environmental sustainability, including energy, carbon, material, maintenance, and life-cycle implications; and (4) equity and accessibility. No intervention is considered successful on the basis of energy, daylight, health, or short-term performance outcomes alone. Its benefits and burdens should be evaluated across occupied use, maintenance, accessibility, and environmental performance. As shown in Figure 2, these four dimensions are integrated within a green health framework for evaluating lighting and technology conditions in K–12 learning environments.

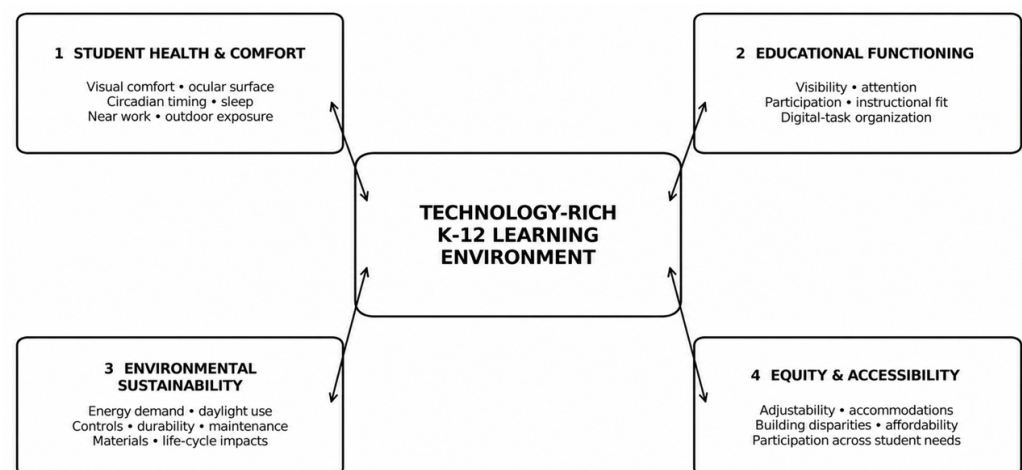


Figure 2. Green health framework for technology-rich K–12 learning environments integrating student health and comfort, educational functioning, environmental sustainability, and equity and accessibility.

The mapped evidence also differed in directness and function, with K–12 empirical studies, indirect adult or higher-education evidence, syntheses, and technical sources contributing differently to interpretation and implementation. Figure 3 summarizes how these evidence types inform the mapped synthesis, evidence-informed school actions, and research priorities.

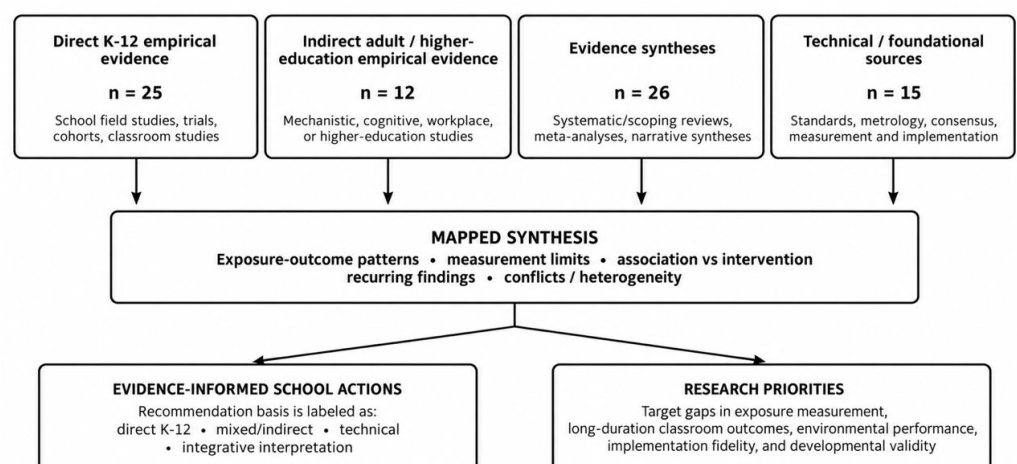


Figure 3. Evidence directness framework showing how direct K–12 empirical evidence, indirect adult or higher-education empirical evidence, evidence syntheses, and technical/foundational sources contribute to the mapped synthesis, evidence-informed school actions, and research priorities.

4.3. Teacher-Controlled Classroom Modifications

Teachers control the immediate sequence of visual and cognitive demands even when they cannot replace fixtures or devices. A feasible approach is to match the instructional medium to the purpose of the task and vary visual demands across a lesson. A simulation, collaborative data set, or accessible digital text may justify a screen; extended annotation, close reading, discussion, laboratory manipulation, or field observation may be better served by another medium. Table 3 presents teacher-controlled modifications that can help educators manage visual and cognitive demands in technology-rich classrooms.

Table 3. Teacher-controlled modifications for technology-rich classrooms.

Action	Operational Example	Primary Purpose	Implementation Caution
Define the purpose of each screen task	State whether the device is being used for reading, simulation, data entry, collaboration, or assessment; close unrelated applications	Reduce off-task switching and unnecessary exposure [11–15,35]	Retain assistive technology and required digital accommodations Evidence basis: indirect higher-education/adult empirical evidence plus learning science syntheses.
Manage glare and luminance contrast	Adjust blinds, screen angle, seating, display brightness, and room lighting so students are not viewing a bright screen in a dark room	Improve legibility and visual comfort [1,3,28–30,63]	Check conditions from multiple student seats rather than from the teacher station Evidence basis: direct K–12 lighting evidence plus visual ergonomics syntheses.
Support readable viewing	Use adequate text size, spacing, contrast, and viewing distance; permit zoom and seating adjustments	Reduce accommodative demand and leaning [1,2,28–30]	Avoid one fixed setting for students with low vision or other visual needs Evidence basis: clinical/visual ergonomics syntheses; indirect for specific K–12 thresholds.
Vary near and distance work	Alternate screen or print reading with discussion, board work, laboratory activity, movement, or outdoor observation	Break continuous near work and static posture [28–33,69–73,81]	Variation should serve the learning goal rather than become an arbitrary timer Evidence basis: direct K–12 myopia trials and pediatric evidence syntheses.
Build natural visual pauses	Use transitions for blinking, posture change, distance viewing, and brief visual recovery	Reduce ocular surface and attentional fatigue [1,2,28–30,62,77–79]	Evidence does not establish one universally optimal break interval [2,28–30] Evidence basis: visual ergonomics syntheses and indirect restoration evidence.
Limit digital competition	Disable unnecessary alerts, consolidate links, reduce tab switching, and use clear device-up/device-down cues	Protect attentional continuity [11–15,35,76]	Explain the rationale so routines are not experienced only as compliance demands Evidence basis: predominantly higher-education/adult classroom evidence and syntheses.
Respond to persistent symptoms	Document patterns, adjust the environment, communicate with families, and refer through school health or eyecare pathways	Identify refractive, binocular, headache-related problems, or ocular surface problems [1,2,28–30,62,64]	Do not diagnose symptoms as blue-light injury or recommend commercial products as treatment [24,25,65,66] Evidence basis: youth observational evidence plus clinical/consensus guidance.

Note. Actions should be adapted to age, disability, subject area, task duration, and available classroom controls. Evidence basis labels indicate directness/source type rather than formal certainty ratings.

4.4. School, District, Technology, and Facilities Actions

System-level decisions determine whether teacher-level modifications are feasible. Lighting and technology projects should therefore be evaluated under occupied conditions rather than solely through fixture specifications, connected load, or procurement claims. Relevant evaluation may include illuminance, luminance and glare, eye-level exposure when non-visual claims are made, temporal light modulation, controls, accessibility, actual energy use, maintenance, and user experience [17,19,20,40,49,80]. Daylight strategies likewise require functional shading and control, while technology governance should reduce unnecessary platform fragmentation and preserve print, hands-on, field, and discussion-based options where they better serve the learning objective [3,18,81]. Table 4 summarizes the corresponding system-level actions, responsible parties, and implementation indicators.

Table 4. System-level actions, ownership, and indicators.

Action	Primary Owner(s)	Implementation Indicator	Green Health and Equity Consideration
Conduct classroom light-screen audits	Facilities, environmental health and safety, technology, teachers	Sampling across orientations, building ages, times, and student seating positions	Prioritize aging buildings, portable classrooms, and rooms serving students with greater accommodation needs Evidence basis: mixed direct K–12 building evidence plus technical guidance.
Specify low-flicker, controllable lighting	Facilities and procurement	Verified modulation metrics across operating and dimming ranges; documented commissioning	Avoid selecting systems by wattage and correlated color temperature alone Evidence basis: technical engineering standards; limited direct K–12 symptom evidence.
Improve daylight and glare control	Facilities and school administration	Operable shading, clean glazing, reduced reflections, maintained teacher control	Do not require teachers to choose between screen visibility and daylight access Evidence basis: direct K–12/building science evidence plus technical guidance.
Set display and accessibility standards	Technology and accessibility teams	Readable defaults, scaling, adjustability, repairability, and assistive technology compatibility	Universal settings should not replace individualized accommodations Evidence basis: visual ergonomics evidence syntheses and accessibility guidance.
Simplify the digital ecosystem	Curriculum and technology leadership	Fewer redundant platforms, logins, notifications, and navigation paths	Include multilingual family access and low-bandwidth alternatives Evidence basis: predominantly indirect learning science and implementation evidence.
Protect outdoor and non-screen learning opportunities	School and district leadership	Outdoor time retained in schedules; field and hands-on options represented in curriculum	Plan for heat, air quality, disability access, and campus safety Evidence basis: direct K–12 randomized trials and pediatric evidence syntheses.
Strengthen screening and referral pathways	Student services, nurses, exceptional student education, administrators	Clear process for persistent headache, blur, dryness, light sensitivity, or functional difficulty	Do not shift the cost of environmental mitigation to families through unproven products Evidence basis: youth observational evidence plus clinical/consensus guidance.
Evaluate energy and health together	Facilities, finance, sustainability, instructional leadership	Post-occupancy review includes energy use, comfort, symptoms, participation, and maintenance	Use life-cycle cost, repairability, and responsible disposal in procurement decisions Evidence basis: direct school energy/building studies plus sustainability standards.

Note. Ownership may differ by district structure; indicators are intended for local adaptation rather than as universal standards. Evidence basis labels identify provenance/directness and do not constitute formal certainty ratings.

4.5. Implementation Principles

Implementation should begin with universal environmental improvements, followed by individualized accommodations for students who continue to experience functional difficulty. Such accommodations may include adjustments to seating, display size, contrast, brightness, viewing distance, task duration, or instructional medium [1–3,28–30,62–64]. Technical compliance alone does not establish functional comfort; student and teacher reports should therefore be considered alongside objective measurements.

New lighting, technology, or instructional systems should be piloted in representative classrooms and evaluated for intended outcomes and unintended effects. Post-implementation assessment should consider visual comfort, instructional functioning, accessibility, energy and carbon performance, maintenance, and life-cycle implications alongside relevant engineering measures [1–3,9–22,28–30,40,45–56,60–62,80–82]. Green health stewardship is strongest when environmental performance and student functioning are measured together rather than assumed to move in the same direction.

5. Evidence Gaps and Research Priorities

The principal gap was the limited number of long-duration studies conducted under authentic K–12 classroom conditions. Much of the available evidence relied on short interventions, narrowly defined outcomes, or controlled conditions that may not reflect variation across schools, seasons, instructional tasks, and student populations [3,9,10,20,46,47,50–61]. Future lighting studies should measure exposure at the eye rather than relying only on room-level horizontal illuminance, report luminance and contrast when glare or display visibility are relevant, provide spectral and alpha-opic quantities when non-visual effects are claimed, characterize temporal light modulation, and document exposure across the school day [4,5,8,16,21–23,40–44,47–49,80]. CCT should not be treated as a substitute for spectral, intensity, timing, and spatial exposure data. Multisite and longitudinal designs would improve applicability across grades, climates, building types, and instructional contexts.

Green health research also requires environmental and occupant outcomes to be measured together. School retrofit studies should report energy use, daylight contribution, control performance, maintenance, and, where feasible, carbon or life-cycle indicators alongside visual comfort, symptoms, participation, and learning. The contrast between modeled daylight harvesting savings [19] and modest occupied LED savings under parasitic losses [20] illustrates why predicted efficiency should be verified under actual use. Longitudinal evaluation should also determine whether benefits persist as controls, shading, equipment, and maintenance conditions change. Such designs would allow sustainability to function as a measured outcome rather than only an interpretive frame.

Screen-related research requires similarly precise exposure and task measurement. Self-reported daily screen time does not distinguish instructional reading, simulation, collaborative work, passive viewing, assessment, or off-task use, despite substantial differences in cognitive demand and visual behavior [11–15,34,35,75,81]. Future studies should therefore characterize task type, display and viewing conditions, continuous near-work duration, interruptions, outdoor exposure, and evening timing. These measures should be paired with validated assessments of visual symptoms, sleep, refractive outcomes, and classroom functioning [6,7,26–33,62–74]. Device-generated activity logs or structured observations could supplement self-report and reduce exposure misclassification.

Intervention research should examine coordinated strategies that schools can realistically implement rather than isolated changes under highly controlled conditions. Cluster-randomized, stepped-wedge, or pragmatic studies could evaluate combinations of glare control, low-flicker lighting, daylight and occupant controls, digital-platform simplification, variation among instructional modes, and protection of outdoor time. Studies should

document implementation fidelity, usability, maintenance, measured energy performance, accessibility, unintended consequences, and student outcomes. This is important because an energy-efficient intervention may still create visual or instructional difficulties, while a comfortable intervention may carry avoidable environmental or life-cycle costs.

Developmental and equity questions also remain open. Pediatric validation is needed before adult-derived melanopic-light recommendations are translated into school exposure thresholds [8,44]. Research should examine variation by age, pubertal stage, chronotype, refractive status, disability, sensory sensitivity, socioeconomic context, climate, building quality, and access to outdoor space. Studies should also distinguish modifications that provide broad benefits from those requiring individualized clinical, accessibility, or educational support. This would help schools avoid one-size-fits-all standards while identifying interventions that are environmentally responsible and educationally equitable.

6. Limitations

This review mapped a broad interdisciplinary literature, but that breadth introduced methodological and interpretive limitations. Terminology, exposure definitions, and outcome measures varied across lighting science, ophthalmology, sleep research, environmental psychology, building science, engineering, and education. Light was characterized through measures such as illuminance, correlated color temperature, spectral composition, alpha-opic quantities, daylight availability, luminance, contrast, glare, and subjective lighting quality. Screen exposure was measured through device ownership, self-reported duration, task time, evening use, or specific display conditions. Outcomes ranged from visual and refractive measures to sleep, mood, behavior, attention, reading, and academic performance. This heterogeneity limited direct comparison across publications and precluded treatment of the literature as a single uniform exposure–outcome evidence base.

The review did not conduct a meta-analysis or apply a formal risk-of-bias or certainty-of-evidence framework. It therefore cannot estimate comparative effect sizes, rank interventions, or identify a universally superior lighting spectrum, exposure threshold, screen use limit, or classroom modification. Because the evidence map included heterogeneous study designs, syntheses, consensus statements, and technical standards, domain counts describe the distribution of publications rather than evidence strength. Some syntheses may overlap with primary evidence; counts therefore represent publications rather than independent datasets or samples.

Initial title and abstract screening, full-text eligibility assessment, and data charting were conducted by a single reviewer. Independent duplicate screening was not performed prospectively. To strengthen methodological verification, an independent reviewer subsequently examined all 78 substantive publications included in the evidence map against the established PCC eligibility criteria and verified the corresponding charted study characteristics, evidence role classifications, primary evidence-domain assignments, and green health relevance coding. No discrepancies in eligibility status, charted characteristics, or classifications were identified during independent verification. Although category-level reasons and counts were preserved for the original 132 full-text exclusions, a source-level roster of those publications was not retained; individual original exclusion decisions therefore cannot be independently audited retrospectively. The eight additional full-text exclusions identified through the subsequent Scopus and Web of Science searches were documented prospectively using the same exclusion framework.

The search strategy also had coverage limitations. PubMed and ERIC constituted the original database searches, with targeted supplementary searching used to extend coverage into standards, professional and consensus sources, publisher platforms, disciplinary journals, reference lists, and citation chains. Multidisciplinary coverage was subsequently

expanded through additional searches of Scopus and Web of Science, whose complete result sets were deduplicated and screened using the same established eligibility criteria. These additional searches identified no new eligible publications, providing some reassurance that expansion to broader multidisciplinary databases did not materially alter the substantive evidence map. Nevertheless, no search strategy can ensure complete retrieval across a heterogeneous interdisciplinary literature. Eligibility was limited to English-language sources, and unpublished school evaluations, facilities reports, dissertations, and null findings may remain underrepresented.

Adult laboratory studies, higher-education research, workplace investigations, consensus recommendations, and technical publications were included when they contributed mechanistic, measurement, cognitive, or implementation context [4,5,8,11–17,21–25,28–30,34,35,40–44,49,62,63,65,66,74–82]. These sources should not be interpreted as pediatric exposure standards or assumed to produce equivalent effects in authentic K–12 settings. Adult-derived recommendations therefore require validation in school contexts before translation into universal thresholds or policies.

School-based lighting evidence also had important design limitations. Studies were often conducted in small samples, single schools, or short intervention periods, and many altered several lighting or instructional variables simultaneously [50–56]. These bundled interventions make it difficult to isolate the component responsible for changes in reading, concentration, behavior, mood, or comfort. Expectancy effects, season, daylight availability, classroom orientation, prior light exposure, and instructional context may also have influenced outcomes. These design limitations restrict generalization of individual lighting interventions across K–12 settings.

Much of the literature on screen use, sleep, attention, and cognition was observational or relied on self-reported exposure [6,7,11–15,26,27,34,35,75]. Associations may reflect task content, family routines, baseline sleep, outdoor exposure, refractive status, socioeconomic conditions, or self-selection in addition to the measured environmental variable. Broad measures such as total screen time also combine activities with substantially different visual and cognitive demands. These limitations restrict causal interpretation and make it difficult to distinguish effects of display characteristics from prolonged near work, displacement of sleep or outdoor activity, attentional interruption, or task content.

Finally, the practical actions presented here are evidence-informed translations rather than clinical treatment protocols, universally applicable engineering specifications, or a formal sustainability rating system. Local implementation must account for building design, climate, controls, maintenance, accessibility, instructional goals, student characteristics, and technical capacity. The green health framework should therefore be interpreted as an organizing and evaluative framework integrating health, educational functioning, sustainability, and equity rather than as evidence that every proposed action has been directly tested across all four dimensions. Persistent visual, neurologic, or sleep-related symptoms should receive appropriate school health or clinical evaluation rather than being attributed to blue light or any single environmental exposure alone.

7. Conclusions

This scoping review shows that classroom light and screen exposure cannot be reduced to a single blue-light question and that green health cannot be reduced to daylight use or energy efficiency alone. The evidence base spans visual comfort, ocular surface stress, near work, outdoor exposure, circadian timing, sleep, attention, instructional design, school visual environments, lighting engineering, and environmental performance. Recurring findings across the map favor environmental and instructional modification over reliance on blue-light-filtering products or a universal lighting prescription. Teachers can improve

immediate conditions through purposeful screen use, glare and luminance management, readable displays, mode variation, visual pauses, and reduced digital competition. Lasting improvement requires district action on lighting quality, daylight and shading, controls, commissioning, platform governance, outdoor opportunity, accessibility, maintenance, measured energy performance, and life-cycle-aware procurement. A green health approach therefore asks whether school systems support student health and learning while also using energy, materials, controls, and maintenance resources responsibly and equitably.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/greenhealth2040027/s1>, Table S1. Database-specific and supplementary search strategies, dates, retrieval counts, and screening disposition; Table S2. Source-level characteristics, evidence-role/directness classification, and green-health relevance of the 78 substantive publications included in the evidence map; Table S3. Full-text exclusion categories, operational definitions, final counts, and audit documentation; PRISMA 2020 Checklist; PRISMA 2020 for Abstracts Checklist [83]. Reference [83] identifies the reporting guideline associated with the supplementary PRISMA 2020 checklist and was not included among the 82 sources retained for the scoping review.

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Abbreviations

CIE	Commission Internationale de l’Eclairage
IEEE	Institute of Electrical and Electronics Engineers
JBI	Joanna Briggs Institute
K–12	Kindergarten through grade 12
LED	Light-emitting diode
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews
CCT	Correlated color temperature
IES	Illuminating Engineering Society
mel-EDI	Melanopic equivalent daylight illuminance
sDA	Spatial daylight autonomy
UDI	Useful daylight illuminance

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