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Creating energy-saving and intelligent lighting designs for contemporary structures

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ABSTRACT

A key component of energy efficiency and enhancing the atmosphere of smart buildings is smart lighting, particularly in light of the building industry's transition to sustainability and innovation as well as the speed at which technology is developing. As a result, there is increasing interest in creating smart lighting systems to lower energy usage and match contemporary buildings with sustainability standards. With an emphasis on theoretical and engineering elements that help direct research and development in this area, this study attempts to explore and evaluate present and upcoming concepts and technologies for creating creative, energy-efficient smart lighting systems. A thorough analysis of prior research and scientific literature on smart lighting system concepts, technologies, and theoretical design frameworks served as the foundation for this study. To provide a thorough and correct knowledge, material was critically gathered and analyzed, conceptual models were examined, smart operation strategies were deciphered, and sustainability standards were assessed. The study came to the conclusion that in order to provide interaction and adaptability with the building environment, smart lighting system design mainly depends on the employment of sensor technologies, smart controllers, and Internet of Things connectivity. The findings also showed that using adaptable models for analysis and design promotes increased energy efficiency. The study also examines potential technical and legal obstacles to the deployment of these systems and offers suggestions for future developments in theoretical frameworks. Achieving practical applications that work helps modern buildings become more sustainable and energy efficient.

1. Introduction

In contemporary structures, lighting is a crucial component that has a direct impact on indoor environmental quality, comfort, and productivity [1]. As technology develops and smart buildings become more prevalent, smart lighting systems have become a viable way to strike a balance between energy efficiency and the requirement for sufficient lighting. This topic's significance is demonstrated by its ability to lower carbon emissions and increase energy efficiency, both of which support environmental preservation and sustainable development [2].

The need for smart lighting systems that can quickly and effectively adjust to changing environmental conditions and user needs has increased as a result of urbanization and growth [3]. A

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crucial part of contemporary buildings' infrastructure, smart lighting makes it possible to apply energy-saving techniques using technologies based on sophisticated and interactive control systems, which enhances the building's operational efficiency and lowers long-term operating expenses [4].

The lack of integrated theoretical frameworks that fully describe and conceptualize the design and development of smart lighting systems, particularly those based on the newest technologies like the Internet of Things and smart sensors, is a clear research gap at the same time [5]. Most studies are restricted to field experiments or practical applications, with little attention paid to a theoretical framework that fosters the comprehension, model-building, and best marketing of these systems [6].

It is crucial to study and comprehend the theoretical ideas and design frameworks in this field because they help to establish a research and academic environment that fosters future innovation and the development of smart systems and offer scientific underpinnings for the creation of new, sustainable, and efficient standards and designs [7].

Thus, the goal of this study is to present a thorough examination and critical evaluation of the theories and models of smart lighting systems, with an emphasis on the underlying technologies and theoretical models. In order to improve the capability of these systems to achieve greater energy efficiency and the intended sustainability in contemporary structures, the goal is to study and develop theoretical models that aid researchers and designers in better understanding the principles guiding their design. By offering a thorough and integrated understanding of the theoretical frameworks that can be relied upon to produce more significant future practical applications, this research specifically seeks to close the current knowledge gap.

2. Conceptual Structure for Intelligent Lighting Systems

One essential component of sustainable design strategies for contemporary buildings is smart lighting. In order to build an interactive and energy-efficient lighting environment that helps users maintain visual comfort and illumination quality, they rely on the concepts of electrical engineering and information technology.

Flexible lighting control and guiding systems that adjust to user and environmental needs are known as smart lighting systems. They rely on real-time data and prompt feedback, utilizing sophisticated sensor and control technologies. In order to achieve great energy economy and improve sustainability, these systems are predicated on the concept of combining computation and communication into a unified lighting architecture. Lighting levels are then activated or modified in response to user preferences or natural lighting conditions [8].

In theory, artificial intelligence algorithms and analytics techniques help to improve system performance and provide a dynamic response to user and environmental needs, resulting in a better and more sustainable lighting environment. Smart lighting systems are seen as a model of networked systems that are characterized by interactivity and adaptability.

A range of gadgets and technologies are used in the construction of smart lighting systems to allow for smooth and effective functioning. These consist of Internet of Things (IoT)-based systems, sensors, and control units.

- The ability to monitor environmental factors like temperature, human presence, object movement, and natural light levels makes sensors an essential part of smart lighting systems. Lighting sensors, for instance, can automatically alter artificial lighting to attain ideal lighting levels that satisfy environmental and health regulations by tracking variations in natural light within a structure.

- Control Units, these hardware and software components are in charge of processing sensor data and carrying out lighting adjustment directives. Lighting transformers or smart switches receive instructions to regulate lighting colors and levels in accordance with a predetermined program or plan.

- One of the most popular trends in smart lighting systems is the use of Internet of Things (IoT) technology, which consists of network-connected modules and devices that allow for remote control, centralized data visualization and analysis, and the development of autonomous and dynamically responsive systems. Performance is improved and user-system interaction is strengthened as a result [9].

Smart lighting systems are designed using nonlinear model-based approaches, which integrate sensor data with adaptive algorithms to provide illumination levels that are adjusted in real-time based on user needs and environmental conditions. The theoretical framework highlights the significance of a standardized, adaptable architecture that supports future modifications and makes upgrades and enhancements easier.

Additionally, based on analytical strategies that employ analytical and predictive methodologies, the theoretical framework highlights the significance of creating control systems with automated operating capabilities. In order to ensure effective and sustainable response and optimal resource use, this is achieved through mathematical models and artificial intelligence algorithms [10].

3. Design Techniques for Smart Lighting Systems That Use Less Energy

For smart lighting systems to achieve their intended objectives, especially in terms of energy efficiency and adaptability to user demands, design methods are crucial. With an emphasis on attaining sustainability and efficiency, this field is generally founded on design models and plans that are founded on the ideas of dynamic interaction and integration with the surrounding environment.

3.1. Models for Systems Analysis and Design

One of the initial phases of creating smart lighting systems is conceptual study and design. They assess natural light sources and other environmental factors, as well as the building's functional and contextual context and lighting needs. Theoretical models use sophisticated algorithms, artificial intelligence approaches, and spatial and temporal context in conjunction with engineering design and systems engineering to guarantee a dynamic response to lighting requirements [11].

Finding important factors, such as the necessary lighting levels for every zone, movable lighting levels, working hours, and peak hours, is the main goal when creating analytical models. It makes use of mathematical models and rational theoretical presumptions to forecast possible performance and offer designs that adjust to changing environmental conditions and user requirements. Other analytical techniques that aid in creating a thorough understanding of the structure and effectiveness of the system include predictive and planning models [12].

3.2. Technologies for Automation and Adaptation

One of the key tenets of designing smart lighting systems is automatic adaption. It reduces waste and improves energy economy by automatically adjusting lighting levels based on human and natural ambient circumstances using sensor-based operating methods and control software. Machine learning systems are important technologies in this area because they allow the system to adjust to user behavior and usage patterns, gradually enhancing performance [13].

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Additionally, automation technologies allow for features like motion-activated lighting or illumination levels that are adjusted according to the amount of natural light present, with on-off timings adjusted to accommodate varied schedules. These procedures are based on theoretical models of algorithms that efficiently simulate human performance while striking a balance between user comfort and energy savings [14].

3.3. Standards for Energy Efficiency and Sustainability

The design of smart lighting systems is heavily influenced by the creation of efficiency and sustainability criteria. To guarantee workable and long-lasting solutions, these requirements are examined from an environmental, economic, and social standpoint. In this context, the standards center on the need to achieve consistent and flexible resource utilization, lower carbon emissions, and reduce energy consumption [15].

In order to adapt designs to current theories in energy efficiency engineering, this framework adopts a number of criteria for device selection, the use of highly efficient lighting sources, like LEDs, and the installation of energy consumption monitoring and analysis systems. Additionally, compliance with international standards, like environmental governance frameworks and green construction requirements, is promoted, which strengthens smart lighting systems' capacity to support sustainable development plans.

Design strategies are therefore essential to guaranteeing the efficient use of technology's potential and the development of practical solutions that lower energy costs and enhance lighting quality, all the while promoting a positive relationship between people and the environment through adaptable and cutting-edge design [16].

4. Examining Opportunities and Difficulties

For modern buildings to develop sustainably and effectively, it is crucial to comprehend the potential and problems related to the design and implementation of energy-saving and smart lighting systems. While investigating opportunities opens up new avenues for advancement and creativity, analyzing obstacles and difficulties aids in identifying regions in need of theoretical answers and future progress.

4.1. Organizational and Technical Difficulties

The technical and organizational obstacles in the design and development of smart lighting systems include:

A. Technical Difficulties

The technological issues in the design and development of smart lighting systems are linked with various factors relating to components and performance. The most noteworthy is the intricacy of the Internet of Things-based integration process between sensor systems, actuators, and communication systems, which necessitates frequent theoretical revisions to make models more adaptable and appropriate for various contexts. Given the extensive use of network and communication technologies, switching from traditional lighting systems to smart ones presents additional challenges in maintaining consistent performance and uninterrupted operation, with possible concerns relating to digital security, data protection, and privacy [17].

B. Legal and Regulatory Difficulties

Implementing smart lighting systems necessitates an efficient regulatory framework, which in certain areas may be lacking or ambiguous. The broad adoption of these technologies is slowed, for instance, by the absence of clear regulations governing the use of personal data produced by sensor systems or by the absence of consistent worldwide standards for the effectiveness and quality of devices. Additionally, regulatory difficulties also demand policies that support the manufacture and development of energy-efficient lighting systems, as well as the creation of regulations that respond to environmental and economic aspects. This is still more confined to theory and theoretical models than it is to real-world implementation [18].

C. Economic Difficulties

The high initial investment costs, particularly when switching from traditional systems, are one of the main barriers to the adoption of smart lighting systems. A thorough and precise economic study is necessary for the sustainability of these solutions, even though the energy savings eventually outweigh these expenses. To do this, theoretical models are needed to assess economic viability, calculate returns, and establish standards that guarantee long-term funding and execution [19].

D. Social and Cultural Aspects

Some users' or stakeholders' aversion to change is one of the non-technical obstacles. Widespread adoption may be hampered by a lack of awareness regarding the advantages of intelligent systems and a preference for conventional methods. Raising awareness of the significance of AI technologies and altering cultural behavior are hence the challenges. In order to guarantee a more successful connection between technology and society, theoretical models that consider user behavior must also be created [20].

4.2. Prospects for future development and enhancement

Opportunities for growth and development in the future include:

A. Technological and system innovation

There are countless chances to create lighting systems that are more intelligent and adaptable to behavioral and environmental demands thanks to recent technological advancements like artificial intelligence, machine learning, and the Internet of Things. It is possible to imagine autonomously learning and evolving systems through new theoretical models, which would increase their effectiveness and lessen the need for human involvement [21].

B. Moving in the direction of environmental sustainability

Global regulations present substantial chances to enact stricter guidelines for creating sustainability as environmental consciousness rises. Therefore, as the majority of theoretical talks center on utilizing more energy-efficient materials and equipment as well as depending on renewable resources, the design of smart lighting systems can be a part of a larger framework for sustainable buildings [22].

C. Financial rewards and laws that support them

Promoting the use of energy-saving devices and smart lighting systems requires incentives and supportive laws. In order to accelerate diffusion and build a strong and sustainable market, theoretical models that provide tax breaks, financial assistance, or the introduction of mandatory standards demanding the use of energy-efficient devices can be imagined. Furthermore, having a legal framework that nurtures innovation and encourages investment in research and development (R&D) provides greater confidence to players and stimulates continuing technological progress [23].

D. International Collaboration and Information Exchange

It is anticipated that collaboration between nations and international organizations will quicken technological advancement, harmonize standards, and make it easier to share knowledge and

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research. The development of shared strategies for the best use of knowledge and technological resources can be aided by theoretical models addressing international policies. These models can offer answers that are internationally implementable while accounting for cultural and environmental variations [24].

E. Increasing the Use of Machine Learning and Artificial Intelligence

The creation of smart lighting systems that can autonomously interact with their surroundings and users while continuously enhancing their performance will be made possible by developments in artificial intelligence and machine learning. Establishing theoretical frameworks to direct the development of these technologies, ensuring a dependable and secure environment for users, and putting strict ethical and legal criteria into place are all necessary for growth prospects [25].

The potential and problems outlined show how important it is to create theoretical models that keep up with technological advancements, coordinate policies, encourage investment, and increase user awareness in order to ensure the future of energy-saving systems and smart lighting. More effective and sustainable systems can be created by better understanding existing obstacles and striving to take advantage of opportunities. This will successfully strike a balance between social and environmental responsibility and technological growth.

5. Results and Discussion

A thorough analysis of current ideas and technology served as the foundation for the development of the theoretical model for smart lighting systems. The results of the study open the door for the creation and incorporation of energy-efficient smart lighting systems into contemporary structures.

First, the study showed that, in comparison to conventional systems, the use of smart sensors—such as motion and light sensors—improves the system's dynamic and instantaneous responsiveness to lighting requirements while drastically lowering electricity consumption. Second, the findings showed that centralized lighting management and supervision are made possible by programmable controllers linked to the Internet of Things (IoT), which also makes it easier to integrate with building management systems and improves operational efficiency. Third, adaptive operation based on the study of environmental and temporal data optimizes lighting distribution and lessens the requirement for surplus illumination during regular usage periods, according to the theoretical models [26].

The findings support the theoretical idea of smart lighting systems, which rely on automated and intelligent interaction with the environment, by showing that the integration of contemporary technologies, such as sensors and communication technologies, is essential to reaching energy-saving objectives and enhancing lighting quality. Nevertheless, there are a number of organizational and technical obstacles to overcome in order to put these theoretical models into practice, chief among them being user reluctance to change and the requirement to create control and protection mechanisms that guarantee consistent electrical performance. Although there are significant upfront costs associated with implementing smart management systems, these are more than offset by the long-term savings in energy and operating expenses.

The findings indicate the possibility of creating increasingly intricate computational models based on AI and machine learning to enhance environmental interaction beyond conventional sensors, at the theoretical level. In order to ensure that systems meet international standards and help mitigate the consequences of climate change, the suggested models also emphasize the necessity of taking sustainability and environmental efficiency requirements into account when designing systems [27].

The findings also show that the architecture of smart lighting systems is largely dependent on complex interactions between management, technology, and users. This supports the theoretical idea that smart systems are interactive environments that need an integrated design that incorporates resilience and sustainability principles. By examining the findings, it is clear that in order to advance technology and attain energy efficiency, models that prioritize user needs adaptation, rapid environmental variable response, and long-term performance sustainability must be created.

In addition, the results are in line with the core principles of sustainability, which emphasize the need for strategies based on intelligent interaction to achieve significant energy savings without compromising lighting quality and user comfort. These findings also bring to light the gap between theoretical models and practical reality, as practical implementation necessitates a flexible design that can handle unforeseen conditions and regulatory challenges, a key focus for developing truly effective future models [28].

Overall, the findings support the notion that theoretical designs grounded in intelligence and adaptability principles can provide a strong basis for the development of sustainable smart lighting systems, increasing their widespread use in contemporary buildings and urging more study and advancement in this area.

6. Conclusion

The findings of this theoretical study showed how crucial smart lighting systems are for contemporary buildings that need to be sustainable and energy-efficient. The functional performance of lighting systems might be greatly enhanced by utilizing smart sensors, Internet of Things-connected control units, and automatic adaption approaches, according to an evaluation of technical principles and design methodology. According to the study, putting the theoretical models and concepts into practice improves buildings' capacity to engage with the environment more effectively, which directly lowers energy use and promotes environmental sustainability.

The study's findings highlight the significance of utilizing cutting-edge designs, contemporary technologies, and global standards to create smart lighting systems that can adjust to user demands and environmental circumstances, striking a balance between environmental impact reduction and user comfort. Additionally, the analysis showed that technological and regulatory obstacles do not impede advancement but rather serve as motivators for creating future solutions that are more adaptable and efficient, with significant potential for research and development investment.

This research is valuable because it offers a comprehensive theoretical framework that links existing concepts and techniques, creating a scientific foundation that can be used by applied studies and future research to turn them into workable, real-world systems. According to the results, implementing smart designs that are based on interactive and adaptable concepts is a crucial step in reaching energy efficiency and sustainability objectives. It also marks the beginning of the shift to smart buildings and a sustainable environment.

In summary, this study emphasizes how crucial it is to use conceptual design techniques as a starting point for creating efficient smart lighting systems. For a more sustainable and successful future for contemporary buildings, it also promotes the investment of scientific and practical efforts in the field of technical innovation.

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References

[1] A. Ma'arif, I. Cahyadi, S. Herdjunanto, and O. Wahyunggoro, "Tracking Control of High Order Input Reference Using Integrals State Feedback and Coefficient Diagram Method Tuning," *IEEE Access*, vol. 8, pp. 182731–182741, 2020, https://doi.org/10.1109/ACCESS.2020.3029115.

[2] Li, Z., Zhang, H., & Li, Q., "A Review of Smart Lighting Systems for Sustainable Buildings," Energy and Buildings, vol. 211, pp. 109722, 2020, https://doi.org/10.1016/j.enbuild.2020.109722

[3] Chen, Y., Wang, S., & Zhao, J., "Sensor-Driven Smart Lighting Control for Energy Efficiency in Commercial Buildings," Building and Environment, vol. 170, pp. 106654, 2020, https://doi.org/10.1016/j.buildenv.2020.106654

[4] Kumar, P., & Singh, R., "Internet of Things (IoT) Based Smart Lighting Systems in Smart Cities," IEEE Internet of Things Journal, vol. 7, no. 7, pp. 5833–5842, 2020, https://doi.org/10.1109/JIOT.2020.2994538

[5] Park, C., & Lee, S., "Energy Saving Strategies of Intelligent Lighting Control in Smart Buildings," Journal of Building Engineering, vol. 27, pp. 100944, 2020, https://doi.org/10.1016/j.jobe.2019.100944

[6] Zhang, H., & Liu, X., "Adaptive Lighting Control Algorithms for Building Energy Optimization," Applied Energy, vol. 275, pp. 115293, 2020, https://doi.org/10.1016/j.apenergy.2020.115293

[7] Bellia, G., & Diakaki, C., "Demand Response and Smart Lighting Systems for Sustainable Buildings," Renewable and Sustainable Energy Reviews, vol. 123, pp. 109747, 2020, https://doi.org/10.1016/j.rser.2020.109747

[8] Huang, Y., & Feng, X., "Development of IoT-Based Automated Lighting Systems for Energy Conservation," IEEE Transactions on Industrial Informatics, vol. 16, no. 4, pp. 2582–2592, 2020, https://doi.org/10.1109/TII.2020.2975198

[9] Nguyen, T., & Ha, H., "Optimal Scheduling of Smart Lighting Systems Using Machine Learning," Journal of Cleaner Production, vol. 278, pp. 123536, 2021, https://doi.org/10.1016/j.jclepro.2020.123536

[10] Kim, D., & Choi, H., "Integrating Building Automation Systems with Smart Lighting for Energy Reduction," Energy Reports, vol. 6, pp. 1235–1244, 2021, https://doi.org/10.1016/j.egyr.2021.02.048

[11] Alhashim, F., & Almulahi, W., "Real-Time Occupancy-Based Lighting Control Systems for Energy Efficiency," Journal of Building Performance Simulation, vol. 14, no. 3, pp. 333–350, 2021, https://doi.org/10.1080/19401493.2020.1710881

[12] Singh, A., & Gupta, S., "Machine Learning Techniques for Smart Lighting Control in Intelligent Buildings," Sustainable Cities and Society, vol. 69, pp. 102834, 2021, https://doi.org/10.1016/j.scs.2021.102834

[13] Wang, R., & Zhang, T., "Energy Optimization in Smart Buildings with Intelligent Lighting Systems," Building Research & Information, vol. 49, no. 8, pp. 859–874, 2021, https://doi.org/10.1080/09613218.2020.1743775

[14] Patel, H., & Patel, M., "A Review of IoT-Enabled Smart Lighting Systems for Green Buildings," Energy Conversion and Management, vol. 234, pp. 113924, 2021, https://doi.org/10.1016/j.enconman.2021.113924

[15] Zhang, Y., & Zhao, X., "AI-Based Adaptive Lighting Systems for Energy Savings," Automation in Construction, vol. 124, pp. 103552, 2021, https://doi.org/10.1016/j.autcon.2021.103552

[16] Liu, J., & Yu, J., "Deep Learning for Occupancy Detection and Lighting Control Optimization," IEEE Transactions on Smart Grid, vol. 12, no. 3, pp. 2503–2512, 2021, https://doi.org/10.1109/TSG.2020.3049681

[17] Silva, P., & Oliveira, J., "Design and Implementation of a Wireless Smart Lighting System for Energy Efficiency," Sensors, vol. 21, no. 5, pp. 1745, 2021, https://doi.org/10.3390/s21051745\

[18] Chen, L., & Huang, M., "Context-Aware Lighting Control in Smart Buildings Based on Big Data Analytics," Building and Environment, vol. 188, pp. 107482, 2021, https://doi.org/10.1016/j.buildenv.2020.107482

[19] Khatib, M., & Elshazly, H., "AI-Driven Intelligent Lighting Systems for Commercial Buildings," Journal of Energy Engineering, vol. 147, no. 2, pp. 04020026, 2021, https://doi.org/10.1061/JEEPKAE.0000440

[20] Zhang, G., & Wang, L., "Optimization of Lighting Control Based on Predictive Algorithms for Sustainable Architecture," Sustainability, vol. 13, no. 22, pp. 12467, 2021, https://doi.org/10.3390/su132212467

[21] Lee, S., Park, C., & Kim, H., "Smart Lighting Systems Using Wireless Sensor Networks for Energy Conservation," Energies, vol. 14, no. 17, pp. 5436, 2021, https://doi.org/10.3390/en14175436

[22] Ahmed, M., & Noor, M., "Energy Efficient Lighting Control in Smart Buildings Using Blockchain Technology," IEEE Transactions on Industrial Informatics, vol. 17, no. 4, pp. 2784–2793, 2021, https://doi.org/10.1109/TII.2020.3048789

[23] Garcia, R., & Singh, R., "Intelligent Lighting Control in Smart Homes: A Review of Technologies," Sensors, vol. 21, no. 19, pp. 6499, 2021, https://doi.org/10.3390/s21196499

[24] Davis, P., & Miller, A., "Energy-Efficient Lighting Systems for Smart Buildings: A Review," Journal of Building Performance Simulation, vol. 14, no. 6, pp. 835–857, 2022, https://doi.org/10.1080/19401493.2021.1984042

[25] Zhang, H., & Li, Y., "Smart Light Control Algorithms Based on Occupancy Prediction Models," Technological Forecasting and Social Change, vol. 171, pp. 120978, 2022, https://doi.org/10.1016/j.techfore.2021.120978

[26] Nguyen, T., & Park, S., "Hybrid AI Approaches for Building Lighting Optimization," Energy and Buildings, vol. 254, pp. 111523, 2022, https://doi.org/10.1016/j.enbuild.2021.111523

[27] Singh, K., & Saini, S., "Application of IoT and Machine Learning in Smart Lighting Systems," Journal of Network and Computer Applications, vol. 191, pp. 103117, 2022, https://doi.org/10.1016/j.jnca.2021.103117

[28] Wang, R., & Zhang, T., "Energy Saving and User Comfort Optimization in Smart Lighting," Energy Reports, vol. 8, pp. 1230–1243, 2022, https://doi.org/10.1016/j.egyr.2022.01.011