

THE USAGE OF SMART LIGHTING IN SMART HOME

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Purpose: The purpose of this publication is to present the usage of smart lighting in smart home.

Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.

Findings: The integration of smart lighting systems in smart homes signifies a paradigm shift, revolutionizing how individuals engage with and manage the lighting environment in their living spaces. Beyond traditional lighting solutions, smart lighting offers a plethora of advantages, enhancing comfort, energy efficiency, and overall convenience. Remote control capabilities through dedicated mobile applications empower users to make dynamic adjustments based on preferences and daily routines. The adaptability and versatility of smart lighting enable personalized environments tailored to specific activities or moods, further contributing to a transformative user experience. Noteworthy contributions to energy efficiency, automation facilitated by motion sensors, and seamless integration with other smart home devices underscore the system's impact on home automation and security. Despite challenges such as interoperability issues and privacy concerns, the advantages of smart lighting position it as a cornerstone in the broader smart home ecosystem, offering hands-free operation, security integration, and the potential for future innovations. The ongoing evolution of smart homes and advancements in smart lighting technology promise an intelligent, adaptable, and user-centric future, shaping the way individuals perceive and interact with illumination in a more sophisticated, sustainable, and connected living experience.

Originality/Value: Detailed analysis of all subjects related to the problems connected with the usage of smart lighting in smart home.

Keywords: Smart City, energy efficiency, smart home, smart house, digitalization, smart lighting.

Category of the paper: literature review.

1. Introduction

The integration of smart lighting systems within smart homes represents a paradigm shift in how individuals interact with and control the lighting environment of their living spaces. Smart lighting goes beyond the conventional on/off switch, offering a myriad of features and functionalities that contribute to enhanced comfort, energy efficiency, and overall convenience.

In the context of smart homes, the usage of smart lighting is integral to creating a technologically advanced and interconnected living space. One of the primary advantages is the ability to control lighting remotely. Through dedicated mobile applications, users can manage and customize their lighting settings from anywhere with the touch of a button on their smartphones or tablets. This remote control capability not only adds a layer of convenience but also allows for the dynamic adjustment of lighting scenarios based on user preferences and daily routines (Alsaedi et al., 2023).

The purpose of this publication is to present the usage of smart lighting in smart home.

2. Smart lighting in smart home

Smart lighting is a revolutionary technological advancement that has significantly transformed the way we illuminate our homes and commercial spaces. Unlike traditional lighting systems, smart lighting integrates cutting-edge technology to provide users with unprecedented control, efficiency, and customization. At its core, smart lighting involves the use of connected devices, such as smart bulbs, LED strips, and fixtures, that can be controlled remotely through various means. This control can be achieved through dedicated mobile applications, voice commands via virtual assistants like Amazon Alexa or Google Assistant, or even automation based on sensors and preset schedules (Chaudhari et al., 2023).

One of the key features of smart lighting is its adaptability and versatility. Users have the ability to adjust the brightness and color of the lights to create different moods and atmospheres. Whether it's a warm, cozy ambiance for a relaxing evening or a bright, energetic setting for productivity, smart lighting allows for seamless customization to suit individual preferences. Moreover, smart lighting contributes significantly to energy efficiency and sustainability. With the integration of LED technology, smart bulbs consume less energy compared to traditional incandescent or fluorescent bulbs. The ability to schedule lighting based on occupancy or time of day further reduces unnecessary energy consumption, resulting in lower electricity bills and a smaller environmental footprint (Huda et al., 2024).

Automation is another key aspect of smart lighting that enhances convenience and efficiency. Motion sensors can detect when a room is occupied and automatically turn on or off the lights accordingly. Additionally, users can create personalized automation scenarios, such as gradually dimming the lights as bedtime approaches or simulating sunrise in the morning to wake up more naturally (Wu et al., 2023). Furthermore, smart lighting systems often integrate with other smart home devices, creating a cohesive and interconnected ecosystem. For example, lights can be synchronized with smart thermostats, security cameras, or doorbell cameras to enhance overall home automation. This integration not only streamlines daily routines but also contributes to an enhanced sense of security (Raff et al., 2024).

In commercial spaces, smart lighting plays a pivotal role in creating dynamic and adaptive environments. Offices can optimize lighting conditions based on the time of day or specific tasks, promoting employee well-being and productivity. Retail establishments can utilize smart lighting to enhance the shopping experience, guiding customers through different sections with tailored lighting schemes (Sobhani et al., 2023). As technology continues to advance, the capabilities of smart lighting are likely to expand even further. Innovations such as Li-Fi (Light Fidelity), which uses light to transmit data, may become integral components of future smart lighting systems, offering faster and more secure connectivity.

Smart lighting represents a paradigm shift in how we perceive and interact with illumination. Its combination of customization, energy efficiency, automation, and integration with other smart devices positions it as a cornerstone in the broader ecosystem of smart homes and buildings, contributing to a more intelligent and sustainable future (Ramanujam et al., 2024).

Customization is a key aspect of smart lighting usage in smart homes. Residents can tailor the brightness and color temperature of lights to suit different activities, moods, or time of day. Whether it's creating a warm and cozy ambiance for a relaxed evening or a bright, invigorating atmosphere for focused work, the adaptability of smart lighting ensures that the lighting environment aligns with the occupants' specific needs and preferences (Douha et al., 2023). Energy efficiency is a crucial consideration in the design and implementation of smart lighting systems. The integration of energy-efficient LED technology not only reduces power consumption but also contributes to long-term cost savings (Patheja et al., 2023). Smart lighting goes a step further by allowing users to schedule lighting based on occupancy or time of day, minimizing unnecessary energy usage and promoting a more sustainable approach to home lighting (Afroz et al., 2024).

The interconnected nature of smart homes is further emphasized through the seamless integration of smart lighting with other smart devices. Whether it's syncing with smart thermostats to create a holistic approach to energy management or integrating with security systems for enhanced safety, smart lighting becomes an integral part of a broader ecosystem that operates in harmony to enhance overall home automation (Ameur et al., 2023). Voice control adds an additional layer of sophistication to smart lighting usage. With compatibility

with popular virtual assistants such as Amazon Alexa or Google Assistant, users can simply issue voice commands to control their lights (Valencia-Arias et al., 2023). This hands-free functionality not only enhances convenience but also aligns with the trend towards more intuitive and natural interactions with smart home technology. Moreover, the incorporation of motion sensors ensures that smart lighting systems respond to the immediate needs of occupants. Lights can automatically turn on or off based on detected motion, adding an element of energy efficiency and hands-free operation (Dhaou, 2023). This feature is particularly useful in areas where constant manual control may not be practical, such as hallways or closets (Hussain et al., 2023).

The usage of smart lighting in smart homes transcends traditional lighting paradigms. It embodies a fusion of technological innovation, customization, energy efficiency, and seamless integration with the broader smart home ecosystem. As smart homes continue to evolve, smart lighting remains a cornerstone, enriching the living experience by providing intelligent, adaptable, and user-centric lighting solutions (Rhode et al., 2023).

Table 1 contains descriptions of key features of smart lighting usage.

Table 1.
Key features of smart lighting usage

Key Features of Smart Lighting	Description
Remote Control	Users can effortlessly manage and control their lighting system remotely through dedicated mobile applications, providing the flexibility to adjust settings from anywhere with the convenience of a smartphone or tablet.
Customization	Smart lighting allows for precise customization, enabling users to tailor brightness levels and color temperatures to create specific atmospheres. This feature is ideal for setting the mood, enhancing aesthetics, and adapting lighting to different activities.
Energy Efficiency	The integration of energy-efficient LED technology minimizes power consumption, resulting in cost savings on electricity bills and contributing to a more environmentally sustainable approach to lighting.
Automation	Smart lighting systems can be programmed to automate lighting based on various parameters such as time schedules, occupancy sensors, or specific scenarios. This automation enhances energy efficiency and simplifies daily routines for users.
Integration with Smart Home Ecosystem	Seamless integration with other smart home devices, such as thermostats, security cameras, and voice assistants, creates a cohesive ecosystem. This interconnected setup allows for centralized control and enhances the overall efficiency of smart home automation.
Voice Control	Compatibility with popular virtual assistants like Amazon Alexa or Google Assistant enables users to control their lights using simple voice commands. This hands-free functionality adds an extra layer of convenience to smart lighting systems.
Motion Sensors	Motion sensors integrated into smart lighting systems detect occupancy and trigger automatic lighting adjustments. This feature enhances both convenience and energy efficiency by ensuring lights are only active when needed.
Color Adjustment	Beyond traditional white light, smart lighting systems offer color adjustment options, allowing users to change the color of their lights. This feature is not only visually appealing but also adds a dynamic and personalized touch to the lighting environment.

Cont. table 1.

Security Integration	Smart lighting can be synchronized with security cameras and other smart security devices. This integration enhances the overall security of a home by coordinating lighting with surveillance, deterring potential intruders and increasing overall awareness.
Health and Well-being Features	Tunable lighting options support circadian rhythms, positively impacting health and well-being. These features allow users to adjust lighting to mimic natural sunlight, promoting better sleep patterns and overall physical and mental well-being.
Commercial Applications	In commercial settings, smart lighting solutions offer adaptive lighting configurations for offices and retail spaces. These configurations are designed to optimize productivity, create inviting atmospheres, and enhance the overall customer experience.
Firmware Updates and Future Innovations	Regular firmware updates ensure ongoing compatibility and may introduce new features. Additionally, the potential for future innovations, such as Li-Fi technology, can expand the capabilities of smart lighting systems.

Source: (Gøthesen et al., 2023; Alsaedi et al., 2023; Chaudhari et al., 2023; Huda et al., 2024; Husain et al., 2023; Rhode et al., 2023; Basarir-Ozel et al., 2023; Tong et al., 2023; Chen et al., 2023; Douha et al., 2023; Sobhani et al., 2023).

3. The advantages and problems of using smart lightings

The adoption of smart lighting in smart homes brings forth a plethora of advantages that transcend the limitations of traditional lighting systems. This technologically advanced approach to illumination not only enhances convenience but also contributes to energy efficiency, security, and overall well-being. One of the primary advantages of incorporating smart lighting into a smart home ecosystem is the unparalleled level of control it offers. With the convenience of remote control through dedicated mobile applications, users can effortlessly customize and manage their lighting settings from anywhere. This flexibility allows for dynamic adjustments, accommodating different activities, moods, or preferences with a simple tap on a smartphone (Bsarir-Ozel et al., 2023).

Customization stands out as another key advantage, as smart lighting systems provide users with the ability to tailor the brightness, color, and ambiance of their lights. This level of personalization empowers occupants to create bespoke lighting environments that complement specific activities, enhancing the overall living experience and fostering a sense of comfort and individuality within the home. Energy efficiency takes center stage in the advantages of smart lighting. The integration of energy-efficient LED technology, coupled with features like scheduling and automation, enables optimal energy consumption. Smart lighting systems can adapt to occupancy patterns and time-based schedules, ensuring that lights are only active when necessary. This not only reduces electricity bills but also aligns with sustainable practices, contributing to a greener and more environmentally conscious home (Hussain et al., 2023).

The seamless integration of smart lighting with the broader smart home ecosystem amplifies its advantages. Centralized control and coordination with other smart devices create a cohesive and intelligent environment. This interconnectedness allows for sophisticated automation scenarios, where lighting can seamlessly interact with other smart systems such as thermostats, security cameras, and voice assistants, enhancing the overall efficiency and functionality of the smart home. Voice control represents a leap forward in user interaction. With compatibility with virtual assistants like Amazon Alexa or Google Assistant, smart lighting becomes effortlessly accessible. Users can issue voice commands to adjust lighting settings, adding a layer of convenience and hands-free control to their smart home experience (Olabode et al., 2023).

Security integration is another significant advantage of smart lighting. By synchronizing with security systems, smart lighting can play a pivotal role in enhancing home security. Integrated lighting scenarios, triggered by sensors or surveillance devices, act as a deterrent and provide additional visibility, contributing to a comprehensive and effective security strategy (Gajdzik et al., 2023; Jonek-Kowalska, Wolniak, 2021, 2022). The health and well-being features of smart lighting contribute to the occupants' overall quality of life. Tunable lighting options that support circadian rhythms can positively impact sleep patterns and create a healthier living environment. By mimicking natural sunlight, smart lighting systems address not only functional lighting needs but also promote physical and mental well-being within the smart home (Tong et al., 2023).

In terms of aesthetics, smart lighting adds a creative and dynamic dimension to home design. The ability to change colors and create visually appealing lighting schemes allows users to transform the ambiance of their living spaces, adapting to different occasions or personal preferences. This flexibility in aesthetics enhances the overall beauty and character of the home. Lastly, the adaptability of smart lighting to future innovations ensures that homeowners can stay at the forefront of technological advancements. Regular firmware updates and the potential integration of emerging technologies, such as Li-Fi, keep the smart lighting system current and future-proof, providing users with a long-lasting and evolving investment in the ever-changing landscape of smart home technology. In conclusion, the advantages of smart lighting in smart homes encompass control, customization, energy efficiency, security, well-being, aesthetics, and future readiness, collectively contributing to an elevated and intelligent living experience (Chen et al., 2023).

Table 2 highlighting the advantages of using smart lighting in smart home.

Table 2.
Advantages of using smart lighting

Advantage	Description
Remote Control	Users can conveniently control and customize lighting settings remotely through dedicated mobile applications, providing flexibility and adaptability to different scenarios and preferences from anywhere with a connected device.
Customization	Smart lighting allows for personalized adjustments in brightness, color, and ambiance, catering to specific activities, moods, or time of day. This customization enhances the living experience, allowing occupants to create tailored lighting environments that suit their preferences and contribute to the overall comfort of the home.
Energy Efficiency	Integration of energy-efficient LED technology coupled with scheduling and automation features promotes optimal energy usage. Smart lighting systems can adapt to occupancy and time-based patterns, reducing unnecessary consumption and contributing to long-term cost savings while aligning with sustainable practices.
Integration with Smart Home Ecosystem	Smart lighting seamlessly integrates with other smart home devices, fostering a cohesive ecosystem. This integration allows for centralized control, coordination with other smart systems, and the creation of comprehensive automation scenarios, enhancing the overall efficiency and intelligence of the smart home.
Voice Control	Compatibility with virtual assistants like Amazon Alexa or Google Assistant enables users to control lights using voice commands. This hands-free functionality adds a layer of convenience, allowing occupants to interact with their smart lighting system effortlessly and efficiently, contributing to a more intuitive and user-friendly smart home experience.
Motion Sensors	Incorporation of motion sensors enables automatic adjustments based on occupancy. Lights can turn on or off in response to detected motion, improving energy efficiency and providing hands-free control, particularly in areas where constant manual interaction may not be practical or necessary, such as hallways, bathrooms, or closets.
Security Integration	Synchronization with security systems enhances home security. Smart lighting can be integrated with cameras and other security devices to create dynamic lighting scenarios, acting as a deterrent and increasing overall visibility. This integration contributes to a comprehensive smart home security strategy, providing both functional illumination and an additional layer of safety.
Health and Well-being Features	Tunable lighting options support circadian rhythms and overall well-being. Users can adjust lighting to mimic natural sunlight, promoting better sleep patterns and creating a healthier living environment. These features contribute to the holistic integration of smart lighting into the occupants' daily lives, addressing not only functional needs but also enhancing their physical and mental well-being.
Enhanced Aesthetics	The ability to change colors and create dynamic lighting schemes adds an aesthetic dimension to smart homes. Smart lighting allows users to transform the look and feel of their living spaces, creating visually appealing environments for different occasions, events, or personal preferences. This flexibility in aesthetics adds a layer of creativity and personalization to the overall design and ambiance of the home.
Firmware Updates and Future Innovations	Regular firmware updates ensure ongoing compatibility and may introduce new features. The potential for future innovations, such as Li-Fi technology, adds value by keeping the smart lighting system up-to-date with the latest advancements, expanding functionality, and ensuring a future-proof investment for users in the ever-evolving landscape of smart home technology.

Source: (Gøthesen et al., 2023; Alsaedi et al., 2023; Chaudhari et al., 2023; Huda et al., 2024; Husain et al., 2023; Rhode et al., 2023; Basarir-Ozel et al., 2023; Tong et al., 2023; Chen et al., 2023; Douha et al., 2023; Sobhani et al., 2023).

Table 3 highlighting some of the common problems and challenges associated with the problems of using smart lightings in smart homes.

Table 3.
Problems of using smart lighting

Problem	Description	Methods of Overcoming
Interoperability Issues	Incompatibility between different smart lighting devices or platforms may arise, leading to challenges in achieving a seamless and integrated smart home experience.	Prioritize devices from the same manufacturer or those designed to work within a specific ecosystem. Verify compatibility before purchase. Invest in smart home hubs that support multiple protocols for better integration.
Reliability and Connectivity	Issues related to connectivity, such as Wi-Fi outages or device malfunctions, can disrupt the reliability of smart lighting systems, causing inconvenience and potential downtime.	Ensure a robust home Wi-Fi network. Opt for smart lighting systems with local control capabilities, reducing dependence on external servers. Regularly update firmware for improved stability and performance.
Security Concerns	The connectivity of smart lighting introduces potential vulnerabilities, posing security risks such as unauthorized access or hacking, leading to privacy concerns for homeowners.	Implement strong, unique passwords for smart devices. Regularly update firmware to address security vulnerabilities. Consider network segmentation to isolate smart devices from critical home systems.
Cost of Implementation	The initial investment required to implement a comprehensive smart lighting system, including the purchase of smart bulbs, controllers, and other accessories, may be perceived as expensive for some homeowners.	Start with gradual implementation, focusing on key areas. Look for cost-effective smart lighting solutions or consider retrofitting existing fixtures with smart bulbs. Evaluate long-term energy savings for cost justification.
Complexity of Setup and Use	The setup and configuration of smart lighting systems may be perceived as complex for users who are not tech-savvy, potentially leading to frustration or underutilization of the advanced features.	Choose user-friendly smart lighting products with intuitive setup processes. Follow manufacturer-provided guides or seek assistance from customer support. Invest time in learning and exploring the system's capabilities.
Dependency on Power Sources	Smart lighting systems rely on a stable power source, and disruptions such as power outages may render the smart features temporarily unavailable, reverting to conventional lighting control.	Install backup power solutions, such as uninterruptible power supplies (UPS), to maintain functionality during short power outages. Consider hybrid setups that allow manual control in the absence of power.
Software and Firmware Updates	Irregular or cumbersome software and firmware updates may lead to compatibility issues, bugs, or the loss of certain features, impacting the overall performance and functionality of smart lighting systems.	Regularly check for and apply software and firmware updates. Choose smart lighting products from reputable manufacturers with a history of providing timely and reliable updates. Test updates in a controlled environment before applying them.
Privacy Concerns	Smart lighting systems may involve data collection for optimization or user behavior analysis, raising privacy concerns among homeowners who are sensitive to the potential misuse of personal information.	Review privacy policies of smart lighting products. Opt for systems that offer transparent data usage practices. Consider local processing options that minimize reliance on external servers for data storage and analysis.

Cont. table 3.

Limited Compatibility with Fixtures	Some smart lighting solutions may not be compatible with certain types of fixtures or may have limitations in terms of dimming capabilities, restricting the choice of lighting aesthetics for homeowners.	Verify compatibility with existing fixtures before purchasing smart bulbs or switches. Explore product specifications and user reviews to ensure that the chosen smart lighting solution meets specific fixture requirements.
Environmental Impact	The manufacturing and disposal of smart lighting components, particularly batteries in some devices, may contribute to environmental concerns. Additionally, frequent technology upgrades may result in electronic waste.	Choose products with sustainable manufacturing practices. Dispose of electronic waste responsibly through recycling programs. Consider long-term usage and durability when selecting smart lighting solutions.

Source: (Gøthesen et al., 2023; Alsaedi et al., 2023; Chaudhari et al., 2023; Huda et al., 2024; Husain et al., 2023; Rhode et al., 2023; Basarir-Ozel et al., 2023; Tong et al., 2023; Chen et al., 2023; Douha et al., 2023; Sobhani et al., 2023).

4. Conclusion

The integration of smart lighting systems in smart homes represents a transformative shift in how individuals interact with and control the lighting environment within their living spaces. The advent of smart lighting brings forth a multitude of advantages that extend beyond conventional lighting solutions, offering enhanced comfort, energy efficiency, and overall convenience. The ability to control lighting remotely stands out as a primary advantage, facilitated through dedicated mobile applications. This remote control capability not only provides convenience but also allows for dynamic adjustments based on user preferences and daily routines. Smart lighting's adaptability and versatility enable users to customize brightness, color, and ambiance, creating personalized environments tailored to specific activities or moods.

Smart lighting's contribution to energy efficiency is pivotal, with LED technology reducing power consumption and scheduling features minimizing unnecessary energy usage. Automation, facilitated by motion sensors and preset schedules, enhances both convenience and efficiency. The seamless integration of smart lighting with other smart home devices further amplifies its impact, creating a cohesive ecosystem that enhances overall home automation and security. Commercially, smart lighting plays a crucial role in creating adaptive environments in offices and retail spaces, optimizing lighting conditions for productivity and enhancing the customer experience. As technology evolves, innovations such as Li-Fi hold the potential to further enhance the capabilities of smart lighting systems, offering faster and more secure connectivity.

However, the adoption of smart lighting is not without its challenges. Interoperability issues, reliability concerns, and security vulnerabilities pose potential obstacles. The cost of implementation and the complexity of setup may deter some users, and dependency on power sources could result in temporary disruptions during outages. Privacy concerns, limited fixture compatibility, and environmental impact also require careful consideration. Despite these challenges, the advantages of smart lighting, including control, customization, energy efficiency, and integration, position it as a cornerstone in the broader ecosystem of smart homes. The hands-free operation through voice control, security integration, health and well-being features, and the potential for future innovations underscore the transformative potential of smart lighting.

The continued evolution of smart homes and the ongoing advancements in smart lighting technology promise an intelligent, adaptable, and user-centric future. As users weigh the advantages against potential challenges, smart lighting remains a key player in shaping the way we perceive and interact with illumination, contributing to a more sophisticated, sustainable, and connected living experience.

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