Survey of Artificial Intelligence of Things for Smart Buildings: A closer outlook

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Abstract

Artificial Intelligence of Things (AIoT) is a term used to describe the integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies. AIoT combines the capabilities of AI algorithms with the data generated by IoT devices to enable real-time decision-making and automation of various processes. Smart buildings refers to a type of building that utilizes advanced technologies to improve its efficiency, performance, and functionality of indoor tasks in a way that provide a safe and comfortable environment for occupants. This paper provides an overview of the research literature on AIoT technologies that is contribute to the development of smart buildings and their functionality. We discuss the benefits of AIoT empowered smart buildings, which include reduced energy consumption and costs, improved occupant comfort and productivity, and increased safety and security. we also discusses the challenges associated with the deployment of AIoT in smart buildings, including data privacy and security concerns, interoperability issues, and the need for specialized expertise. Further, we discuss the promising areas of future research that pave the way for further research on AIoT empowered smart buildings. We concludes our work with a discussion of the potential for AIoT empowered smart buildings to contribute to the sustainability of cities and improve the quality of life for their occupants.

Keywords: Internet of Things (IoT); Artificial Intelligence; Smart Buildings; Security; Sustinabilty

1. Introduction:

The advent of AI has completely changed the way we interact with machines, allowing us to streamline our lives through the automation of mundane chores. Advances in smart building technology are one area where AI is making a noticeable impact. A smart building is a dwelling that has numerous gadgets and equipment that can be managed remotely through the use of a computer, tablet, or smartphone. Artificial intelligence allows these gadgets to adapt to our individual needs by picking up on our routines and preferences. smart building technology has come a long way, from programmable thermostats to voice-activated assistants that can shut off lights and lock doors. In addition, AI systems can assess our energy consumption and offer advice on how to cut back, so lowering our monthly electricity costs. Although there are numerous advantages to having a smart building powered by AI, some people worry about their privacy and security. There needs to be a high level of security and privacy protection in smart buildings because of the amount of personal information that is collected and processed. It's conceivable that as AI develops further, smart buildings will become much more advanced, allowing us to enjoy even higher levels of automation and comfort. But, as we welcome this innovative technology into our lives, it is essential that we keep in mind the hazards involved and take precautions to ensure our privacy and safety [1-3].

Machine learning (ML) is an effective method for enhancing smart building software. ML algorithms may learn our tastes and behaviors by evaluating data from numerous sensors and gadgets, and then alter smart building systems accordingly to make our lives more easy and more pleasant. In the context of smart building energy management, for instance, ML can play a vital role in assisting households in optimizing energy usage and lowering associated costs. Machine learning algorithms can study past and present energy use patterns in buildings by processing data from sensors, smart meters, and other devices. ML can also be used to improve smart building security by alerting residents

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to danger before it's too late. Several forms of ML can be used for outlier detection, face recognition, vulnerability scanning, personalized security, and identity verification in the context of smart building safety [4-6].

ML is an exciting new technology for improving building automation, which will allow building owners to make their buildings more comfortable, convenient, and unique. For instance, ML algorithms may learn a resident's preferences for lighting, temperature, and other parameters, and then modify smart building systems to those conditions. The program may, for instance, modify the room's illumination in response to the user's preferences for brightness and color temperature. In addition, ML systems can examine information gathered by smart building gadgets to foretell when repairs will be required. With this knowledge, repairs, and upgrades may be planned ahead of time, minimizing equipment downtime and maximizing gadget usefulness. Moreover, ML algorithms can adapt the smart building to the individual's habits by learning their patterns over time. The algorithm might automate tasks like adjusting the temperature and lighting in the building to optimize productivity and ease of use depending on the resident's routine [7-9].

As more researchers begin to focus on AIoT empowered smart buildings, the existing body of work on AI for smart buildings spreads out across several disciplines. This timely research fills a knowledge vacuum and provides useful insights into AI methods and their use in smart buildings. This is a summary of the most important contributions from this investigation. First, We provide a comprehensive review of the history and presence of AIoT in smart buildings. The significance of this review rests in the basis it sets for integrating AIoT technologies into a dynamic market. Our review is brief in comparison to other studies, and it concentrates on the reasons why AIoT technologies and smart buildings are a suitable fit for one another [10-12]. This summary not only highlights recent breakthroughs in the field but also the creative methods being taken to old challenges, which should inspire additional research. Second, we provide a new discussion on several uses (for example, data sharing for smart buildings) that are supported by the state-of-the-art study. This article's intent is to help accomplish this by showcasing some design strategies that capitalize on the unique qualities of AI and smart buildings. Third, we call attention to the most critical challenges (such as cost, security concerns, and technological obstacles) while also introducing novel areas of inquiry that merit further investigation from academics and practitioners in related fields. The scope of potential future research is illuminated by this analysis, and suggestions are made regarding the broader implications of using AIoT for empowering the smart building system[12-18].

The rest of this study is divided into four major bodies of argument. The second section provides context for AIoT and its role in modern smart buildings. In the third section, we'll take a look at the relevant research. The plan for future directions is outlined in the fourth section. The overall of this work is summarized in the last section.

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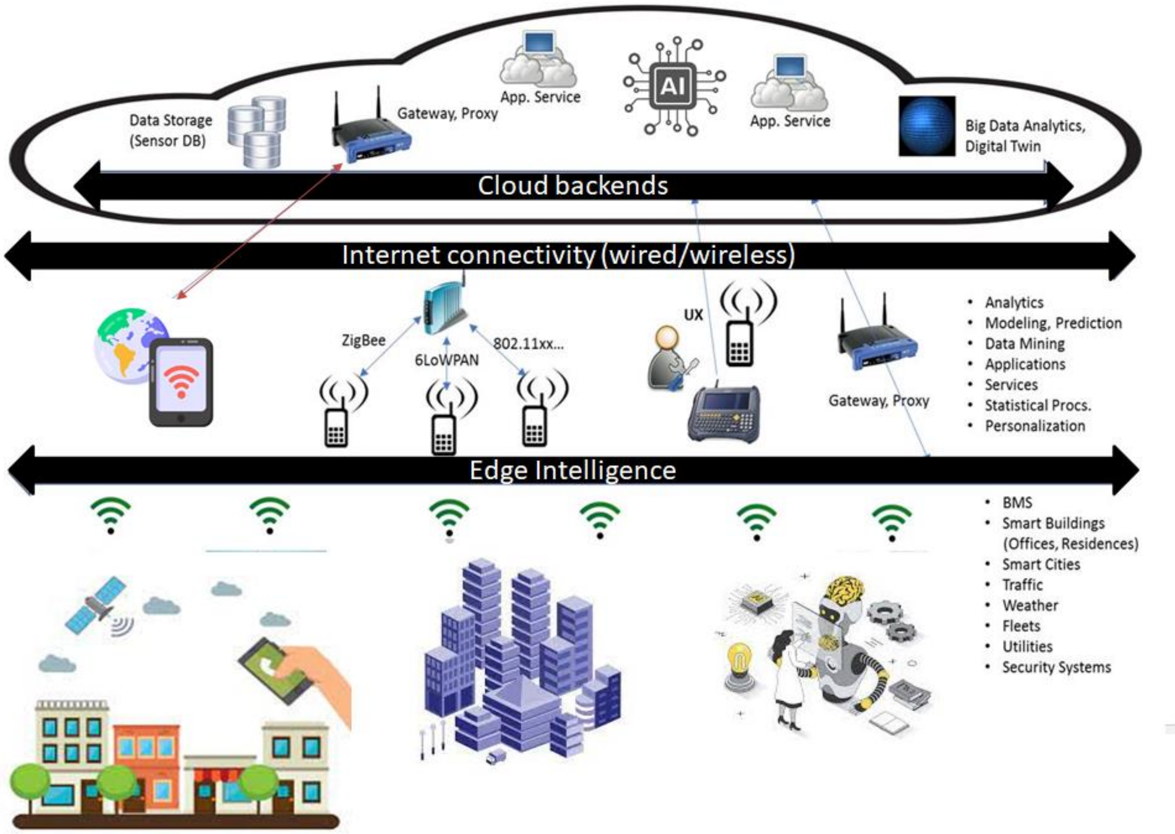

Figure 1: conceptual framework of AoT empowered smart building.

2. Background Information

The concept of smart buildings has been around for several decades, with the earliest examples dating back to the 1980s. However, recent advances in technology, particularly in the areas of Artificial Intelligence (AI) and the Internet of Things (IoT), have led to a new generation of smart buildings that are more intelligent, efficient, and adaptable than ever before. AIoT empowered smart buildings to represent the integration of AI and IoT technologies into the design, construction, and operation of buildings [14-17]]. This integration allows for the creation of intelligent buildings that can adapt to the needs of their occupants and optimize building performance in real time. The use of AI algorithms in smart buildings allows for the analysis of large amounts of data from sensors and other devices, enabling building operators to make more informed decisions about building operations and maintenance. The benefits of AIoT-empowered smart buildings are numerous. They can reduce energy consumption and costs, improve occupant comfort and productivity, and enhance building security. Smart buildings can also contribute to the sustainability of cities by reducing the carbon footprint of buildings and improving the efficiency of energy usage. Despite the many benefits of AIoT-empowered smart buildings, there are also several challenges associated with their deployment. These include data privacy and security concerns, interoperability issues, and the need for specialized expertise to design, build, and operate smart buildings (See Figure 1).

The integration of AIoT into the design, construction, and operation of buildings has given rise to a new generation of smart buildings that are more intelligent, efficient, and adaptable than ever before. This has led to the emergence of several companies that are using AIoT-empowered smart building technologies to create innovative solutions for the building industry [7-10]. Siemens, for example, has developed a range of smart building solutions that use AI and IoT technologies to optimize building performance, reduce energy consumption, and enhance occupant comfort. Their solutions include intelligent HVAC systems, lighting control systems, and building automation systems, which use data analytics and machine learning algorithms to optimize building operations and reduce energy costs. Honeywell is another enterprise that offers a range of smart building solutions, including intelligent HVAC systems, lighting control systems, and security systems that use AI and IoT technologies to improve building efficiency and security.

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Their solutions are designed to provide real-time insights into building performance and occupancy, enabling building operators to make more informed decisions about building operations and maintenance. Schneider Electric is another corporation that has developed a range of smart building solutions that use AI and IoT technologies to optimize building performance and reduce energy consumption. Their solutions include building automation systems and energy management systems, which use data analytics and machine learning algorithms to optimize building operations and reduce energy costs [4].

IBM's Watson IoT platform provides a range of smart building solutions, including predictive maintenance and energy management systems that use AI and IoT technologies to optimize building performance and reduce energy consumption. The platform is designed to provide building operators with real-time insights into building operations and maintenance, enabling them to make more informed decisions about building performance and energy usage. Johnson Controls is another corporation that offers a range of smart building solutions, including intelligent HVAC systems, lighting control systems, and security systems that use AI and IoT technologies to improve building efficiency and security. Their solutions are designed to provide building operators with real-time insights into building performance and occupancy, enabling them to make more informed decisions about building operations and maintenance [16].

2.1 Challenges meeting AIoT in smart buildings

The emergence of AIoT technologies has immense potential to revolutionize various industries by combining the capabilities of AI and IoT to create intelligent systems that can learn, adapt, and make decisions independently. However, the implementation of AIoT also poses several challenges that need to be addressed. These challenges include issues related to data privacy and security, interoperability, and user acceptance. This essay will examine these challenges in more detail and explore possible solutions to ensure the successful implementation of AIoT in different industries [3]. With the help of AIoT technologies, building owners and facility managers can now control various building systems such as lighting, heating, ventilation, and air conditioning (HVAC) with greater precision and efficiency. However, despite these advancements, the smart building industry still faces several challenges that must be addressed to achieve a truly sustainable and intelligently built environment. In this essay, we will explore some of the major challenges that smart building research faces today and suggest potential solutions to overcome them.

- Data Security: As more devices become interconnected, the risk of a security breach increases, especially when sensitive data is involved. Smart buildings often deal with confidential data such as employee information, financial data, and sensitive business data. This requires robust security measures to protect against unauthorized access, hacking, and cyber-attacks [1].
- Interoperability: Interoperability is a significant challenge in AIoT-empowered smart buildings. The devices and systems in these buildings use different communication protocols, which can make it difficult to connect and exchange data. For example, a lighting system might use Zigbee, while an HVAC system uses BACnet, and a security system uses Wi-Fi. Ensuring that all these systems can communicate with each other is critical for the smooth operation of the smart building. Data formats are another interoperability challenge in AIoT-empowered smart buildings. Devices generate data in various formats, such as text, audio, video, or image, among others. Each format has unique challenges, and processing them requires different methods and tools. For example, a security camera may capture video footage in a format that is incompatible with the building management system, making it difficult to analyze the data. The challenge is to ensure that all data formats can be easily processed and analyzed by the various systems in the building. Many smart buildings also have legacy systems that are not compatible with the latest IoT devices and AI systems. These systems may use different communication protocols or data formats, making integration challenging. Upgrading or replacing these legacy systems can be costly and time-consuming, but it may be necessary to ensure compatibility with new technology [7-11].
- Scalability: Scalability is a critical factor in the design and implementation of AIoT-empowered smart buildings. These buildings are designed to support a range of IoT devices and systems that can be added or removed as needed to adapt to changing building needs. However, scaling up the number of devices and systems can pose several challenges. One of the scalability challenges is related to the communication infrastructure. As the number of devices and systems in the building increases, the communication infrastructure must be able to handle the additional data traffic. The network must be designed to support a

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high volume of data transfer while maintaining low latency to ensure real-time communication between devices. Another scalability challenge is related to the management of devices and systems. With a large number of devices and systems, managing them can become increasingly complex. The management system must be able to identify and track all devices, monitor their status, and respond to any issues promptly. This can be particularly challenging when devices use different protocols, data formats, or interfaces. Maintaining the security of the smart building is also a critical challenge when scaling up the number of devices and systems. With a large number of devices connected to the network, the potential for cyber-attacks and data breaches increases. It is essential to have a robust security framework that can detect and respond to security threats promptly. Another scalability challenge is related to the interoperability of devices and systems. As the number of devices and systems in the building increases, ensuring interoperability between them becomes increasingly difficult. Devices and systems may use different protocols or data formats, making it difficult to exchange data or communicate with each other. To address these scalability challenges, it is essential to have a well-designed and scalable infrastructure that can accommodate the growing number of devices and systems. The infrastructure should be designed to support a high volume of data transfer, maintain low latency, and ensure high availability. Additionally, the management system should be designed to monitor and manage devices and systems efficiently. the security framework should be designed to detect and respond to security threats promptly [13-17].

- User Experience: The adoption of AI and IoT in smart buildings must prioritize the user experience to ensure that occupants can easily navigate the building and interact with the technology. This requires an intuitive user interface and user-friendly design.
- Energy Efficiency: Smart buildings use AI and IoT technology to optimize energy consumption and reduce costs. However, this requires the system to continuously monitor energy usage, adjust heating and cooling, and lighting levels based on occupancy patterns, and use predictive maintenance to reduce energy waste. Implementing these measures can be a challenge.

2.2 *Opportunities of AIoT in Smart Buildings*

AIoT has revolutionized the way we design and operate smart buildings, bringing about exciting new opportunities. AIoT integrates artificial intelligence with IoT (Internet of Things) technology to enhance the capabilities of smart buildings, making them more intelligent, efficient, and sustainable. The integration of AI and IoT enables devices to communicate, collect and analyze data, and make intelligent decisions, resulting in significant improvements in building performance and user experience. In this essay, we will explore the opportunities that AIoT presents in smart buildings, including energy efficiency, predictive maintenance, improved occupant comfort and productivity, and enhanced security [5-13].

AIoT presents a wide range of opportunities for smart buildings, which can lead to significant improvements in building performance, user experience, and sustainability. The following are some of the key opportunities that AIoT offers in smart buildings:

- Energy efficiency: AIoT systems can optimize energy consumption by analyzing data from various sensors and devices in the building. For example, an AIoT system can automatically adjust lighting, heating, and cooling based on occupancy levels and environmental conditions, resulting in significant energy savings [8].
- Predictive maintenance: AIoT systems can collect and analyze data from sensors to detect potential equipment failures before they occur. This enables building managers to schedule maintenance proactively, reducing downtime and minimizing repair costs.
- Improved occupant comfort and productivity: AIoT systems can adjust the environment based on occupancy levels and preferences, resulting in a more personalized and comfortable environment. For example, an AIoT system can adjust the temperature, humidity, and air quality to optimize occupant comfort and productivity [11].
- Enhanced security: AIoT systems can monitor and analyze data from various security devices, such as cameras and access control systems, to detect and respond to security threats quickly. This can help prevent theft, vandalism, and other security breaches.
- Personalized recommendations: AIoT systems can provide personalized recommendations to occupants based on their preferences and behavior. For example, an AIoT system can suggest a meeting room based on the occupant's schedule and location [3].

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- Real-time data analytics: AIoT systems can provide real-time data analytics that can help building managers make informed decisions about building operations and maintenance. For example, an AIoT system can provide real-time data on energy consumption and equipment performance.
- Sustainability: AIoT systems can help buildings reduce their environmental footprint by optimizing energy consumption and reducing waste. For example, an AIoT system can optimize the use of renewable energy sources, such as solar panels.
- Cost savings: AIoT systems can help buildings reduce maintenance costs, equipment downtime, and energy consumption, resulting in significant cost savings.
- Data-driven decision-making: AIoT systems can provide valuable data that can help building managers make data-driven decisions about building operations and maintenance. For example, an AIoT system can provide data on occupancy levels and equipment performance, which can help building managers optimize building operations.
- Enhanced user experience: AIoT systems can enhance the user experience by providing a personalized and comfortable environment, which can lead to improved productivity and satisfaction. For example, an AIoT system can adjust the lighting, temperature, and air quality to optimize occupant comfort [7].

3. Related work

The integration of AIoT technology in smart buildings has been the subject of significant research in recent years, with a focus on the potential benefits and challenges associated with this integration. Several studies have highlighted the potential benefits of AIoT in smart buildings, including increased energy efficiency, improved occupant experiences, and greater automation and optimization of building systems. In [1], the authors introduced a detailed overview of the progress, challenges, and opportunities in the field of AIoT, covering topics such as architecture, hardware, software, and applications. They discussed the various challenges associated with the integration of AI and IoT, including interoperability, scalability, and security, and explore the potential opportunities for AIoT in various application domains. They investigated the development in AI research for IoT from four standpoints namely perception, learning, reasoning; and behaving. In [2], the authors studied the challenges of managing and optimizing the diverse systems in smart buildings, which are often designed and operated by different vendors and are not interoperable. Honeycomb was designed to provide an open-source platform that can integrate these diverse systems and support the development of smart building applications. They described the architecture of the Honeycomb system, which consists of a network of sensors and actuators that are connected to a cloud-based platform. The platform used ML algorithms to analyze data from the sensors and make predictions about building performance, energy consumption, and occupant behavior. In [3], the authors discussed the various technologies that were used for sensing and controlling smart building systems, including sensors, actuators, and controllers. They also examined the role of IoT infrastructure in smart buildings, including the use of cloud computing, edge computing, and wireless communication technologies. The paper highlighted the potential benefits of these technologies in smart buildings, including improved energy efficiency, enhanced occupant comfort, and greater automation of building systems. The authors also discuss the challenges associated with the integration of these technologies. they also reviewed several case studies of smart building applications, including energy management, indoor air quality monitoring, and occupancy sensing. They demonstrate the potential of these technologies to optimize building performance and improve occupant experiences. In [4], the authors reviewed the use of IoT technologies in building management systems for energy optimization and improved functionality.they debated the importance of smart buildings in the context of the growing demand for energy efficiency and sustainability. It then presents the basic architecture of a smart building management system (SBMS), which includes IoT sensors, gateways, cloud platforms, and analytics tools. They then discuss the key considerations and requirements for designing an effective SBMS. They also explored the different types of IoT sensors that can be used in a smart building, including environmental sensors, occupancy sensors, and energy meters. In [5], the authors created a combined model of obstacles and facilitators to clients, which included four types: individual, social, technological, and environmental, to examine the factors that influence patients' user acceptance of the wireless sensor network (WSN)-based smart building healthcare systems. Patients' perspectives on the system's usefulness and ease of use, their comfort with and familiarity with technological solutions, and their specific health conditions and requirements all play a role. Patients' adoption decisions were influenced by their social networks, which included their families, friends, and healthcare providers. The compatible operation, consistency, and safety were all aspects of the system's technology. Support and resources, the legal and legislative framework, and cultural and societal norms were all elements of the surrounding environment. In [6], the authors studied IoT technologies and their applications in smart building development. They discussed various enabling technologies that were critical for the implementation of IoT in smart buildings, such as wireless sensor networks, radio frequency

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identification (RFID), and machine-to-machine (M2M) communication. The authors also highlighted some of the challenges in implementing these technologies, including power consumption, security, and scalability. They presented several real-world applications of IoT in smart buildings, such as smart lighting, HVAC control, and occupancy monitoring. The authors discuss the benefits and challenges of each application and provide examples of successful implementations In [7], the authors systematically analyzed the SBEMS literature published between 2010 and 2020. The publication count trend over time was analyzed, and then publications were categorized according to the SBEMS subfield, control method, smart technology, and quality attributes. They demonstrated that SBEMS advancements have focused on facilitating utility participation in a communication grid via demand response programs and automatic self-report outage functionality, as well as providing occupants with an interface to monitor, schedule, and modify building energy consumption profiles. They also debated potential future research directions with a focus on enhancing privacy and security while also fostering interoperability.

In [8], the authors surveyed the current state of research in this area, highlighting key difficulties and possibilities for future advancement, and then discussed how AI and big data technologies might be adopted in smart building systems. A comprehensive review of the latest developments was provided, covering topics such as data collection and management, data analytics, optimization and monitoring, and other applications of machine learning and big data technologies in smart buildings. Better data collection methods, more efficient algorithms and models, and increased interconnectivity and standardization were just a few of the challenges and opportunities they uncovered.

In [9], the authors investigated the possibility of the Internet of Things (IoT) and smart building technology enhancing healthcare for the elderly by providing end-user perspectives on the use of these technologies and identifying key factors which can impact their adoption and use. In that study, the authors shared the results of a survey that asked seniors and their caretakers about their thoughts on utilizing IoT and smart building technology to improve medical care. The survey revealed that several factors, including price, privacy worries, and the desire for customization, can influence the rate at which these technologies are adopted and used. In [10], the authors surveyed the current state of research in this field and examined the various prediction algorithms that can be used in smart building systems through a thorough review of the literature and case studies. Data collection, management, algorithm evaluation, and control and optimization were all topics addressed in this work pertaining to prediction algorithms in smart buildings. It also highlighted opportunities and threats for future growth in the field, including the need for improved interoperability and standardization as well as more precise and reliable data collection methods. User engagement, energy consumption modeling, demand response, and renewable energy integration are just some of the topics that [11]'s authors delve into when discussing the role of mobile apps and ML in smart energy grids and their implications for building owners.

4. Future research directions

As the use of smart buildings continues to grow, the integration of AIoT technology is becoming increasingly prevalent. With its ability to analyze vast amounts of data and automate processes, AIoT is poised to play a significant role in the future of smart buildings. In this context, this section charts out the future directions of AIoT in smart buildings, including the challenges that need to be addressed and the potential benefits that can be achieved [1-10].

The future directions of AIoT in smart buildings are vast and exciting, as this technology has the potential to revolutionize the way buildings are designed, operated, and maintained. Here are some of the key areas where AIoT is expected to make significant contributions in the coming years:

- Integration with smart city infrastructure: As cities become smarter and more connected, AIoT technology can play a crucial role in integrating smart buildings with the broader smart city infrastructure. This can lead to greater efficiency and sustainability across the entire city.
- Expansion of edge computing: Edge computing, which involves processing data at the edge of the network rather than in a centralized data center, is expected to become increasingly prevalent in smart buildings. AIoT can enable more advanced edge computing capabilities, allowing buildings to process data in real time and respond more quickly to changing conditions.
- Increased use of predictive analytics: As AIoT systems become more sophisticated, they are expected to be able to predict and prevent building maintenance issues before they occur. This can lead to improved reliability and reduced downtime for critical building systems.

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- Improved indoor air quality: AIoT systems can help improve indoor air quality by monitoring and analyzing data from sensors and adjusting HVAC systems accordingly. This can lead to improved occupant health and productivity.
- Enhanced occupant experiences: AIoT systems can help create more personalized and engaging occupant experiences by analyzing data on occupant behavior and preferences. This can lead to increased satisfaction and loyalty among building occupants.
- Expansion of autonomous systems: As AIoT systems become more advanced, they are expected to be able to operate autonomously in some cases. This can include tasks such as building security and maintenance, allowing building managers to focus on more strategic tasks.
- Increased use of renewable energy: AIoT systems can help buildings optimize their use of renewable energy sources, such as solar panels, by analyzing energy consumption data and adjusting building systems accordingly. This can lead to increased sustainability and cost savings.
- Integration with other smart technologies: AIoT is expected to increasingly integrate with other smart technologies, such as IoT sensors, 5G networks, and blockchain. This can lead to even greater efficiency and security across smart building systems.

5. Conclusion

In conclusion, the integration of AIoT technology in smart buildings represents a significant opportunity for the building industry to optimize building operations, reduce energy consumption, and improve occupant experiences. However, this integration also poses significant interoperability and scalability challenges that need to be addressed to realize the full potential of AIoT in smart buildings. Nevertheless, the future of AIoT in smart buildings is promising, as this technology continues to evolve and mature, and its potential applications expand to areas such as renewable energy, autonomous systems, and integration with other smart technologies. As buildings become more connected and data-driven, the role of AIoT in smart buildings is set to become increasingly important, and it will be exciting to see the innovative ways in which this technology will shape the future of the built environment.

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