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REVIEW ARTICLE

# Lighting in Industrial and Shift-Work Environments and Occupational Health: A Narrative Review

Zahra Zamanian[1], Danial Soleymani-Ghoozhdi[2,3*]

[1]*Department of Occupational Health and Safety Engineering, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran*

[2]*Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran*

[3]*Social Determinants of Health Research Center, Gonabad University of Medical Sciences, Gonabad, Iran*

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## ABSTRACT

**Background:** Workplace lighting is a critical environmental factor influencing not only visual performance but also physiological and psychological well-being. In industrial and shift-based environments, inappropriate lighting conditions can disrupt circadian rhythms, impair alertness, and elevate accident risks. This review aims to highlight the multifaceted role of lighting in promoting occupational health, safety, and productivity.

**Methods:** This narrative review examined studies published between 2010 and 2024 in major scientific databases, including PubMed, Web of Science, Scopus, SID, Magiran, using keywords such as *"lighting," "illumination," "occupational health," "shift work," "circadian rhythm,"* and *"industrial workers."* Relevant peer-reviewed studies addressing the relationship between lighting conditions and occupational health outcomes were identified and analyzed qualitatively.

**Results:** The findings indicated that adequate and well-designed lighting enhances visual comfort, alertness, mood, circadian alignment, and overall job performance. Conversely, poor or inappropriate lighting contributes to eye strain, fatigue, sleep disturbances, cognitive errors, musculoskeletal discomfort, and an increased risk of occupational accidents—primarily through mechanisms such as circadian disruption. Night-shift workers, machine operators, and industrial personnel are particularly vulnerable, as insufficient or mistimed light exposure can misalign biological rhythms and reduce alertness.

**Conclusion:** Lighting is a powerful yet modifiable factor in occupational health. By proactively assessing and optimizing illuminance, color temperature, uniformity, and timing—and by adopting human-centric or dynamic lighting systems—organizations can directly improve worker well-being, reduce accidents, and boost productivity. Effective lighting is not just an environmental adjustment; it is a strategic investment in workforce health and industrial performance.

**KEYWORDS:** *Lighting; Luminance; Health; Circadian rhythm; Shift workers; Health risk*

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****Corresponding author:*** *Danial Soleymani-Ghoozhdi*
***E-mail:*** *Daniel.soleymani74@gmail.com*

# INTRODUCTION

Lighting is a fundamental component of workplace design that plays a critical role in safeguarding worker health, safety, comfort, and performance [1]. In industrial environments—such as manufacturing plants, warehouses, construction sites, and processing facilities—lighting conditions are particularly important due to complex visual demands, the use of heavy machinery, and the elevated risk of accidents [2]. Although often overshadowed by more widely recognized occupational hazards such as noise, chemical exposure, and ergonomic strain, lighting is a physical agent with both acute and chronic health implications [3]. Its effects range from immediate outcomes such as visual fatigue and glare to longer-term consequences including circadian rhythm disruption, sleep disorders, and reduced alertness, particularly among shift workers [4].

Despite its recognized importance, lighting remains an underappreciated and inconsistently regulated factor in occupational health frameworks [5]. Setyowati et al., found that workers in non-standard lighting environments are 4.95 times more likely to experience unsafe conditions [6]. Industrial workplaces are diverse and dynamic, often operating under variable conditions involving artificial and natural light, low-light areas, and shift-based schedules [5]. Such variability challenges visual capacity and contributes to physical and cognitive strain. Poorly designed lighting has been associated with diminished visual acuity, higher error rates, greater risk of injury, and occupational fatigue [7]. Conversely, well-designed lighting systems enhance visibility, reduce accident risk, and support productivity and job satisfaction [4,8]. Recognizing these effects, organizations such as the International Labour Organization (ILO) and the American Conference of Governmental Industrial Hygienists (ACGIH) have established guidelines to evaluate lighting as a critical workplace factor [9–11]. However, implementation of these guidelines remains uneven across industries and regions, and scientific evidence specific to industrial environments remains fragmented. The complexity of lighting as a workplace factor stems from its multifaceted nature. Beyond illuminance (lux), lighting encompasses parameters such as color temperature, distribution, glare, flicker, and spectral composition [12,13]. Each of these dimensions' influences worker perception, comfort, and performance [4,14].

Despite extensive research on lighting and visual performance, most studies have concentrated on office and healthcare environments [14]. However, industrial workplaces present unique conditions—such as prolonged exposure durations, varying light sources, and shift-based schedules—that can affect both visual and non-visual pathways, including circadian regulation and psychological responses. Scientific evidence specific to industrial and shift-based settings remains fragmented, with inconsistencies in exposure parameters (e.g., illuminance, spectrum, and timing) and limited understanding of their integrated effects on health and safety outcomes. This lack of synthesis leaves a gap in identifying how lighting design can be optimized to protect and enhance worker well-being in industrial operations [15].

To address this gap, the present study synthesizes available evidence on the role of lighting in occupational health and safety within industrial settings. Specifically, it aims to 1) identify the types of lighting conditions investigated in these environments, 2) examine associated health and safety outcomes, 3) highlight the occupational groups and work settings most frequently studied, and 4) outline existing research gaps and priorities for future studies. This review seeks to promote a more comprehensive understanding of workplace lighting as a modifiable ergonomic and environmental factor.

# MATERIAL AND METHODS

This study was conducted as a narrative review, aiming to synthesize and interpret existing research on the relationship between workplace lighting and occupational health. The objective of this review was not to provide an exhaustive or systematic aggregation of all available evidence, but rather to identify major trends, conceptual relationships, and practical implications discussed across the literature.

To gather relevant studies, a comprehensive search was performed in both Persian and English scientific databases, including PubMed, Web of Science, and Scopus. The search covered publications from 2010 to 2024. The search strategy used a combination of the following keywords and their Persian equivalents: *"lighting," "illumination," "luminance," "artificial light," "occupational health," "occupational safety," "workplace," "circadian rhythm," "twenty-four-hour rhythm," "diurnal rhythm," "night shift," "shift work," "industrial workers," "sleep," "visual performance," "sleep disorder," "fatigue,"* and *"risk."* Boolean operators ("AND," "OR") were applied to refine the search results.

Studies were included if they met the following

***Table 1.*** Key Lighting Characteristics Investigated

| Characteristic | Impact/Consideration | Ref |
|---|---|---|
| Illumination Intensity | Affects visibility, productivity, and safety; must meet regulatory standards | (1,12,16–18) |
| Uniformity | Reduces visual fatigue and discomfort | (16,17) |
| Glare (UGR) | High glare impairs comfort and task performance | (16,17) |
| Color Temperature | Higher color temperatures (cooler light) linked to better visual acuity and alertness | (19,20) |
| Spectral Composition | Influences circadian rhythms, health, and non-visual effects | (20–22) |
| Flicker/Ripple Coefficient | Impacts psychophysiological state and fatigue | (20) |
| Daylight Integration | Supports psychological well-being and productivity | (18,23) |

criteria: they were peer-reviewed original research articles, reviews, or experimental studies published in English; focused on industrial, manufacturing, or shift-based occupational environments; examined lighting parameters such as intensity, color temperature, distribution, spectrum, or flicker in relation to health, safety, or performance outcomes; and provided either quantitative or qualitative data relevant to worker well-being, safety, or ergonomic effects of lighting. Only full-text articles were considered for inclusion.

Studies were excluded if they primarily focused on residential, educational, or clinical environments unrelated to occupational contexts, or if they addressed lighting solely as an architectural or engineering element without considering worker health or safety. Articles that were letters to the editor, commentaries, or conference abstracts without empirical data were also excluded. In addition, studies lacking accessible full texts or sufficient methodological detail, as well as duplicate records retrieved from multiple databases, were omitted.

The narrative review design was intentionally selected for this study. The existing research on workplace lighting and occupational health is characterized by high heterogeneity in study designs, populations, exposure metrics, and outcomes, spanning visual performance, circadian regulation, fatigue, musculoskeletal strain, and accident risk. Given these methodological differences, a systematic or quantitative meta-analysis was deemed unsuitable. Instead, a narrative synthesis approach enables the integration of findings from diverse disciplines to provide a broader conceptual understanding of how lighting influences worker health and safety.

## RESULTS

### *Types of Lighting Conditions Studied in Industrial Settings*

**Question**: Which lighting characteristics and systems have been investigated in industrial occupational settings?

In industrial environments, lighting plays a crucial role not only in enhancing visual performance and task efficiency but also in promoting worker safety, regulating circadian rhythms, and supporting psychological well-being. Research on lighting conditions in these settings has examined a broad range of factors, including the type and source of lighting, as well as more subtle characteristics such as color temperature, uniformity, and exposure timing (Table 1).

A primary distinction in the literature is between natural and artificial lighting. Natural light, primarily obtained from windows or skylights, has been linked to enhanced mood, improved sleep quality, and better overall health outcomes [24,25]. A study found that employees with access to natural elements and sunlight reported better mental health and work attitudes (26). However, due to the architectural and operational constraints of many industrial facilities—such as factories, warehouses, and underground operations—workers often rely heavily on artificial lighting. Consequently, research has focused on artificial sources such as fluorescent tubes, halogen lamps, and, more recently, LED technologies. These sources differ in spectral distribution and energy efficiency, which can influence both visual comfort and non-visual physiological responses [27,28]. A study by Kazemi et al. comparing task performance, visual comfort, and alertness under different lighting conditions found no significant differences among three types of lighting: LED, warm-temperature fluorescent, and halogen lamps [29].

Illuminance levels, commonly measured in lux, are a fundamental factor studied in various industrial settings. The adequacy of lighting is typically evaluated against established standards (e.g., ISO 8995, EN 12464-1) [30]. However, research indicates that even when

***Table 2.*** Positive and Negative Effects of Workplace Lighting on Worker Outcomes

| Outcome Type | Positive Lighting Effects | Negative Lighting Effects | Ref |
|---|---|---|---|
| Visual | Comfort, less eye strain, better vision | Discomfort, headaches, fatigue | (43–46) |
| Physiological | Alertness, better sleep, circadian health | Fatigue, sleep issues, circadian disruption | (47–52) |
| Psychological | Improved mood, less stress, satisfaction | Depression, stress, dissatisfaction | (7,43,49,53–55) |

lighting meets these standards, worker performance can vary based on task requirements, individual sensitivity, and exposure duration [4]. Insufficient lighting has been associated with visual fatigue and higher error rates, while excessively intense lighting may cause glare and discomfort [31].

Furthermore, color temperature—expressed in Kelvin—has garnered significant attention in recent years, particularly regarding its role in circadian rhythm entrainment. Cool, blue-enriched light (e.g., 5000–6500 K) has been shown to promote alertness and delay melatonin secretion, which can benefit night shift workers but may disrupt sleep if exposure occurs too late. Conversely, warmer lighting (<3000 K) tends to support relaxation but may reduce task focus [32,33].

Recent studies have highlighted the benefits of dynamic lighting systems that mimic natural light cycles or adjust intensity to accommodate shift work requirements, thereby enhancing circadian regulation, alertness, and overall well-being [34]. For example, Wang et al. [35] investigated dynamic lighting interventions at nurses' stations, comparing medium (300 lx) and high (1000 lx) illuminance during the first half of shifts while maintaining normal lighting standard during the other half. The intervention, implemented across shift cycles, resulted in reductions in sleepiness, assessed using the Karolinska Sleepiness Scale, improvements in reaction time and accuracy measured by the Psychomotor Vigilance Task, decreased fatigue (MFI-20), improved mood (SAS and HAMD), and enhanced sleep quality (PSQI and BSWSQ). In addition, the intervention was associated with increased salivary melatonin levels and a tendency toward longer total sleep duration. Although higher illuminance produced stronger effects on performance and mood, medium illuminance was more effective in improving sleep-related outcomes. These findings demonstrate that dynamic lighting can substantially enhance both physiological and psychological outcomes in shift workers, with benefits persisting beyond the intervention period, and underscore underscoring of optimizing lighting parameters for different work schedules [35].

Other important variables include light distribution and uniformity, flicker, and glare. Poor uniformity in lighting across a workspace can cause eye strain and reduce productivity, while flickering—especially in older fluorescent systems—has been linked to headaches, eye discomfort, and even the exacerbation of neurological conditions in sensitive individuals [36]. Glare, whether discomfort glare or disability glare, remains a common issue in environments with reflective surfaces or poorly shielded luminaires [37].

In addition to examining individual characteristics, researchers have evaluated a variety of lighting systems that incorporate these features into practical workplace solutions. The most commonly studied systems include:

• **LED Lighting**: Provides superior energy efficiency, a longer lifespan, and enhanced visual and cognitive performance compared to fluorescent lighting. LEDs also reduce fatigue and promote alertness, particularly at higher color temperatures [17,19,38].

• **Smart Lighting Systems**: Enable dynamic adjustment of illumination based on user needs, behavior, or operational requirements, resulting in energy savings and enhanced worker satisfaction [39,40].

• **Controllable Task Lighting**: Allows workers to adjust their personal lighting levels, which has been linked to increased productivity, comfort, and satisfaction [41].

• **Human-Centric Lighting (HCL)**: Designed to align with circadian rhythms and address the non-visual effects of light, with the goal of reducing fatigue and minimizing occupational injuries [22,42].

Overall, the reviewed evidence indicates that no single lighting parameter alone can ensure optimal occupational health and performance. Rather, the interplay among illuminance, color temperature, light distribution, and temporal dynamics collectively shapes visual comfort, circadian alignment, and psychological well-being. Recent research underscores the importance of addressing both visual and non-visual dimensions of light exposure, moving beyond mere compliance with lighting standards. Integrative and adaptive lighting approaches—particularly LED-based and human-centric systems—offer promising pathways to enhance worker safety, productivity, and well-being. Consequently, the development of holistic lighting strategies and workplace policies that harmonize technical specifications with human physiological needs represents a critical step toward healthier and more sustainable industrial environments.

### *1.2 Health and Safety Outcomes Associated with Light Exposure*

**Question**: what does workplace lighting influence visual, physiological, and psychological outcomes among workers?

Lighting conditions in industrial environments have far-reaching effects beyond visual performance, extending into occupational health and safety. Numerous studies have demonstrated that inadequate or inappropriate lighting—whether in terms of intensity, timing, spectrum, or uniformity—can lead to a variety of negative physiological, psychological, and behavioral outcomes for workers.

Circadian disruption is one of the most extensively studied health effects associated with light exposure [56]. The human circadian system is primarily regulated by light, especially short-wavelength (blue-enriched) light, though other time cues such as sleep timing, food intake, and social interaction (known as Zeitgebers) also contribute [57]. Proper alignment with the light–dark cycle supports metabolic stability, cognitive function, and restorative sleep, while circadian misalignment is associated with fatigue, sleep disturbances, impaired alertness, and increased long-term risks such as metabolic and cardiovascular disorders [58,59]. In occupational settings, circadian disruption commonly arises during night or rotating shift work, when the biological clock is forced out of alignment with work hours [60]. This condition resembles jet lag, with consequences including reduced alertness, performance errors, and sleep difficulties.

Adaptation to night shifts varies depending on lighting conditions: moderate workplace lighting (e.g., ~500 lux) often induces only partial phase shifts, leading to incomplete adjustment. In contrast, strong and sustained nighttime illumination, coupled with reduced conflicting daytime light exposure, facilitates more complete circadian adaptation, as observed in controlled experiments and in industries such as offshore oil platforms. These findings emphasize the central role of light exposure in managing fatigue, alertness, and health outcomes among shift workers [58]. A field study involving industrial shift workers found that exposure to bright, blue-enriched light (≈192 lux melanopic Equivalent Daylight Illuminance) improved sleep efficiency, reduced sleep latency, and enhanced alertness compared to standard lighting [61]. Also, A systematic review and meta-analysis demonstrated that lighting interventions, specifically blue-enriched white light with a color temperature exceeding 5000 K, significantly reduced sleepiness among night-shift workers. This finding is particularly salient for the nursing workforce, which constitutes the largest group of health professionals. Implementing such lighting could enhance patient safety, reduce occupational accidents, and improve overall work efficiency and job satisfaction, warranting its consideration for adoption in healthcare settings [62].

Exposure to insufficient daylight or artificial lighting with inappropriate timing or spectral characteristics can desynchronize circadian rhythms, resulting in poor sleep quality, chronic fatigue, reduced alertness, and mood disturbances such as depression and anxiety. Shift workers are particularly vulnerable, as irregular lighting exposure disrupts melatonin production and sleep–wake cycles, contributing to long-term health consequences, including cardiovascular and metabolic disorders [63]. A three-month field study conducted in an industrial setting evaluated the efficacy of a scheduled bright light (~6,000–12,000 lux) and darkness intervention to realign the circadian rhythms of rotating shift workers [64]. The results provided objective physiological evidence of circadian adaptation, with all evaluated subjects exhibiting suppressed morning melatonin levels during night shifts and half demonstrating a statistically significant phase shift in their circadian pacemaker. However, subjective measures of alertness, performance, and sleep quality yielded mixed and inconsistent findings. A notable reported adverse effect was increased difficulty adjusting to days off following the night shift. This study constitutes a seminal demonstration that bright light technology can physiologically alter circadian rhythms in an actual industrial environment, though its perceived benefits on worker well-being were ambiguous. The authors consequently propose essential criteria for assessing the suitability of worksites for such interventions [64]. Hoshi et al. [65] demonstrated that relatively short exposures to lighting levels above 300 lux, even for 1–2 hours, can suppress melatonin secretion and disrupt circadian regulation, leading to impaired sleep quality in night-shift workers. In a non-randomized open-label trial involving 20 rotating-shift nurses, the researchers compared dark room lighting (110 lx) with brighter room lighting (410 lx) during night shifts. The findings indicated that fatigue and sleepiness were significantly higher under dark lighting conditions, whereas no significant improvements were observed in sleep quality or in the incidence of errors and accidents between the two lighting environments. These results suggest that while excessive nocturnal lighting can disrupt circadian rhythms, overly dim environments may exacerbate fatigue and sleepiness during work, underscoring the need to balance biological and performance-related outcomes when designing lighting strategies for shift work settings (65).

Beyond circadian effects, visual strain caused by low illuminance levels, glare, or uneven lighting distribution can lead to eye fatigue, headaches, and musculoskeletal discomfort resulting from awkward postures adopted to compensate for poor visibility. These conditions not only impair worker well-being but may also increase absenteeism and reduce productivity (4,66). For example, Glimne et al. demonstrated that lighting deficiencies—particularly glare, uneven luminance, and suboptimal illuminance—contribute to increased visual and physical strain among workers. In industrial control rooms, stark contrasts and glare were linked to self-reported visual fatigue and heightened neck–shoulder discomfort, while also imposing a greater cognitive load on operators [67]. Also, Evidence indicates that workplace lighting significantly impacts musculoskeletal health by influencing posture and physical comfort. Pirmoradi et al. reported that inadequate illumination—measured at 30–38% below occupational exposure limits—was significantly associated with poor posture and a higher prevalence of musculoskeletal pain, particularly in the neck and lower back among office workers [68]. In contrast, Joines et al. demonstrated that the introduction of adjustable LED task lighting led to significant improvements in musculoskeletal comfort, posture, and visual well-being, with users reporting reduced discomfort and eye fatigue. Collectively, these studies highlight lighting as a modifiable ergonomic factor with direct effects on both visual and musculoskeletal health, underscoring the importance of providing sufficient and adaptable lighting conditions in occupational environments [69].

From a safety perspective, inadequate lighting significantly impairs hazard detection, slows reaction times, and reduces task accuracy, thereby increasing the risk of occupational accidents and injuries. Experimental studies demonstrate that higher illumination levels enhance visual performance, shorten reaction times, and decrease errors in both cognitive and physical tasks [19,70]. In industrial settings such as mining, insufficient lighting diminishes postural stability and obscures trip hazards, whereas increased illuminance improves hazard recognition and stability [71]. Field studies corroborate these findings: in Sri Lankan factories, a significant negative correlation was observed between lighting levels and accident rates ($r = -0.506$) [72], while in Tanzanian office environments, glare and flicker were associated with reduced visual comfort, focus, and operational efficiency [4]. Furthermore, parameters such as intensity, uniformity, and color temperature critically influence visual acuity, reaction times, and cognitive performance [73]. Conversely, well-designed lighting systems with adequate illuminance and appropriate spectral quality not only enhance safety by improving hazard detection and situational awareness but also contribute to increased productivity and worker well-being [73]. Recent research highlights the significant impact of lighting design on psychological comfort and cognitive function. Laboratory studies show that subliminal flickering—undetectable fluctuations in lighting—can impair mood and problem-solving abilities, whereas stable, high-frequency lighting enhances emotional states and performance [74]. Field studies in office settings demonstrate that dynamic LED lighting, which adjusts in intensity and spectral composition throughout the day, improves alertness, mood stability, and overall well-being [49]. Simulated workplace experiments further indicate that such dynamic lighting reduces sleepiness and helps maintain vitality and self-regulation during the workday [75]. Similarly, in older adult populations, structured light schedules aligned with natural light cycles result in significant improvements in mood and cognitive function [76].

Workplace lighting is a critical factor in occupational health and safety. Optimal workplace lighting — characterized by adequate brightness, appropriate color temperature, and access to natural light— should simultaneously address circadian alignment, visual ergonomics, and safety requirements. Considering all three domains in lighting design can enhance worker well-being, reduce fatigue, and improve overall performance in occupational settings.

### *1.3 Occupational Groups and Work Environments Most Commonly Studied*

**Question**: Which worker populations and workplace environments have been most frequently studied in occupational lighting research?

A critical aspect of understanding the role of lighting in occupational health is identifying the worker populations and environments that have been the focus of empirical research. Different occupational groups encounter varying lighting demands and exposures depending on the nature of their tasks, workplace design, and shift schedules.

Occupational lighting research has predominantly focused on office workers in administrative and open-plan office environments, industrial and manufacturing workers (including those in factories, workshops, and specialized settings such as tunnel construction), and shift workers, particularly those working night shifts or in confined or enclosed environments [38,49,77,78].

Office environments are the most common settings for studies examining the impact of lighting on visual comfort, productivity, and well-being among administrative staff, knowledge workers, and individuals using computers or visual display terminals [4,73,79–85]. Also, shift workers, particularly those on night shifts, constitute a widely studied group due to their misalignment with natural circadian rhythms. This group includes occupations in sectors such as oil and gas, automotive manufacturing, steel production, and food processing [55,86–90]. These workers are especially vulnerable to sleep disturbances, reduced alertness, and increased safety risks resulting from prolonged exposure to artificial light at night or insufficient exposure to natural light during the day [91].

Research has also expanded to specialized environments such as control rooms, laboratories, and cleanrooms, where precision and continuous monitoring under stable lighting conditions is critical. In these settings, lighting is often designed to minimize glare and flicker; however, even slight variations in intensity or spectral quality can affect worker concentration and cognitive function [67,92].

Occupational lighting research most commonly focuses on office workers in administrative and open-plan settings, industrial and manufacturing employees, and shift workers in healthcare, hospitality, and industrial environments. These settings are prioritized because of their prevalence, visual demands, and the significant influence of lighting on health, safety, and productivity. In contrast, less attention has been devoted to commercial, educational, and underground environments, as well as to demographic diversity and user preferences.

## DISCUSSION

This review demonstrates that workplace lighting exerts multidimensional effects on visual, physiological, and psychological outcomes across industrial settings. Adequate lighting—characterized by optimal illuminance, spectral composition, and uniformity—enhances visual comfort, circadian stability, and task accuracy, while poorly designed systems increase fatigue, error rates, and accident risk [21,45,47,93,94]. The findings consistently indicate that lighting is not merely a technical requirement but a determinant of occupational health and safety performance.

Evidence also suggests that artificial lighting parameters interact with individual and environmental factors such as age, task type, and shift schedules, producing variable effects on alertness, productivity, and well-being [95]. For instance, Blue-enriched light can significantly improve vigilance in night-shift workers, but its effectiveness depends on precise timing and application within the circadian cycle. Multiple studies demonstrate substantial performance benefits: Scott et al., [96] found ~50% fewer cognitive lapses with circadian-informed lighting, while T. Sletten et al., [97] showed improved alertness and performance metrics during night shifts. A systematic review by Wu et al., [62] confirmed that blue-enriched white light (>5000 Kelvin) effectively reduces sleepiness. However, the research also underscores the need for context-specific design. Scott et al., [91] noted that carefully timed blue-enriched and blue-depleted lighting can improve sleep duration and vigilance, highlighting that indiscriminate light exposure could potentially disrupt circadian rhythms. The evidence suggests that precise timing and spectral characteristics are crucial for maximizing benefits while minimizing potential negative impacts.

### *Implications for Occupational Health and Safety Practice*

The reviewed literature reinforces the importance of integrating lighting considerations into occupational risk assessments and workplace design. Ergonomists and occupational hygienists should evaluate lighting not only against compliance standards (e.g., ISO 8995, EN 12464-1) but also with respect to biological and psychological outcomes. Implementing adjustable, dynamic, or human-centric lighting systems can enhance worker safety, comfort, and productivity, particularly in shift-based operations and high-precision tasks [35,49].

Furthermore, the strong linkage between lighting quality and musculoskeletal health underscores the ergonomic dimension of illumination design—where posture and visual strain are jointly influenced by lighting geometry, glare control, and task luminance [66,68].

### *Gaps in Current Research on Occupational Lighting*

Despite a growing body of evidence highlighting the importance of lighting in occupational health and safety, several critical gaps remain in the existing literature. These research deficiencies hinder the development of comprehensive lighting standards and interventions tailored to diverse workplace environments.

First, many studies have primarily focused on office, healthcare, and night-shift environments, while other occupational sectors—such as agriculture, construction, logistics, and small enterprises—are significantly underrepresented. These settings often involve dynamic lighting conditions, frequent transitions between indoor and outdoor environments, or exposure to combinations of natural and artificial light; however, they remain insufficiently explored [98]. Second, much of the existing research focuses primarily on visual performance and ergonomic outcomes, with less attention given to the broader physiological and psychological effects of inadequate lighting. There is a need for more comprehensive studies examining how lighting influence's endocrine function, mood disorders, long-term sleep health, and cognitive load, especially across different age groups and vulnerable populations (e.g., older workers or individuals with pre-existing health conditions). Third, the literature lacks standardized methodologies for assessing lighting exposure in occupational settings. Variability in the measurement of lighting intensity, spectral quality, duration, and timing makes it difficult to compare findings across studies. This inconsistency hinders the development of evidence-based lighting guidelines applicable across industries. Fourth, there is limited longitudinal and interventional research. Most studies rely on cross-sectional or short-term designs, which do not adequately capture the cumulative or delayed effects of lighting on worker health and performance. Longitudinal studies would provide critical insights into how chronic exposure to suboptimal lighting conditions affects health trajectories over time. Finally, emerging lighting technologies—such as tunable LED systems and circadian lighting—have shown promise in laboratory or simulated environments; however, their real-world application in workplaces remains under-investigated. There is a pressing need to evaluate the feasibility, cost-effectiveness, and worker acceptance of these innovations in operational settings.

Addressing these gaps is essential for advancing occupational hygiene practices, optimizing workplace design, and ultimately enhancing worker well-being and safety through improved lighting strategies.

## CONCLUSIONS

This narrative review underscores the critical yet often underestimated role of lighting in occupational environments. Beyond mere visibility, lighting profoundly shapes workers' health, safety, and performance, influencing circadian rhythms, sleep quality, alertness, and cognitive and mental well-being. The literature demonstrates that inadequate lighting—whether in intensity, spectrum, timing, or duration—can compromise these outcomes, particularly in industrial settings where sustained attention and physical effort are demanded.

Existing studies have explored various lighting conditions, including natural versus artificial light, high-intensity versus low-level illumination, dynamic lighting systems, and shift-specific exposures. However, the research has been largely sector-specific—focusing on manufacturing, mining, and transportation—with limited attention to other high-risk occupations such as food processing, waste management, and maintenance. Moreover, few studies examine the long-term cumulative health effects of poor lighting, and psychological and social dimensions, including mood, mental fatigue, and perceived safety, remain underexplored. Demographic factors such as gender, age, and individual light sensitivity are also rarely addressed.

Key gaps highlighted by this review include the lack of interdisciplinary approaches integrating lighting ergonomics with occupational hygiene, mental health, and organizational design, as well as the limited evidence on the real-world effectiveness of innovative lighting technologies such as tunable LEDs and circadian-friendly systems. Addressing these gaps is essential to develop comprehensive, evidence-based lighting standards that optimize both worker well-being and operational efficiency.

Future research should adopt a systems-oriented, holistic approach, combining expertise from occupational hygienists, engineers, lighting designers, and health professionals. Incorporating worker feedback, biometric data, and task-specific requirements will enable the design of lighting strategies that are inclusive, adaptive, and effective across diverse workplace environments. Ultimately, recognizing lighting as a multidimensional determinant of occupational health and safety is not only a scientific necessity but a practical imperative for creating safer, healthier, and more productive workplaces.

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**Conflict of Interest**
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**AI Statement**
During the preparation of this manuscript, ChatGPT was used exclusively to enhance language and readability in certain sections. All scientific content was entirely developed by the authors.

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