Exploring the Application of Energy-Saving Technologies in Building Electrical Design

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Abstract: At present, energy conservation and environmental protection have become mainstream development trends. Integrating this concept into modern building electrical design can effectively reduce various unnecessary resource consumption. This article takes the energy-saving development requirements of building electrical design as a starting point. It first analyzes the importance of energy-saving technologies in ensuring sustainable utilization of energy resources, reducing the whole-life-cycle operational costs of buildings, and contributing to macro environmental protection goals. It then elaborates on the principles of functional adaptation and energy efficiency synergy, whole-cycle economic balance, and technological iteration and system upgrading. Finally, it details the dynamic optimization of power supply and distribution, scenario-based lighting energy savings, and the integrated application of renewable energy, hoping to provide reference for the practical work of relevant professionals.

1. Introduction

The electrical system, as the core link responsible for energy transmission, distribution, and terminal consumption within a building, generates a significant scale of energy consumption during operation. This not only directly relates to the building's overall energy utilization efficiency but also decisively influences the control of total energy consumption throughout the building's entire life cycle. Precisely for this reason, actively exploring and adopting innovative electrical energy-saving technologies has become a crucial core pathway for the construction sector to break through the traditional high-energy-consumption development model, promote the industry's transition towards green and low-carbon directions, and thereby lay a solid foundation for achieving the universally advocated sustainable development goals worldwide.

2. The Importance of Energy-Saving Technologies in Building Electrical Design

2.1 Ensuring Sustainable Utilization of Energy Resources

The building electrical system is the core component of the building's overall energy consumption, and its long-term stable operation relies on continuous energy input [1]. The application of energy-saving technologies in electrical design can reduce dependence on and consumption of traditional non-renewable energy sources by optimizing equipment efficiency and establishing intelligent energy distribution systems. This avoids extensive waste of energy resources, not only improving the utilization efficiency per unit of energy but also extending the overall supply cycle of energy resources, further reserving space for future societal energy demands. It aligns from the design source with the core requirement of "ensuring sustainable resource utilization" in sustainable development.

2.2 Reducing Whole-Life-Cycle Operational Costs of Buildings

Throughout the entire life cycle of a building, from commissioning to decommissioning, the cost of energy consumption by the electrical system constitutes an extremely high proportion. Energy-saving technologies, by embedding the concept of "on-demand energy supply" during the

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electrical design phase [2]—for example, using intelligent control systems to achieve time-based start-stop for lighting and power equipment, and adopting energy-saving electrical components to reduce standby energy consumption—can control energy waste at the source and directly reduce daily electricity expenses during building operation. Simultaneously, low-energy operation can reduce wear and tear on electrical equipment caused by high-load operation, extend equipment service life, and lower subsequent maintenance and replacement costs, alleviating long-term economic pressure for building operators and ultimately enhancing the building's comprehensive economic benefits.

2.3 Contributing to the Achievement of Macro Environmental Goals

The United Nations Sustainable Development Goals have explicitly listed "reducing greenhouse gas emissions" as an important component. The construction industry is one of the key sources of carbon emissions, and electrical system energy consumption is a primary cause of building carbon emissions [3]. Energy-saving technologies can directly reduce carbon dioxide and other greenhouse gas emissions generated by energy combustion by lowering building electrical energy consumption, promoting the transition of the construction industry towards low-carbon practices. Ultimately, this makes buildings not an environmental burden but an important vehicle for achieving carbon reduction goals, enabling the construction industry to align with macro environmental requirements and thereby promote the overall society's progress towards sustainable ecological development goals.

3. Principles of Energy Saving in Building Electrical Design

3.1 Principle of Functional Adaptation and Energy Efficiency Synergy

Energy-saving electrical design for buildings must be premised on functional requirements, ensuring precise adaptation of energy efficiency optimization to application scenarios. Designers need to scientifically configure electrical systems based on building type, usage function, and regional climate characteristics to achieve synergistic progress between basic functions and energy-saving goals. Simultaneously, according to the "Electrical Design Standards for Civil Buildings," the power supply and distribution system must comply with power quality specifications, and the lighting system must meet illumination standards. Furthermore, designers must also analyze solar resources and reasonably configure photovoltaic supplementary energy sources to avoid functional deficiencies caused by blindly pursuing energy savings [4]. For example, campus buildings can adopt Building-Integrated Photovoltaics (BIPV) technology to prioritize meeting their own electricity demand; office buildings can be equipped with AI tidal lighting systems that automatically adjust brightness based on human traffic changes. This not only ensures basic needs such as teaching and office work but also eliminates invalid energy consumption like "always-on lights," achieving a dynamic balance between function and energy saving.

3.2 Principle of Whole-Cycle Economic Balance

Energy-saving design needs to establish a dynamic balance mechanism between capital investment and energy savings, avoiding the increase of additional cost burdens by excessively pursuing energy savings. Designers need to select the most cost-effective solutions through economic and technical comparisons during design, achieving efficient resource utilization in aspects such as equipment selection and circuit layout. Taking industrial plant design as an example, reasonable circuit planning can shorten line lengths and reduce energy loss; selecting high-efficiency transformers and LED luminaires can lower long-term energy consumption; combining prepaid metering systems cultivates users' energy-saving awareness, thereby converting initial investment into long-term returns/benefits. Additionally, designers need to refer to energy efficiency grading standards, prioritize the use of equipment that meets energy-saving levels, utilize policy tools such as subsidies and trade-in programs to reduce equipment update costs, and optimize operational and maintenance expenses through data analysis from energy efficiency monitoring systems, ultimately achieving a win-win situation for both technical energy savings and financial savings.

3.3 Principle of Technological Iteration and System Upgrading

Designers need to rely on technological innovation to enhance the scientific and forward-looking nature of energy-saving design, thereby promoting the development of electrical systems towards intelligence and integration. Designers need to establish a comprehensive energy-saving system encompassing power supply and distribution, lighting, and renewable energy during the design process, achieving full-link monitoring and regulation through an energy efficiency management platform [5]. For instance, the intelligent energy efficiency management system deployed in campus buildings integrates functions such as photovoltaic monitoring, load control, and water usage supervision, and can optimize energy usage patterns through data mining; office buildings apply AI air conditioning energy-saving technology, using environmental sensors to achieve imperceptible energy savings like "start-stop upon reaching temperature" and "shut down when unoccupied." Simultaneously, the design must reserve interfaces for technological upgrades, track the dynamic updates of energy efficiency standards in real-time, actively promote advanced energy-saving equipment, and ensure that the electrical system maintains technological advancement and energy-saving effectiveness throughout its entire life cycle.

4. Application of Energy-Saving Technologies in Building Electrical Design

4.1 Dynamic Energy Efficiency Optimization of Power Supply and Distribution Systems

The building power supply and distribution system is the core link of energy transmission. The application of energy-saving technologies by designers requires breaking through traditional static design thinking and shifting towards dynamic energy efficiency optimization.

Firstly, at the load matching level, designers can establish an "on-demand adjustment" transformer operation mode based on real-time load fluctuations in different functional zones of the building [6]. Using intelligent monitoring systems to collect electricity load data at different times enables automatic adjustment of the number and capacity of transformers in operation. For example, when a commercial building retains only low loads such as security and emergency lighting at night, it can switch to operation with a single small-capacity transformer, avoiding no-load energy consumption from multiple transformers; during peak load hours in the daytime, sufficient transformers are interconnected and put into operation to achieve precise matching between load and power supply capacity.

Secondly, in the reactive power compensation aspect, designers need to upgrade traditional local compensation methods by introducing AI-driven dynamic compensation systems. This system can monitor the reactive power changes of electrical equipment in real-time, automatically adjusting the input capacity and duration of compensation capacitor banks to avoid power loss caused by over-compensation or under-compensation. Simultaneously, addressing the issue of long power supply and distribution lines in high-rise buildings, new cable materials with low impedance and low loss can be used to reduce line resistance loss while meeting current carrying capacity and thermal stability requirements. Combined with the building layout, placing substations and distribution rooms close to areas with high load density shortens the power supply radius and reduces energy loss from cross-regional power transmission.

Finally, designers can achieve refined energy distribution through intelligent zoning management and control of the power supply and distribution system. For instance, dividing the building into multiple independent power supply zones, each equipped with smart meters and load controllers. When abnormally high energy consumption is detected in a particular zone, the system can issue real-time warnings and automatically limit that zone's excess energy consumption, preventing local abnormal energy consumption from affecting the overall power supply and distribution efficiency. This achieves energy-saving upgrades in the power supply and distribution system from multiple dimensions: transmission, compensation, and management control.

4.2 Scenario-Based Intelligent Energy Saving for Lighting Systems

Energy saving in building lighting systems needs to move beyond the singular mindset of simply "reducing power" and shift towards scenario-based intelligent regulation, maximizing energy savings while ensuring lighting quality. Designers can customize exclusive energy-saving solutions tailored to the differing lighting needs of various functional areas. For example, office areas can adopt a mode combining priority for natural light and dynamic adjustment of auxiliary lighting. By installing light sensors to monitor indoor natural illuminance in real-time, the ceiling main lighting in areas near windows can be automatically turned off when the illuminance meets office standards, retaining only local auxiliary lighting in corridors and workstations. Meeting rooms can be configured with three-stage control (reservation, in-use, standby): basic lighting automatically turns on during the reservation period, lighting brightness adjusts based on the number of people during use, and all non-emergency lighting is automatically cut off after the meeting ends, avoiding the "always-on light" phenomenon.

Simultaneously, in commercial settings, designers need to balance display effects with energy consumption control. For instance, shopping mall exhibition halls can use spectrum-adaptive energy-saving light sources, adjusting the light source spectrum according to the type of exhibit. The clothing area can select LED light sources with a high Color Rendering Index (Ra⩾90) to accurately reproduce the colors of garments, while using intelligent dimming systems to reduce lighting brightness in non-key exhibition areas during periods of low customer flow. The jewelry exhibition area can employ directional spotlighting LED lamps, focusing on the exhibits while reducing ambient light waste. Furthermore, designers can integrate the lighting system with the mall's customer flow monitoring system. When customer flow in a certain exhibition area falls below a threshold, part of the redundant lighting is automatically turned off, and gradually restored when customer flow increases, thus achieving dynamic energy saving characterized by "lights brighten upon arrival, adjust upon departure."

Additionally, designers can upgrade traditional sound-activated or light-activated switches in public spaces to intelligent control modules combining human presence detection and delayed power-off [7]. For example, installing microwave radar sensors in underground garages so that when a vehicle or person enters the detection range, only the lighting in the current area and within 30 meters ahead is illuminated, automatically turning off with a 30-second delay after they leave. Stairwells can have optimized sensor sensitivity based on floor location to avoid false triggering of lighting due to wind noise or echoes in high-rise stairwells, further reducing invalid energy consumption. This allows the lighting system not only to meet usage demands but also to achieve precise utilization of energy.

4.3 Integrated Application of Renewable Energy and Building Electrical Systems

Deeply integrating renewable energy into building electrical systems is a key path to break through the traditional reliance on grid power supply models and achieve energy self-sufficiency. On one hand, designers can establish integrated photovoltaic (PV), energy storage, and power distribution systems for solar energy utilization [8]. PV modules can be installed on building rooftops and curtain walls to prioritize power supply for loads such as lighting, air conditioning, and office equipment. Simultaneously, configuring lithium battery energy storage systems allows excess PV power generated during the day to be stored and released during the night or on cloudy days, thereby reducing dependence on the grid. For example, an office building designed with PV modules covering 80% of the roof area, combined with a 100 kW • h energy storage battery, can meet 30% to 40% of its daily electricity demand, significantly reducing grid power consumption. Meanwhile, the energy management platform can monitor PV output, storage status, and building load in real-time, automatically adjusting the power supply ratio from PV, storage, and the grid to maximize solar energy utilization. On the other hand, designers can also explore the complementary application of small-scale wind energy and building electrical systems. Small wind turbines can be installed on the tops of high-rise buildings or in open areas. When wind speed reaches above 3 m/s, the generator starts producing electricity to supplement power supply to loads such as emergency lighting and outdoor landscape lighting. Through intelligent switching devices, the system can automatically switch to grid power when wind energy output is insufficient, ensuring stable operation of the loads. Furthermore, the integration of renewable energy with building electrical systems not only reduces the building's dependence on traditional energy sources but also minimizes losses during energy transmission, providing a new path for building electrical energy saving.

5. Conclusion

Building electrical energy saving is a systematic project covering concepts, principles, and technologies. Guided by the core objectives of ensuring energy sustainability, reducing whole-life-cycle costs, and contributing to environmental goals, and relying on the principles of functional adaptation, economic balance, and technological iteration, an efficient and low-carbon electrical system is established through dynamic optimization of power supply and distribution, scenario-based lighting regulation, and deep integration of renewable energy. This system not only breaks through the energy consumption bottlenecks of traditional building electrical systems but also promotes the low-carbon transformation of the construction industry, further aligning with the national "Dual Carbon" goals and sustainable development needs. In the future, designers need to continuously deepen technological innovation and system integration, making building electrical energy saving a core link in the development of green buildings and injecting sustained momentum into the synergistic advancement of ecological protection and economic development.

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