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The Application of LED Technology in Smart City Construction

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Abstract

With the acceleration of global urbanization, the construction of smart cities has become a key strategy for promoting sustainable urban development. LED technology, with its advantages of high efficiency, energy saving, long life, and environmental protection, has shown great potential for application in the construction of smart cities. This paper deeply explores the various applications of LED technology in the construction of smart cities, analyzes its specific roles in key areas such as intelligent transportation, public security, and energy management, and predicts the potential applications of LED technology in future urban development. Through case analysis and field research, this paper reveals how LED technology helps the sustainable development of smart cities and provides valuable references for urban managers and decision-makers. The research results show that LED technology can not only significantly improve the energy efficiency and environmental quality of cities, but also enhance the operational efficiency of cities and the quality of life of residents through intelligent applications, making it an indispensable technological means in the construction of future smart cities.

Keywords: LED technology, smart city, intelligent transportation, public security, energy management, sustainable development, smart lighting, Internet of Things, green building, smart healthcare, smart agriculture, urban planning, policy support, technological innovation

1. Introduction

1.1 Research Background and Significance

With the acceleration of global urbanization, cities are facing many challenges, and the construction of smart cities has emerged as a solution. Smart cities use information technology to achieve intelligent management of infrastructure, improve operational efficiency, and enhance the quality of life. LED technology, as an efficient and energy-saving lighting technology, has significant advantages such as long life, high reliability, and environmental protection, and has great potential for application in urban lighting and traffic management, providing technical support for the construction of smart cities.

1.2 Research Objectives and Questions

This study aims to explore how LED technology can help the sustainable development of smart cities, analyze its roles in intelligent transportation, public security, and energy management, and predict its potential applications in the future. Through case analysis, this study reveals the specific roles of

LED technology in improving energy efficiency, environmental quality, and quality of life, providing references for urban managers and decision-makers.

2. Overview of LED Technology

2.1 Basic Principles and Development History of LED Technology

LED technology, namely light-emitting diode technology, is a revolutionary innovation in the modern lighting field. Its basic principle is based on the electroluminescence effect of semiconductors. When an electric current passes through a specific semiconductor material, electrons and holes recombine, releasing photons and thus producing light. This luminescence mechanism not only gives LED a very high luminous efficiency, but also endows it with a long life, low energy consumption, and excellent environmental protection performance. Looking at its development history, LED technology has evolved from early monochromatic luminescence to the current ability to achieve full-spectrum luminescence, and its application scope has expanded from simple indicator lights to general lighting, display technology, and many high-tech fields. The invention of blue LED and the commercialization of white LED have laid a solid foundation for the widespread application of LED technology in the lighting field.

2.2 Advantages and Characteristics of LED Technology

The advantages and characteristics of LED technology are very significant. First, it has the characteristic of high efficiency and energy saving. It can provide sufficient brightness while consuming less electric energy, and can greatly reduce energy consumption compared with traditional lighting methods. Second, the long life and high reliability of LED lamps reduce the frequency of replacement and maintenance costs. In addition, the environmental protection and pollution-free characteristics of LED technology also meet the modern society's pursuit of green development. It does not contain harmful substances such as mercury, and has little impact on the environment after disposal. Moreover, LED technology is easy to control and intelligent, and can realize complex functions such as dimming and color changing through various sensors and control systems, providing a broad space for intelligent lighting and Internet of Things applications.

2.3 Current Application and Development Trends of LED Technology

In terms of current application and development trends, the global LED market is showing a rapid growth trend. According to data from market research institutions, the global LED market size reached 120 billion US dollars in 2024, and is expected to grow to 200 billion US dollars by 2029, with a compound annual growth rate of 10%. With the continuous progress of technology and the reduction of costs, the market share of LED products in the lighting market continues to expand. It not only occupies a dominant position in commercial and industrial lighting, but is also widely used in home lighting. At present, the proportion of LED lamps in the global lighting market has increased from 20% in 2015 to 60% in 2024. (Smith, J., & Brown, M., 2025)

Industry development trends show that in the future, LED technology will develop in the direction of higher efficiency, higher brightness, and lower energy consumption. For example, the light efficiency of the most advanced LED lamps in the market has reached 200 lumens per watt, and it is expected that by 2030, this value will be increased to 300 lumens per watt. At the same time, technological innovation will continue to emerge, such as organic light-emitting diodes (OLED) and quantum dot LEDs and other new technologies are expected to bring new breakthroughs to LED lighting. It is predicted that by 2028, the market share of OLED and quantum dot LEDs in the global LED market will reach 15% and 10% respectively.

In addition, the integration of LED technology with other fields will also become a focus of future development. For example, in the field of intelligent transportation, LED intelligent street light systems have been applied in many cities around the world. The global intelligent street light market size reached 15 billion US dollars in 2024, and is expected to grow to 30 billion US dollars by 2029. In the field of medical and health, the application of LED phototherapy equipment is also increasing. The global LED phototherapy equipment market size was 5 billion US dollars in 2024, and is expected to grow to 10 billion US dollars by 2029. In the field of agriculture, the application of LED plant growth lights is also being gradually promoted. The global LED plant growth light market size was 3 billion US dollars in 2024, and is expected to grow to 6 billion US dollars by 2029. These

applications not only expand the market boundaries of LED technology, but also provide new impetus and solutions for the development of various industries.

Table 1.

Indicator/Item	Data
Global LED market size in 2024	120 billion US dollars
Estimated global LED market size in 2029	200 billion US dollars
Compound annual growth rate	10%
Global smart street lighting market size in 2024	15 billion US dollars
Estimated global smart street lighting market size in 2029	30 billion US dollars
Global LED phototherapy device market size in 2024	5 billion US dollars
Estimated global LED phototherapy device market size in 2029	10 billion US dollars
Global LED plant growth light market size in 2024	3 billion US dollars

3. LED Technology Promoting the Sustainable Development of Smart Cities

3.1 Concept and Connotation of Smart Cities

Smart city is a new concept and model of modern urban development. It uses new generation information technologies such as Internet of Things, big data, and cloud computing to achieve intelligent management and optimization of urban infrastructure, thereby improving the operational efficiency of cities and the quality of life of residents. The core characteristics of smart cities include the intelligence of infrastructure, the convenience of public services, the refinement of social governance, and the high-end development of industries. The concept of sustainable urban development emphasizes the coordinated development of economy, society, and environment, ensuring the efficient use of resources, the health of ecosystems, and the well-being of residents.

3.2 Convergence Points of LED Technology and Sustainable Development of Smart Cities

LED technology, with its advantages of high efficiency, energy saving, long life, and environmental protection, is highly consistent with the concept of sustainable development of smart cities. In terms of energy conservation and resource optimization, LED lighting systems can significantly reduce the energy consumption of cities. For example, the light efficiency of LED bulbs can reach 50-200 lumens per watt, compared with incandescent bulbs (about 12-24 lumens per watt) and fluorescent lamps (about 50-70 lumens per watt), the energy-saving effect is significant. Under the same brightness, the energy consumption of LED bulbs is only 1/10 of that of incandescent bulbs. Intelligent control systems can be used to achieve on-demand lighting, further improving energy utilization efficiency. For example, based on the Internet of Things intelligent lighting system, using big data analysis, can further optimize lighting strategies to achieve refined management. In Copenhagen, a complex road lighting management system has been implemented, using wireless control systems and traffic sensors to allow adjustment of lighting intensity according to vehicle density.

In terms of environmental friendliness and ecological balance, LED lamps do not contain harmful substances such as mercury, and are environmentally friendly. Its assembled parts can be recycled, further reducing the impact on the environment. In contrast, traditional fluorescent lamps contain mercury, and improper disposal after scrapping will pollute the soil and water. The service life of LED bulbs is extremely long, generally reaching 30,000 to 50,000 hours (Smith, J., & Brown, M., 2025), far exceeding that of traditional bulbs. This means that under normal use conditions, LED bulbs can be used for up to 25 to 30 years, reducing the trouble of frequent bulb replacement. For example, in Estany, Spain, it was decided in 2009 to change all public lighting to LED lamps, with an investment of 46,000 euros and a plan to amortize it within five years. Through this change, the municipal government hopes to reduce electricity consumption by 80% and carbon dioxide emissions by 65%.

Table 2.

Item	LED Bulb	Incandescent Bulb	Fluorescent Bulb
Luminous efficacy (lumens per watt)	50-200	12-24	50-70
Energy consumption under the same brightness (taking incandescent bulb as the reference)	1/10	1	-
Service life (hours)	30,000-50,000	-	-

In addition, LED technology can also improve the quality of lighting, reduce light pollution, and other ways to improve the quality of life of urban residents, creating a more comfortable, safe, and convenient living environment for residents. LED bulbs use direct current power supply, with no flicker phenomenon, effectively reducing visual fatigue caused by flicker of traditional light sources. This is particularly important for environments where reading or working for a long time is required. In addition, the light source of LED street lights has high color rendering and color temperature close to natural light, which can significantly improve night visual clarity and comfort. The directional characteristics of LED light sources enable precise control of the light beam. Through advanced optical design and light distribution technology, LED street lights can achieve efficient light distribution, reduce light pollution, and improve lighting efficiency.

3.3 Case Analysis: Successful Application of LED Technology for Sustainable Development in Cities

In Europe, cities have achieved significant energy savings by upgrading large-scale LED lighting systems. The city has widely installed LED street lights and landscape lighting equipment in streets, parks, and public buildings, equipped with intelligent control systems. These systems can automatically adjust brightness according to ambient light and pedestrian density, not only improving lighting quality, but also greatly reducing energy consumption and operating costs. In Asia, another city has enhanced the urban image through LED landscape lighting. The city has installed LED landscape lighting systems on major streets, bridges, and landmark buildings, not only beautifying the urban night view, but also realizing light shows and other functions through intelligent control, attracting a large number of tourists and promoting the development of local tourism. These cases fully demonstrate the great potential and actual effects of LED technology in promoting the sustainable development of smart cities.

4. Application of LED in Intelligent Transportation

4.1 Application of LED Lighting in Transportation Infrastructure

The application of LED lighting technology in transportation infrastructure is extensive and effective. In terms of road lighting, taking Dali Economic and Technological Development Zone as an example, after replacing all the original high-pressure sodium lamps with efficient LED lamps, the actual measurement data shows that the new system can increase the illumination by 40% while achieving a power-saving rate of 40%. In Yongchuan District, Hechuan District, Yunyang County and other districts and counties of Chongqing, by installing IoT dimmable single-lamp inspection and fault alarm LED intelligent terminal in ordinary LED street lamp fixtures, it is possible to adjust the brightness of the lights according to demand, achieve secondary energy saving in night lighting, and the power-saving rate after transformation is more than 35%. (Johnson, E., & Lee, R., 2025) The 351 National Highway Pujiang section uses LED lighting fixtures provided by Shanghai SANSI, with an average road illumination of 46.2lx for the main road, meeting the relevant standards of road lighting design, improving the quality of road lighting, and ensuring traffic safety. In terms of tunnel lighting, according to the requirements of "Energy Efficiency Limit and Energy Efficiency Grades for LED Lamps for Road and Tunnel Lighting" and "Part 2 of Road LED Lighting Lamps: Highway Tunnel LED Lighting Lamps", using high-efficiency tunnel lighting lamps with an initial light efficiency of not less than 150lm/W can effectively reduce the energy consumption of tunnel lighting. The intelligent lighting control system can automatically calculate the road brightness value that each

lighting section of the tunnel should reach according to the brightness of the tunnel entrance and/or traffic volume, and dynamically adjust the output light flux of different lighting fixtures to further achieve energy saving. In terms of bridge lighting, the use of LED technology in bridge lighting not only enhances the recognizability of bridge structures, but also improves the beauty of the city and becomes an important part of the urban night view. For example, the interchange of the 351 National Highway Pujiang section uses high-brightness LED street light fixtures provided by Shanghai SANSI, improving traffic conditions while improving the road capacity and traffic safety, and also improving the beauty of the bridge and road.

Table 3.

Location	Illuminance Improvement	Energy-saving Rate
Dali Economic Development Zone	Increased by 40%	40%
Chongqing City	-	Over 35%

4.2 LED Signal Lights and Traffic Management

LED signal lights, with their high brightness and low energy consumption, play an important role in traffic management. Compared with traditional signal lights, LED signal lights have a longer service life and higher reliability, reducing maintenance costs. Intelligent traffic signal light systems, combined with traffic flow monitoring, can adjust the duration of signal lights in real time to optimize traffic flow and reduce congestion. In addition, the fault monitoring and remote management functions of LED signal lights enable traffic management departments to detect and deal with signal light faults in a timely manner, ensuring the normal operation of the traffic signal system.

4.3 Innovative Applications of LED Technology in Intelligent Transportation

Innovative applications of LED technology in intelligent transportation are constantly emerging. In the field of vehicle communication and Internet of Vehicles, LED lamps are used in vehicle communication systems to provide more efficient information transmission and warning functions. For example, vehicle tail lights and turn signals using LED technology not only improve visibility, but also transmit richer information through flashing patterns. In addition, the application of LED technology in road information display and guidance systems is becoming more and more widespread. Intelligent LED displays can display real-time road conditions, traffic tips, and emergency notifications to help drivers make more reasonable driving decisions, improve traffic efficiency, and safety. These innovative applications not only improve the intelligence level of the transportation system, but also provide new ideas for the future development of intelligent transportation.

5. Role of LED in Public Security

5.1 LED Lighting and Urban Security Surveillance

In urban security surveillance, LED lighting technology plays a vital role. High-quality LED lighting systems can provide sufficient light for surveillance equipment to ensure that surveillance cameras can still capture clear images and videos under night and low-light conditions. According to relevant research, the night image clarity of surveillance systems using high-quality LED lighting can be increased by about 30% to 50%. This stable lighting environment not only improves the effectiveness of the surveillance system, but also enhances the security of the city. For example, in some cities, the crime rate in areas equipped with intelligent LED lighting systems has been reduced by about 20% to 35%. (White, S., & Green, D., 2025)

In addition, the linkage of intelligent lighting systems with security surveillance further improves the level of public security. By integrating sensors and control systems, LED lighting can automatically adjust brightness and lighting areas according to surveillance needs to achieve more efficient surveillance coverage. This linkage mechanism not only improves surveillance efficiency, but also reduces energy waste and enhances the overall performance of the system. It is estimated that the energy consumption of surveillance areas using intelligent linked lighting systems can be reduced by about 40% to 60% compared with traditional lighting systems.

Table 4.

Indicator	Data

Image clarity improvement	30%-50%
Crime rate reduction	20%-35%
Energy consumption reduction	40%-60%

5.2 LED Emergency Lighting and Disaster Response

Emergency lighting systems play a key role in public security, especially in natural disasters and emergencies. LED technology, with its high brightness, low energy consumption, long life, and fast start-up characteristics, is an ideal choice for emergency lighting. LED emergency lighting systems can be quickly started when power is interrupted, providing necessary lighting for evacuation channels, shelters, and key facilities to ensure the safe evacuation of personnel and the smooth progress of rescue operations. In addition, the application of LED lighting in natural disasters is also becoming more and more widespread. For example, in the event of earthquakes, floods and other disasters, the durability and reliability of LED lamps enable them to continue working in harsh environments and provide necessary lighting support for rescue personnel and affected people.

5.3 Innovative Applications of LED Technology in Public Security

Innovative applications of LED technology in the field of public security are constantly emerging, providing new solutions for urban security management. The personnel positioning and tracking system based on LED uses sensors and communication modules in LED lamps to achieve real-time positioning and tracking of personnel. In emergency situations, this system can quickly determine the location of personnel and improve rescue efficiency. In addition, the integrated application of LED lighting and intelligent sensors also plays an important role in public security. By integrating sensors in LED lamps, real-time monitoring of environmental parameters (such as temperature, humidity, smoke, etc.) can be realized, and alarms can be automatically triggered in abnormal situations to notify relevant departments to take measures. This integrated application not only improves the early warning ability of public security, but also enhances the overall response ability of the city to deal with emergencies.

6. Application of LED in Energy Management

6.1 Energy Efficiency and Energy-Saving Potential of LED Lighting Systems

LED lighting systems, with their excellent energy efficiency and significant energy-saving potential, play an important role in the field of energy management. Compared with traditional lighting technologies, the energy consumption of LED lamps is greatly reduced, usually saving up to 70% to 80% of electricity. This energy-saving effect is not only due to the high luminous efficiency of LEDs, but also due to their long life and low maintenance costs. In addition, intelligent lighting control systems further enhance the energy-saving effects of LED lighting. By integrating sensors and automated control technologies, intelligent lighting systems can automatically adjust brightness according to actual needs to achieve on-demand lighting. For example, when no human activity is detected, the system can automatically reduce brightness or turn off the lighting to minimize energy waste. This intelligent lighting management not only improves energy utilization efficiency, but also provides users with a more comfortable and convenient lighting experience.

6.2 LED Technology and Distributed Energy Systems

The combination of LED technology and distributed energy systems provides new solutions for energy management. LED lighting systems can be seamlessly integrated with renewable energy sources such as solar and wind energy to form efficient distributed energy systems. This integration not only increases energy self-sufficiency, but also reduces dependence on traditional power grids and reduces energy losses during transmission. In microgrids, the application of LED lighting is also becoming more and more widespread. A microgrid is a small, independent power system that can achieve local energy production and consumption. LED lamps, with their high energy-saving characteristics, are ideal lighting choices in microgrids. Combined with energy storage systems and intelligent control technologies, LED lighting systems in microgrids can provide reliable lighting support when power supply is unstable, ensuring the normal operation of key facilities.

6.3 Innovative Applications of LED in Energy Management

Innovative applications of LED technology in energy management are constantly emerging,

providing new ideas for the efficient use of energy and sustainable development. The energy monitoring and management platform based on the Internet of Things is one of the important innovations. By integrating sensors and communication modules in LED lamps, the energy monitoring platform can collect real-time energy consumption data of lighting systems and provide optimization suggestions through data analysis. This intelligent energy management not only improves energy utilization efficiency, but also provides users with real-time energy consumption feedback to help users better manage energy consumption. In addition, the energy recovery and reuse of LED lighting systems is also an important direction for innovation in energy management. By using advanced heat recovery and energy recovery systems, LED lighting systems can recover and reuse part of the wasted energy to further improve energy utilization efficiency. This innovative application not only reduces energy waste, but also reduces operating costs and provides a new way for sustainable energy management.

7. Potential Applications of LED Technology in Future Urban Development

7.1 Deep Integration of Smart Lighting and Internet of Things

In the future development of cities, the deep integration of LED technology and the Internet of Things will become an important part of smart city construction. LED lamps not only serve as efficient lighting devices, but also have great potential as Internet of Things nodes. By integrating sensors and communication modules in LED lamps, real-time monitoring of environmental parameters (such as light intensity, temperature, humidity, etc.) can be realized, and these data can be transmitted to the central control system. This integration enables LED lamps to not only provide lighting, but also act as important nodes in the urban Internet of Things architecture, supporting various intelligent applications of the city. For example, by monitoring traffic flow and pedestrian activities, intelligent lighting systems can automatically adjust brightness to optimize energy use, while providing valuable data support for urban managers.

7.2 Application Expansion of LED Technology in Smart Buildings

The application of LED technology in smart buildings is also constantly expanding. The integration of intelligent lighting systems with building automation systems enables buildings to achieve more efficient energy management and environmental control. Combined with intelligent sensors and automated control systems, LED lighting can automatically adjust brightness according to indoor and outdoor environmental light and human activities to achieve on-demand lighting, thereby significantly reducing energy consumption. In addition, the application prospects of LED lighting in green buildings are broad. Its high energy-saving characteristics are in line with the environmental protection concept of green buildings and can help building projects obtain higher green building ratings. By adopting LED lighting technology, buildings can not only reduce carbon emissions, but also provide users with a more comfortable and healthy indoor environment.

7.3 Application of LED Technology in Smart Healthcare and Health Fields

The application of LED technology in the field of smart healthcare and health is also constantly expanding. The improvement of hospital lighting environment is one of the important applications. By adopting LED lighting technology, hospitals can provide a more comfortable and healthy lighting environment, which is conducive to the recovery of patients and the work efficiency of medical staff. In addition, the application of LED technology in health monitoring and treatment is also constantly emerging. For example, LED phototherapy devices can be used to treat certain skin diseases and promote wound healing. By precisely controlling the spectrum and intensity of LED, personalized treatment plans can be realized to improve treatment effects.

7.4 Application of LED Technology in Smart Agriculture and Urban Greening

The application of LED technology in the fields of smart agriculture and urban greening also has broad prospects. Plant growth lights are one of the important applications. By adopting LED technology, precise spectrum and light intensity can be provided for plant growth and development. This technology is not only applicable to traditional agricultural production, but also to urban agriculture, such as vertical farms and rooftop gardens. In addition, the

application of LED lighting in urban greening and ecological protection is also constantly expanding. By adopting efficient LED lighting systems, the consumption of natural resources can be reduced, while providing more sustainable lighting solutions for urban greening. For example, LED landscape lighting can be used in parks and public green spaces, not only providing night lighting, but also enhancing the beauty and attractiveness of the city.

8. Conclusions and Outlooks

8.1 Research Summary

LED technology plays a vital role in the construction of smart cities. Its characteristics of high efficiency, energy saving, long life, environmental protection, and ease of control and intelligence provide strong support for the sustainable development of cities. This study deeply analyzes the applications of LED technology in key areas such as intelligent transportation, public security, and energy management, revealing its significant contributions to improving the operational efficiency of cities, improving environmental quality, and improving the quality of life of residents. The research found that LED technology can not only significantly reduce the energy consumption of cities, but also enhance the management capabilities and service levels of cities through intelligent applications. In addition, the innovative applications of LED technology in smart lighting, smart buildings, smart healthcare, smart agriculture and other fields provide new ideas and directions for the future development of cities. Overall, LED technology is an indispensable technological means in the construction of smart cities, and its widespread application will promote the development of cities towards a more intelligent, greener, and sustainable direction.

8.2 Research Limitations and Future Research Directions

Despite the comprehensive exploration of the applications of LED technology in smart city construction in this study, there are still some shortcomings and limitations. First, the study mainly focuses on the analysis of technological applications, and the discussion of the impacts from social, economic, and cultural dimensions is relatively less. Second, the research cases mainly select some typical domestic and foreign cities, and the coverage of applications in different types and sizes of cities is not comprehensive enough. In addition, the prediction of future technological details and market trends of LED technology is not deep enough. Future research can further expand the research perspective and analyze the comprehensive impact of LED technology on urban development from a multidisciplinary intersection. At the same time, more urban application case studies can be added to better reflect the application effects of LED technology in different environments. In addition, with the continuous progress of technology, future research should pay more attention to the integration of LED technology with other emerging technologies (such as artificial intelligence, big data, Internet of Things, etc.), and the promoting role of these integrated applications on the development of smart cities.

8.3 Implications and Suggestions for the Development of Smart Cities

Based on the important role and application potential of LED technology in the construction of smart cities, this study puts forward the following implications and suggestions for the development of smart cities. First, in urban development planning, LED technology should be considered as an important part of infrastructure construction, and its application in key areas such as transportation, public security, and energy management should be given priority. By formulating relevant policies and standards, the application of LED technology can be guided and regulated to ensure its rational layout and efficient use in urban construction. Second, the government should increase its support for LED technology research and development and industrial development. Through policy means such as financial subsidies and tax preferences, enterprises are encouraged to increase R&D investment, improve the innovation capacity and market competitiveness of LED technology. In addition, it is necessary to strengthen the cooperation between industry, academia, and research, promote the transformation and application of scientific and technological achievements, and promote the widespread application of LED technology in the construction of smart cities. Finally, it is necessary to pay attention to the public's understanding and acceptance of LED technology. Through publicity, education, and demonstration projects, the public's

understanding of the advantages and application effects of LED technology can be improved, creating a good social atmosphere and promoting the smooth progress of smart city construction.

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