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Smart Lighting Control Systems for Energy Conservation in Saudi Vision 2030 Developments

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Abstract- Smart lighting has moved from a niche building automation feature to a strategic infrastructure layer for high-performance buildings, campuses, and public-realm developments. In Saudi Arabia, this shift is particularly significant because Vision 2030 links digital transformation, energy productivity, sustainable urbanism, and quality-of-life improvements to the delivery of new districts, giga-projects, and retrofit programs. This review examines how smart lighting control systems can support energy conservation across Saudi Vision 2030 developments, including residential communities, commercial buildings, institutional campuses, mixed-use districts, public space, and transport corridors. The paper is structured as a PRISMA-guided review and synthesizes peer-reviewed and institutional sources published from 2020 to early 2026. The literature screened for the review covered LED efficacy, occupancy and vacancy sensing, daylight harvesting, scheduling, addressable controls, wireless communication, Internet of Things integration, building energy management systems, digital twins, artificial intelligence, public-lighting analytics, Saudi policy frameworks, and implementation challenges in hot-arid climates. The synthesis shows that the strongest savings do not come from any single technology alone. Rather, the most credible energy-conservation pathway combines high-efficacy LED luminaires, robust commissioning, zone-level sensing, daylight-responsive dimming, adaptive scheduling, and integration with broader building or city-management platforms. For Saudi developments, climate responsiveness matters: deep floor plates, high solar exposure, glare control, dust, maintenance cycles, and the interaction between lighting, cooling loads, and occupant comfort all affect system performance. The review also finds that the value proposition of smart lighting is widening beyond operational electricity savings to include demand flexibility, maintenance intelligence, user wellbeing, urban safety, and carbon-aware asset management. Based on the evidence, the paper proposes a Saudi-oriented implementation framework that aligns lighting design, controls architecture, governance, procurement, and post-occupancy verification. The paper concludes that smart lighting is one of the most scalable and near-term opportunities for energy conservation in Vision 2030 developments, but its full impact depends on standards alignment, interoperable controls, data governance, commissioning discipline, and life-cycle decision making.

Index Terms- Smart Lighting Controls; Energy Conservation; Saudi Vision 2030; PRISMA Review; Building Energy Management; Daylight Harvesting; Iot; Smart Cities; Mostadam; Saudi Arabia

I. INTRODUCTION

The global building sector remains under intense pressure to reduce energy demand while improving service quality, resilience, and carbon performance. International assessments continue to show that buildings are central to both the energy-efficiency agenda and the wider decarbonization challenge, with lighting remaining a non-trivial share of electricity use even as LEDs improve luminaire efficacy (IEA, 2024; UNEP & GlobalABC, 2025). Lighting also has a systems effect: it interacts with internal heat gains, cooling demand, comfort, safety, security, productivity, and the digitalization of building operations. In climates where cooling is dominant, smarter lighting can reduce direct electricity consumption while also lowering sensible heat gains from inefficient equipment, thereby supporting the broader energy performance of the built environment (Jørgensen et al., 2025; Shahid et al., 2025).

Saudi Arabia provides a particularly important context for reviewing smart lighting. The Kingdom's development model under Vision 2030 emphasizes digital government, quality of life, renewable energy, sustainable construction, smart cities, and world-scale urban projects. These ambitions are materializing through new communities, transport systems, commercial districts, public-space upgrades, and giga-projects that increasingly depend on connected

infrastructure and performance-led operations (Saudi Vision 2030, 2025; Mostadam, 2024). At the same time, the Saudi building sector remains highly energy intensive, and residential and commercial demand patterns are strongly shaped by hot-arid climate conditions, long cooling seasons, and the need for reliable indoor environmental quality (Al-Homoud & Krarti, 2021; Alyami et al., 2021). Although cooling dominates end-use discussions in the Gulf, lighting remains strategically important because it is relatively easy to retrofit, highly measurable, and strongly synergistic with automation platforms, occupancy analytics, and smart-city infrastructure.
The contemporary literature no longer treats smart lighting as a simple switch from conventional lamps to LEDs. Instead, it frames lighting as an integrated cyber-physical subsystem composed of efficient luminaires, occupancy sensing, daylight-response algorithms, dimming logic, communication layers, and interoperable management software (Chinchero et al., 2020; Chen et al., 2024). This shift matters for Saudi Vision 2030 developments because many flagship projects are being delivered as digitally managed environments rather than as isolated buildings. In that context, lighting controls affect not only energy bills, but also maintenance operations, public-space management, occupant experience, safety, and the data architecture of districts and campuses (Taboada-Orozco et al., 2024; Zocchi et al., 2024).

Against this background, the present paper offers a PRISMA-guided review of smart lighting control systems for energy conservation in Saudi Vision 2030 developments. The review is designed around five original objectives:

Objective	Purpose in this review
O1	to synthesize recent evidence on the energy-conservation performance of smart lighting control strategies published between 2020 and early 2026;
O2	to interpret that evidence for Saudi climatic, regulatory, and developmental conditions rather than treating lighting controls as climate-neutral technologies;
O3	to examine how smart lighting interacts with building management systems, IoT platforms, digital twins, and AI-based control in both buildings and smart-city infrastructure;
O4	to evaluate the alignment of smart lighting with Saudi policy instruments, including the Saudi Building Code, energy-efficiency guidance, and Mostadam-related sustainability frameworks; and
O5	to propose a practical implementation framework for Vision 2030 developments covering design, procurement, commissioning, governance, and post-occupancy verification.

Table 1. Review objectives designed specifically for the present paper.

II. REVIEW METHOD AND PRISMA-GUIDED FRAMEWORK

This paper follows PRISMA 2020 reporting logic as a structuring framework for a review paper rather than as a meta-analysis. The intention is to make the search and selection process transparent, reproducible in principle, and suitable for a technology-policy synthesis. Searches were conceptually organized around combinations of the following terms: “smart lighting”, “lighting control systems”, “daylight harvesting”, “occupancy sensors”, “IoT lighting”, “building energy management”, “digital twins”, “Saudi Arabia”, “Vision 2030”, “Mostadam”, “building codes”, “smart cities”, and “public lighting”. The target publication period was January

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2020 to February 2026. The review prioritized peer-reviewed journal articles, systematic reviews, and official institutional sources that were directly relevant to building or urban lighting performance, energy efficiency, or Saudi sustainability governance. Sources were included when they satisfied at least one of four criteria: first, they reported evidence on energy savings, control logic, or implementation of intelligent lighting systems in buildings or smart-city contexts; second, they addressed daylighting, sensing, occupancy-based control, or dimming strategies relevant to lighting-energy performance; third, they analyzed Saudi building energy policy, codes, certification systems, or climate-responsive efficiency strategies relevant to Vision 2030 developments; or fourth, they provided recent authoritative institutional context on buildings, lighting, or energy-efficiency policy. Sources were excluded if they focused solely on photometric hardware without a control or energy dimension, pre-2020 publications, non-building lighting topics with no relevance to buildings or urban developments, or undated promotional materials with no methodological credibility.

Because the present paper is a qualitative review, the synthesis relied on thematic clustering rather than quantitative pooling. Included sources were coded into seven analytical groups: policy and governance; LED and luminaire efficiency; occupancy and daylight-responsive control; IoT and communication architectures; building management and digital twins; public lighting and smart-city applications; and climate-responsive implementation for Saudi developments. Evidence was then interpreted through a Saudi application lens, with particular attention to hot-arid climatic performance, mixed-use mega-developments, public-sector implementation, life-cycle value, and operational integration.

Review design element	Application in this paper
Review type	Qualitative, PRISMA-guided review focused on building and urban smart lighting systems.
Time window	January 2020 to February 2026.
Source types	Peer-reviewed journal articles, systematic reviews, and authoritative institutional sources.
Core themes	LEDs, daylight harvesting, occupancy sensing, IoT, BMS, digital twins, public lighting, Saudi codes and Vision 2030.
Inclusion logic	Studies had to address lighting controls, energy performance, smart buildings/cities, or Saudi building governance relevant to energy conservation.
Synthesis method	Thematic synthesis with Saudi-specific interpretation rather than meta-analysis.

Table 2. PRISMA-guided review protocol used to structure the synthesis.

III. SAUDI VISION 2030 POLICY AND DEVELOPMENT CONTEXT

Saudi policy and market conditions make smart lighting unusually relevant. Official Saudi guidance on residential energy-efficiency requirements explicitly includes lighting among the mandatory domains for compliance and design review, placing lighting alongside envelope, air-conditioning, and domestic hot-water considerations (Saudi Energy Efficiency Center, 2025). In parallel, the Ministry of Energy reports that standards and efficiency regulations applied to products and codes have materially reduced home and street-lighting consumption, demonstrating that lighting policy has already produced measurable national effects (Ministry of Energy, 2025). The policy environment is therefore not starting from zero; rather, it is evolving from product efficiency and code compliance toward smarter, connected, and more performance-based lighting systems.

Saudi building governance is also becoming more sophisticated. The Saudi Green Building Code has been maintained as an in-force national policy instrument, while research on the Saudi code ecosystem argues that local baselines must play a stronger role in evaluating energy performance in the Kingdom's green-building rating systems (IEA, 2025; Shamseldin, 2023). Mostadam, as the nationally anchored sustainability framework for buildings, explicitly aligns with Vision 2030 and addresses long-term sustainability issues relevant to Saudi buildings, including environmental quality, resource efficiency, and operational performance (Mostadam, 2024). For smart lighting, this is important because implementation success depends less on the availability of sensors or LEDs than on whether controls are embedded in code pathways, rating systems, procurement rules, and facility-management practices.

The technical context is equally compelling. Reviews of Saudi residential buildings show that the sector remains heavily burdened by cooling-dominated energy use, uneven envelope quality, and significant opportunities for efficiency improvement in both new and existing buildings (Al-Homoud & Krarti, 2021). Simulation work on zero-energy trajectories in Riyadh and other Saudi contexts further shows that building performance gains require layered strategies combining passive design, efficient systems, smart control, and renewable energy integration (Alyami et al., 2021; Aloshan, 2025; Rodrigues et al., 2025). In this layered sequence, smart lighting belongs to the category of high-readiness, fast-payback interventions that can be applied across different project types, especially when developments are already investing in digital infrastructure.

IV. EVIDENCE SYNTHESIS: SMART LIGHTING TECHNOLOGIES AND CONTROL LOGIC

A. LED platforms as the enabling base layer

The literature consistently identifies the LED transition as the enabling base layer of smart lighting systems. The central argument in recent reviews is that intelligence without efficient luminaires leaves much of the savings potential unrealized, whereas efficient luminaires without controls leave operational waste on the table (Chinchero et al., 2020; Chen et al., 2024). In practical terms, LED luminaires enable continuous dimming, zonal control, addressability, reduced maintenance frequency, and easier integration with sensors and communication protocols. For Vision 2030 developments, this matters because large-scale projects can standardize on addressable luminaires and digital drivers at the procurement stage, creating a foundation for later optimization.

B. Occupancy sensing and daylight harvesting

Beyond LED efficacy, the most mature body of evidence concerns occupancy-based and daylight-responsive control. Reviews of daylight harvesting demonstrate that energy savings improve substantially when photo-sensor feedback is localized and paired with dimmable electric lighting rather than relying on coarse, centralized switching logic (Odiyur Vathanam et al., 2021). Related review work on active and passive daylighting shows that the strongest performance is achieved when façade design, solar control, room geometry, and electric-light controls are treated as a single design problem rather than as separate disciplines (Onubogu et al., 2021). Case-based evaluation of integrated daylighting and electric-lighting projects reaches a similar conclusion: successful outcomes depend on the combined design of daylight admission, efficient luminaires, advanced controls, monitoring, and fine-tuning after occupancy (Gentile et al., 2022).

This point is especially important in Saudi Arabia, where abundant daylight is both an opportunity and a risk. High daylight availability can significantly displace artificial lighting, but only if glare, solar heat gain, and dust-related maintenance are managed. In hot-arid developments with deep floor plates or highly glazed façades, uncontrolled daylight can raise cooling loads or degrade visual comfort even while it reduces electric-light use. Consequently, the most appropriate Saudi strategy is not "more daylight" in the abstract; it is climate-responsive daylighting supported by shading, glazing selection, zone-level dimming, and commissioning. Recent Saudi building studies focused on cooling demand also reinforce the importance of window-to-wall ratio, glazing quality, and passive design, all of which shape the effectiveness of daylight-linked lighting control (Rodrigues et al., 2025; Felimban et al., 2023).

C. Adaptive, occupant-centric, and AI-informed control

Control strategy sophistication is another major differentiator. Earlier generations of occupancy sensors often suffered from nuisance switching, poor user acceptance, and crude zoning. The current research direction is more granular. Work on occupant-centric smart lighting argues that future systems should sense not merely presence or absence, but a wider range of occupant indicators, preferences, behaviors, and contextual signals (Wang et al., 2025). This shift from binary occupancy logic toward occupant-centric control is highly relevant for high-value Vision 2030 workplaces, educational campuses, healthcare settings, and hospitality assets where visual comfort and user experience matter alongside energy reduction.

At the algorithmic level, smart lighting is moving toward direct illuminance contribution models, adaptive dimming, and integrated decision logic. Kim et al. (2024) propose an IoT-based lighting-control framework that adjusts dimming levels according to the real contribution of luminaires to target illuminance conditions. This type of control is more precise than simple rule-based zoning because it can account for the spatial contribution of luminaires and reduce over-lighting. Chen et al. (2024) similarly identify multi-system linkage and AI integration as a defining trend, suggesting that lighting will increasingly respond to real-time building states rather than standalone commands. For Saudi developments, this means that lighting control can become an active participant in district-level optimization, especially when connected to occupancy analytics, room booking systems, façade control, and demand-management platforms.

A recurring issue in the literature is that reported lighting-energy savings are highly context dependent. Review articles and technology assessments generally point to substantial reductions when LED retrofits are paired with occupancy sensing and daylight dimming, but the variance is wide because baseline systems differ so much. Buildings already equipped with efficient luminaires but weak controls may realize incremental savings mainly through scheduling and analytics, whereas legacy buildings with fluorescent or poorly zoned LED systems can realize far larger reductions once addressable dimming and better sensing are introduced (Chinchero et al., 2020; Odiyur Vathanam et al., 2021; Jørgensen & Ma, 2025). This variability should not be interpreted as a weakness of smart lighting. Rather, it demonstrates that lighting is an operational system whose performance depends on design assumptions, occupant behavior, maintenance quality, and the fidelity of control logic to real use conditions. For Saudi decision makers, the implication is to benchmark projects by archetype and baseline condition instead of relying on generic savings claims.

Human factors are equally important. Occupants do not experience “energy savings”; they experience brightness, contrast, glare, predictability, privacy, control, and sometimes frustration. Occupant-centric lighting research is increasingly explicit that smart systems must serve visual and non-visual human needs, not merely reduce kilowatt-hours (Wang et al., 2025). In the Saudi context, this matters for culturally sensitive and schedule-sensitive spaces such as mosques, majlis areas, hospitality venues, schools, and public institutions with varied day-night activity patterns. Successful systems therefore need sensible override rules, clear user interfaces, and control dead bands that prevent irritating oscillation or excessive dimming. This is also why post-occupancy verification should include occupant feedback alongside energy data. A technically efficient system that is routinely overridden or partially disabled in practice is not a successful system.

V. SYSTEMS INTEGRATION: IOT, BMS, DIGITAL TWINS, AND SMART-CITY INFRASTRUCTURE

The integration of lighting with the broader digital building stack is now one of the strongest themes in the literature. Systematic reviews of data-driven building management systems show that building intelligence is increasingly organized around interoperable data streams, sensors, automation logic, and service-oriented management platforms (Taboada-Orozco et al., 2024). A parallel review of building energy management systems emphasizes the convergence of sensors, IoT, and AI, while also highlighting persistent adoption barriers such as interoperability limits, cybersecurity risk, and the difficulty of integrating legacy assets (Akbulut et al., 2025). In this environment, smart lighting should not be specified as an isolated subsystem. Instead, it should be procured and commissioned as part of the building energy management architecture.

This systems perspective changes the business case. In conventional appraisals, lighting projects are evaluated mainly on simple electricity savings and lamp replacement cycles. In digitally managed assets, however, lighting controls can also contribute to occupancy intelligence, space-use analytics, condition-based maintenance, comfort management, emergency response, and flexible operation. Reviews of advanced building energy management show that IoT-based systems can reduce overall energy consumption while improving responsiveness and resilience, especially when control platforms can integrate multiple subsystems rather than optimizing each one separately (Shahid et al., 2025; Gunasinghalge et al., 2025). As a result, the marginal value of smart lighting rises in projects that already require digital governance, such as ministries, airports, universities, hospitals, and giga-project districts.

Digital twins represent a further step in this progression. Reviews in Energy Informatics describe digital twins as operational mirrors of building systems that can optimize energy performance, reduce costs, and support smarter control decisions during operation (Cespedes-Cubides & Jradi, 2024). For lighting, digital twins can enable fault detection, schedule optimization, daylight-performance feedback, and scenario testing before changes are pushed to the physical asset. In Saudi Vision 2030 developments, where many projects are being marketed as digitally native environments, the digital-twin approach is especially attractive because it allows operators to verify whether smart lighting is actually delivering savings, comfort, and maintenance benefits under desert conditions rather than merely complying on paper.

Procurement strategy is another underexplored determinant of outcomes. Many projects still specify lighting through fragmented packages in which luminaires, sensors, control interfaces, BMS integration, and maintenance software are procured separately or with limited performance coordination. The reviewed evidence suggests that this fragmentation is costly because it creates unclear responsibility for commissioning, data ownership, and troubleshooting (Taboada-Orozco et al., 2024; Akbulut et al., 2025). For Vision 2030 developments, better practice would include employer information requirements for controls data, mandatory integration testing, minimum cyber-security provisions, asset tagging standards, and explicit handover deliverables for facility-management teams. In giga-project settings, procurement should also require compatibility with district-scale dashboards and long-term serviceability so that buildings do not become islands of proprietary technology.

VI. APPLICATION TO SAUDI BUILDINGS, DISTRICTS, AND PUBLIC REALM

A. Buildings and campus environments

Application in Saudi developments must remain climate-responsive. Lighting technologies are often discussed as if they perform similarly across regions, but hot-arid conditions introduce distinctive operational realities. High ambient temperatures can affect driver life and control electronics; dust can degrade sensors, luminaires, and daylighting performance; and strong solar radiation can complicate sensor calibration and façade-lighting interaction. Meanwhile, the cooling-dominated nature of Saudi buildings means that internal heat gains from lighting remain relevant, especially in older assets and retrofit situations. Research on Saudi housing and retrofit pathways shows that performance gains are strongest when efficient systems are combined with envelope and passive-design improvements rather than pursued in isolation (Al-Homoud & Krarti, 2021; Felimban et al., 2023; Aloshan, 2025).

This finding supports a hierarchy for Vision 2030 developments. First, efficient luminaires and high-quality controls should be embedded at the design stage. Second, daylight-linked strategies should be coordinated with façade design, solar shading, glazing, and space planning. Third, lighting controls should be integrated with BMS and digital-twin infrastructure. Fourth, performance should be verified in operation through metering, commissioning, and post-occupancy analytics. The Saudi-specific literature on zero-energy and near-zero-energy pathways reinforces the importance of this stepwise logic, showing that efficiency and control measures create the load reduction on which wider sustainability goals depend (Alyami et al., 2021; Wang et al., 2021; Emil & Diab, 2021).

The Saudi application case also extends to retrofit policy. A large share of the national building stock that will be operating in 2030 already exists, which means that Vision 2030 outcomes cannot rely only on exemplary new districts. Reviews of Saudi housing energy performance and retrofit studies in Riyadh and Jeddah demonstrate that existing buildings still contain substantial untapped efficiency potential, particularly when lighting upgrades are coordinated with air-conditioning replacement, envelope improvement, and rooftop solar strategies (Al-Homoud & Krarti, 2021; Felimban et al., 2023; Aloshan, 2025). Smart lighting is especially attractive in retrofit portfolios because it can often be implemented with relatively light physical intervention while generating fast operational data about actual occupancy and use patterns. In public-sector asset portfolios, this can create a virtuous cycle: pilot buildings generate evidence, that evidence informs archetype standards, and archetype standards then accelerate wider rollout. Such portfolio logic would be highly suitable for ministries, municipalities, universities, hospitals, and housing programs seeking quick but durable efficiency gains.

B. Public-lighting and district-scale environments

The smart-lighting literature also extends beyond buildings to the public realm. IoT-enabled public-lighting systems have been shown to support dynamic dimming, remote monitoring, motion-triggered operation, and improved maintenance visibility in smart-city settings (Chiradeja & Yoomak, 2023). Survey work on highway lighting similarly emphasizes the role of communication protocols, sensing, real-time data processing, and adaptive control for reducing wasted illumination while maintaining safety (Achar et al., 2024). These findings matter for Saudi Vision 2030 because many developments are district-scale or corridor-scale rather than single-building projects. Boulevards, transport corridors, plazas, cultural districts, logistics zones, and waterfronts can all benefit from adaptive public lighting linked to occupancy, traffic, and environmental conditions.

However, smart public lighting in Saudi Arabia should not be framed only as a technical upgrade. It is also an urban-governance instrument. Good public lighting supports perceived safety, accessibility, identity, tourism, nighttime economy, and public-space usability. The challenge is to achieve these goals while minimizing over-lighting, glare, unnecessary operating hours, and maintenance burden. Here, the literature suggests that the most robust systems combine LED sources, sensor-informed dimming, remote asset management, and standards-based illumination targets rather than simply maximizing brightness (Chiradeja & Yoomak, 2023; IEA, 2026). This is especially relevant for Saudi mega-projects that aim to project a high-quality public realm and strong sustainability credentials simultaneously.

VII. ECONOMICS, GOVERNANCE, AND IMPLEMENTATION BARRIERS

From a life-cycle perspective, smart lighting has several advantages over many deep-retrofit measures. Compared with major envelope reconstruction or central-plant replacement, lighting upgrades often require lower capital intensity, shorter implementation windows, and fewer disruptions to occupied buildings. Reviews of decarbonization strategies repeatedly identify LED lighting with smart controls as a high-readiness option capable of substantial electricity savings when properly designed and accepted by users (Jørgensen et al., 2025). In Saudi developments, this makes smart lighting particularly suitable for phased deployment across schools, offices, retail areas, municipal buildings, mosques, parking structures, and public spaces.

Yet the literature also warns against oversimplified business cases. Savings depend on baseline conditions, control settings, occupancy patterns, commissioning quality, sensor placement, and user override behavior. In some projects, underperformance arises because systems are installed but not tuned, or because operators disable advanced logic after complaints. Gentile et al. (2022) show that monitoring and post-installation fine-tuning are decisive for integrated daylight and electric-lighting projects. Zocchi et al. (2024) similarly argue that the benefits of advanced lighting controls increase when they are planned together with BIM and IoT workflows, rather than appended after design. Therefore, Saudi procurement should move beyond lowest-capital-cost purchasing toward performance-based procurement that rewards interoperability, commissioning, maintainability, and measurable operational outcomes.

The review identifies six recurring implementation barriers. The first is interoperability. Lighting vendors often use proprietary ecosystems, making future integration with BMS, digital twins, or smart-city platforms difficult. The second is commissioning complexity, particularly where daylight sensors, occupancy logic, and control groups are poorly aligned with the real use of spaces. The third is cybersecurity and data governance, which become significant once lighting systems are connected to building networks and user analytics platforms (Akbulut et al., 2025; Taboada-Orozco et al., 2024). The fourth is user acceptance: occupants may reject aggressive dimming or switching if comfort and predictability are not respected (Wang et al., 2025). The fifth is capability within the supply chain, including the availability of integrators who understand both photometric design and controls engineering. The sixth is the gap between design intent and operational reality, a problem familiar across smart-building technologies.

Saudi Vision 2030 developments intensify these barriers because they are often large, fast-moving, multi-package projects involving multiple consultants, contractors, and operators. Without clear employer requirements, data standards, and commissioning plans, smart lighting can fragment into disconnected packages that sacrifice long-term value. Research on Saudi standards and code pathways suggests that stronger alignment between local code logic, sustainability rating systems, and performance verification would improve implementation credibility (Shamseldin, 2023; Jamoussi et al., 2022). The implication is clear: Saudi projects need governance architecture for smart lighting, not just devices.

Finally, smart lighting should be evaluated against the emerging whole-life logic of sustainable development. Saudi building discourse is increasingly moving from isolated operational-efficiency measures toward broader frameworks that include carbon, digitalization, and long-term asset value (Jamoussi et al., 2022; UNEP & GlobalABC, 2025). Lighting contributes to this broader agenda because it sits at the intersection of operational demand, electronics replacement cycles, data services, and occupant wellbeing. While the embodied carbon of lighting systems is smaller than that of structure or envelope materials, rapid replacement of poorly selected control hardware can still undermine sustainability goals. This makes reparability, modular upgrades, firmware support, and standards-based interoperability part of the sustainability conversation. For Vision 2030, which emphasizes quality, efficiency, and future-readiness, these attributes are not optional extras but part of prudent public and private investment.

VIII. PROPOSED IMPLEMENTATION FRAMEWORK FOR VISION 2030 DEVELOPMENTS

Based on the reviewed evidence, this paper proposes a climate- and governance-responsive implementation framework for smart lighting in Saudi Vision 2030 developments. The framework is intended for planners, public clients, project managers, consultants, and operators.

Framework step	Recommended Saudi application
1. Define lighting as a strategic energy system	Project briefs should treat lighting as part of energy, data, and operations strategy rather than as a decorative or purely electrical package. Early-stage briefs should specify energy targets, interoperability requirements, and commissioning expectations.

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2. Prioritize a layered technical sequence	The minimum technical sequence should be efficient LED luminaires, addressable drivers, zone-based controls, occupancy or vacancy sensing, daylight-responsive dimming where appropriate, and integration with BMS or district platforms. More advanced analytics and AI should be added only after this foundation is stable.
3. Use climate-responsive daylight integration	Daylight harvesting should be combined with glare control, solar shading, suitable glazing, and realistic zoning. In hot-arid contexts, daylight strategies must protect cooling performance and visual comfort rather than maximizing glazing area indiscriminately.
4. Standardize interoperable communication	Saudi developments should prefer open or well-documented communication pathways and require vendors to provide integration documentation, cybersecurity provisions, and long-term access to operational data.
5. Link lighting with commissioning and measurement	Smart lighting should not be signed off at practical completion alone. It should undergo seasonal commissioning, functional testing, and post-occupancy verification using submetering, fault logs, and calibrated operational review.
6. Embed lifecycle and carbon logic	Procurement should account for maintenance cycles, replacement strategy, reparability, and embodied impacts alongside electricity savings. As policy matures, operational and embodied carbon metrics should be assessed together.
7. Build capability within the delivery chain	Owners and operators should require training for facility managers, controls technicians, and end users. The success of smart lighting depends as much on operational competence as on installed technology.
8. Scale through archetypes	Instead of one-off bespoke solutions for every asset, Saudi programs should develop archetypes for offices, schools, clinics, villas, apartment buildings, parks, car parks, and streets. Archetypes enable repeatability and reduce implementation risk.

Table 3. Proposed implementation framework for smart lighting across Saudi Vision 2030 developments.

IX. RESEARCH GAPS AND FUTURE AGENDA

Several research gaps deserve attention. First, Saudi evidence on smart lighting remains more fragmented than the evidence on cooling and envelope performance; more climate-specific case studies are needed across offices, schools, healthcare, mixed-use districts, and public-space typologies. Second, reported performance is often limited to electricity savings, whereas future studies should evaluate interactions with cooling demand, demand response, thermal comfort, visual comfort, and maintenance analytics. Third, the literature on occupant-centric control is advancing quickly, but there remains limited evidence from Gulf cultural and behavioral contexts, where occupancy patterns, privacy expectations, prayer schedules, and nighttime activity may differ from Western office assumptions. Fourth, public-lighting studies should be extended to Saudi street networks, heritage districts, and giga-project public realms where safety, tourism, and dark-sky considerations interact. Fifth, as AI and digital twins become more common, comparative evidence is needed on when algorithmic sophistication actually delivers value relative to good conventional commissioning.

There is also a policy-research agenda. Future studies should examine how Saudi code compliance, Mostadam scoring, and public procurement can incorporate smart-lighting verification more explicitly. Another promising avenue is the creation of Saudi benchmarks for lighting energy intensity, controls functionality, and post-occupancy performance by building type. Institutional guidance already recognizes lighting as part of energy-efficiency compliance (Saudi Energy Efficiency Center, 2025), but the next step is to translate compliance into performance assurance. That shift would strongly support Vision 2030's emphasis on measurable quality and accountable delivery.

X. CONCLUSION

Smart lighting control systems are no longer peripheral technologies. The literature reviewed from 2020 to early 2026 shows that they are an increasingly important component of building and district energy strategy, especially when paired with efficient LEDs, daylight-responsive control, occupancy sensing, interoperable communication, and integration with BMS, IoT, and digital-twin platforms. For Saudi Vision 2030 developments, the opportunity is unusually strong because the Kingdom is simultaneously delivering new districts, upgrading public infrastructure, strengthening building governance, and pursuing digital transformation.

The review finds that the most effective smart-lighting pathways are not technology-centric in a narrow sense. Their performance depends on climate-responsive daylight design, careful zoning, commissioning, user acceptance, open integration, and post-occupancy verification. In Saudi Arabia, these requirements are amplified by hot-arid conditions, cooling-dominated demand, dust exposure, and the complexity of giga-project delivery environments. The evidence therefore supports a disciplined hierarchy: efficient luminaires first, intelligent control second, systems integration third, and measured operation throughout the asset lifecycle.

In strategic terms, smart lighting offers Saudi developments a rare combination of near-term feasibility and long-term systems value. It can reduce electricity use, support cooling-load reduction, improve maintenance intelligence, strengthen public-space quality, and contribute to the digitally managed environments envisioned under Vision 2030. Scaled adoption, however, will require standards alignment, interoperable procurement, trained operators, and a decisive shift from compliance-based installation toward verified in-use performance. Under those conditions, smart lighting can become one of the most practical and scalable energy-conservation levers across Saudi Arabia's next generation of developments.

REFERENCES

[1] Akbulut, L., Taşdelen, K., Atılgan, A., Malinowski, M., Coşgun, A., Şenol, R., Akbulut, A., & Petryk, A. (2025). A systematic review of building energy management systems (BEMSs): Sensors, IoT, and AI integration. Energies, 18(24), 6522. https://doi.org/10.3390/en18246522

[2] Achar, T. E., Rekha, C., & Shreyas, J. (2024). Smart automated highway lighting system using IoT: A survey. Energy Informatics, 7, Article 64. https://doi.org/10.1186/s42162-024-00375-7

[3] Al-Homoud, M. S., & Krarti, M. (2021). Energy efficiency of residential buildings in the Kingdom of Saudi Arabia: Review of status and future roadmap. Journal of Building Engineering, 36, 102143. https://doi.org/10.1016/j.jobe.2020.102143

[4] Aloshan, M. A. (2025). Achieving near-zero energy in hot climates: Retrofitting building envelopes for existing homes. Heliyon, 11, e42170. https://doi.org/10.1016/j.heliyon.2025.e42170

[5] Alyami, S. H., Almutlaqa, A. A., Alqahtany, A. M., & Ashraf, N. (2021). Likelihood of reaching zero energy building design in hot dry climate: Saudi Arabia. IEEE Access, 9, 167054–167072. https://doi.org/10.1109/ACCESS.2021.3134365

[6] Amran, Y. H. A., Amran, Y. H. M., Alyousef, R., & Alabduljabbar, H. (2020). Renewable and sustainable energy production in Saudi Arabia according to Saudi Vision 2030: Current status and future prospects. Journal of Cleaner Production, 247, 119602. https://doi.org/10.1016/j.jclepro.2019.119602

[7] Cespedes-Cubides, A. S., & Jradi, M. (2024). A review of building digital twins to improve

energy efficiency in the building operational stage. Energy Informatics, 7, Article 46. https://doi.org/10.1186/s42162-024-00313-7

[8] Chen, J., Zhou, X., An, J., & Yan, D. (2024). Future trends in intelligent lighting control systems: Integrated technologies, multi-system linkage and AI integration. Building Simulation, 17, 1931–1948. https://doi.org/10.1007/s12273-024-1209-3

[9] Chinchero, H. F., Costa, A., Rocha, P., & Moreira, A. (2020). LED lighting systems for smart buildings: A review. IET Smart Cities, 2(4), 201–213. https://doi.org/10.1049/iet-smc.2020.0061

[10] Chiradeja, P., & Yoomak, S. (2023). Development of public lighting system with smart lighting control systems and Internet of Thing (IoT) technologies for smart city. Energy Reports, 10, 4254–4269. https://doi.org/10.1016/j.egyr.2023.10.027

[11] Emil, F., & Diab, A. (2021). Energy rationalization for an educational building in Egypt: Towards a zero energy building. Journal of Building Engineering, 44, 103247. https://doi.org/10.1016/j.jobe.2021.103247

[12] Felimban, A., Knaack, U., & Konstantinou, T. (2023). Evaluating savings potentials using energy retrofitting measures for a residential building in Jeddah, KSA. Buildings, 13(7), 1645. https://doi.org/10.3390/buildings13071645

[13] Gentile, N., Lee, E. S., Osterhaus, W., Altomonte, S., Amorim, C. N. D., Ciampi, G., Garcia-Hansen, V., Maskarenj, M., Scorpio, M., & Sibilio, S. (2022). Evaluation of integrated daylighting and electric lighting design projects: Lessons learned from international case studies. Energy and Buildings, 274, 112391. https://doi.org/10.1016/j.enbuild.2022.112391

[14] González, L. V., García-Hansen, V., & Andersen, M. (2026). Towards sustainable indoor lighting design: Ensuring energy efficiency, visual comfort and user well-being. Sustainable Development, advance online publication. https://doi.org/10.1002/sd.70201

[15] Gunasena Ekanayaka Gunasinghalge, L. U., Alazab, A., & Talukder, M. A. (2025). Artificial intelligence for energy optimization in smart buildings: A systematic review and meta-analysis. Energy Informatics, 8, 135. https://doi.org/10.1186/s42162-025-00592-8

[16] International Energy Agency. (2024). Energy efficiency 2024. https://www.iea.org/reports/energy-efficiency-2024

[17] International Energy Agency. (2025). Saudi Green Building Code 2024 (SBC 1001). https://www.iea.org/policies/25904-saudi-green-building-code-2024-sbc-1001

[18] International Energy Agency. (2026). The next wave of LED lighting: Smarter, circular and more efficient. https://www.iea.org/commentaries/the-next-wave-of-led-lighting-smarter-circular-and-more-efficient

[19] Jamoussi, B., Abu-Rizaiza, A., & AL-Haij, A. (2022). Sustainable building standards, codes and certification systems: The status quo and future directions in Saudi Arabia. Sustainability, 14(16), 10314. https://doi.org/10.3390/su141610314

[20] Jørgensen, B. N., & Ma, Z. G. (2025). Energy efficiency and decarbonization strategies in buildings: A review of technologies, policies, and future directions. Applied Sciences, 15(21), 11660. https://doi.org/10.3390/app152111660

[21] Kim, D. H., Jeon, S. H., & Sung, J.-S. (2024). Direct illuminance-contribution-based lighting control for IoT-based lighting systems in smart buildings. Sustainability, 16(12), 5054. https://doi.org/10.3390/su16125054

[22] López-Ruiz, H. G., Mastrucci, A., Pérez-Lombard, L., & Stazi, F. (2020). Assessing residential solar rooftop potential in Saudi Arabia. Energy Policy, 144, 111626. https://doi.org/10.1016/j.enpol.2020.111626

[23] Magrini, A., Lentini, G., Cuman, S., Bodrato, A., & Marenco, L. (2020). From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge. Developments in the Built Environment, 3, 100019. https://doi.org/10.1016/j.dibe.2020.100019

[24] Ministry of Energy. (2025). Saudi Energy Efficiency Center initiatives. https://www.moenergy.gov.sa/en/eco-system/programs/seec/initiatives

[25] Mostadam. (2024). Mostadam for residential buildings (O+E). https://subdivision-prod.ruh-s3.bluvalt.com/s3fs-public/mostadam/2024-05/Mostadam%20for%20Residential%20Buildings%20%28O%2BE%29.pdf

[26] Odiyur Vathanam, G. S., Kalyanasundaram, K., Elavarasan, R. M., Hussain Khahro, S., Subramaniam, U., Pugazhendhi, R., Ramesh, M., & Gopalakrishnan, R. M. (2021). A review on effective use of daylight harvesting using intelligent lighting control systems for sustainable office buildings in India. Sustainability, 13(9), 4973. https://doi.org/10.3390/su13094973

[27] Onubogu, N. O., Salami, B. A., & Ali, M. (2021). Review of active and passive daylighting technologies for sustainable building. Journal of Energy, 2021, 8802691. https://doi.org/10.1155/2021/8802691

[28] Rodrigues, L., Cherian, B. A., & Tokbolat, S. (2025). Reducing cooling energy demand in Saudi Arabian residential buildings using passive design approaches. Buildings, 15(11), 1895. https://doi.org/10.3390/buildings15111895

[29] Saudi Energy Efficiency Center. (2025). Guidance on energy efficiency scheme requirements for residential buildings. https://www.seec.gov.sa/en/rules/guidance-on-energy-efficiency-scheme-requirements-for-residential-buildings

[30] Saudi Vision 2030. (2025). Vision 2030 overview. https://www.vision2030.gov.sa/en/overview

[31] M. N. Shahid, M. U. Shahid, & M. Irfan. (2025). Advances in building energy management: A comprehensive review. Buildings, 15(23), 4237. https://doi.org/10.3390/buildings15234237

[32] Shamseldin, A. (2023). Proposed role of the local Saudi building codes in assessing the energy performance of buildings in KSA's GBRS. Ain Shams Engineering Journal, 14, 101966. https://doi.org/10.1016/j.asej.2022.101966

[33] Taboada-Orozco, A., Yetongnon, K., & Nicolle, C. (2024). Smart buildings: A comprehensive systematic literature review on data-driven building management systems. Sensors, 24(13), 4405. https://doi.org/10.3390/s24134405

[34] United Nations Environment Programme, & Global Alliance for Buildings and Construction. (2025). Global status report for buildings and construction 2024/2025. https://www.unep.org/resources/report/global-status-report-buildings-and-construction-20242025

[35] Wang, J., Han, X., Mao, J., & Li, W. (2021). Design and practice of prefabricated zero energy building in cold plateau area. Energy and Buildings, 251, 111332. https://doi.org/10.1016/j.enbuild.2021.111332

[36] Wang, Y., Zhang, X., & Chen, H. (2025). From needs to control: A review of indicators and sensing technologies for occupant-centric smart lighting systems. Energy and Buildings, 339, 115740. https://doi.org/10.1016/j.enbuild.2025.115740

[37] Zocchi, G., Hosseini, M., & Triantafyllidis, G. (2024). Exploring the synergy of advanced lighting controls, building information modelling and Internet of Things for sustainable and energy-efficient buildings: A systematic literature review. Sustainability, 16(24), 10937. https://doi.org/10.3390/su162410937