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Urban Planning and Construction

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REVIEW ARTICLE

Double Skin Façades and IoT: A Review of Their Role in Building Energy Conservation and Natural Ventilation

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ARTICLE INFO

Article history

Received: 4 November 2023

Revised: 7 December 2023

Accepted: 8 January 2024

Published Online: 23 January 2024

Keywords:

Internet of Things (IoT)

Energy conservation

Natural ventilation

Building categories

Energy efficiency

Design challenges

Double-skin façades

Materials

Indoor thermal comfort

Real-time data

ABSTRACT

Double skin façades and the Internet of Things (IoT) are pivotal in enhancing a structure's energy efficiency and natural ventilation. Their impact, however, varies based on design size and geographical location, prompting an exploration of the nuanced interplay between IoT technology and energy savings across diverse building types and climates. The paper emphasizes crucial considerations in assessing IoT's impact on energy efficiency, such as building's category and location, whether a towering skyscraper, a modest apartment complex in arid New Mexico, or a structure in frigid Alaska. Investigating whether one type outperforms others and discerning global prevalence becomes essential. The exploration delves into design challenges posed by different building categories, addressing questions about the nature of a particular type presenting intricate obstacles to efficient design and whether regulatory requirements limit creative possibilities. Additionally, it examines the adaptability of double-skin façades concerning materials without compromising performance. Enhancing energy efficiency and indoor thermal comfort involves manipulating materials for façade skins, introducing characteristics like fabrics for outer skins to allow airflow, and mitigating heat radiation from inner skins made of concrete, glass, or metal. This time lag contributes significantly to maintaining ideal indoor thermal conditions. The integration of IoT technology is pivotal, generating real-time data and notifying users of temperature differentials. This data-driven approach ensures optimal façade operation compared to conventional methods. In conclusion, the paper underscores the critical relationship between IoT technology and energy conservation in diverse building categories and climates, shedding light on challenges and opportunities associated with energy efficiency design. It advocates for the intelligent use of materials and IoT technology to realize substantial energy savings and improved indoor comfort. Exploring design challenges and considerations provides valuable insights for practitioners in the field.

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DOI: https://doi.org/10.55121/upc.v2i1.140

1. Introduction

In the current era of technological advancements, the intersection of digital innovation and sustainability has gained unprecedented significance. The Internet of Things (IoT) is at the forefront of this convergence, a transformative force permeating every aspect of modern life. With the potential to revolutionize energy consumption management and natural ventilation in diverse building categories, IoT is a crucial player in the quest for efficient and sustainable solutions.

1.1 Objectives and Scope of the Review

This paper undertakes a comprehensive exploration to unravel the profound implications of IoT technology on energy conservation and natural ventilation across varied building typologies. With escalating environmental concerns and a steady rise in global energy demand, the urgency to adopt more sustainable practices in constructing and operating buildings has never been more pronounced.

1.2 Exploring IoT's Impact

Our investigation delves into the unique challenges and opportunities presented by IoT in different building categories. By seamlessly integrating sensors, data analytics, and automation, IoT solutions hold the potential to optimize energy use, elevate indoor air quality, and enhance overall comfort across residential, commercial, industrial, and institutional structures.

1.3 Addressing Environmental Priorities

The paper scrutinizes how IoT can be harnessed to address each building context's needs and priorities, from retrofitting existing structures to designing energy-efficient buildings. IoT emerged as a promising avenue to mitigate energy waste and reduce the carbon footprint in our built environment.

1.4 Case Studies and Emerging Trends

Throughout this exploration, we will closely examine case studies, emerging trends, and the latest advancements in IoT technology. The aim is to provide a comprehensive understanding of how IoT can reshape the future of energy conservation and natural ventilation across a spectrum of building types.

1.5 Informing Stakeholders

By scrutinizing the interplay between IoT solutions and various architectural and environmental factors, this paper seeks to offer valuable insights. These insights can inform policymakers, architects, engineers, and stakeholders in pursuing sustainable, intelligent, and resilient building solutions. Ultimately, this exploration underscores the pivotal role of IoT in fostering a harmonious relationship between our built environment and the natural world, contributing to a more sustainable and energy-efficient future.

2. Statement of Issue

Amidst the ever-growing global challenges of escalating energy demand, environmental degradation, and climate change, an urgent need exists to reevaluate our approach to building design, construction, and operation. While sustainability has become a watchword in the architectural and construction industries, there is a pressing issue of effectively harnessing emerging technologies, specifically the Internet of Things (IoT), to optimize energy conservation and enhance natural ventilation across various building categories.

The crux of the issue lies in IoT's vast potential to revolutionize how we interact with our built environment. This paper addresses the fundamental question of how IoT can be leveraged to mitigate energy wastage, reduce carbon emissions, and promote the efficient use of resources within a diverse array of building types. The challenge lies in identifying IoT's unique considerations and opportunities in residential, commercial, industrial, and institutional contexts while ensuring that these innovations are scalable, cost-effective, and environmentally responsible.

Furthermore, the issue at hand encompasses the need to strike a harmonious balance between human comfort and environmental responsibility. How can IoT solutions be fine-tuned to improve indoor air quality, thermal comfort, and overall occupant well-being while minimizing the environmental impact of energy consumption? Navigating this delicate equilibrium requires a multifaceted examination of IoT's impact on architecture, engineering, and sustainability practices.

Ultimately, the central issue explored in this paper revolves around the imperative to bridge the gap between technological innovation and sustainable building practices. By addressing this issue, we aim to provide a comprehensive understanding of the transformative potential of IoT in reshaping the future of our built environment, thus advancing the global agenda of energy conservation and environmental stewardship.

3. Research Method

The research methodology described involves a systematic and comprehensive approach to investigate the impact of IoT on energy conservation and natural ventilation in diverse building categories. Here is a more detailed breakdown:

3.1 Systematic Literature Review

Initially, a systematic review of the existing literature will be conducted, thoroughly examining academic papers, articles, reports, and other relevant sources to understand the current state of IoT applications in sustainable building practices. This literature review helps identify key concepts, challenges, and trends in the field.

3.2 Mixed-Methods Approach

Subsequently, a mixed-methods approach will be employed, encompassing qualitative and quantitative research methods, allowing a more comprehensive and holistic understanding of the impact of IoT on sustainable building practices.

3.3 In-depth Case Studies

In-depth case studies are a significant component of the research methodology. Detailed investigations across various buildings will be conducted in categories that involve studying specific structures and engaging with architects, engineers, and occupants to gather insights into the practical implementation of IoT solutions in real-world scenarios.

3.4 Stakeholder Involvement

The case studies involve collaboration with critical stakeholders, including architects, engineers, and occupants. This engagement aims to capture diverse perspectives and experiences implementing IoT solutions in different buildings. Stakeholder involvement provides valuable qualitative data.

3.5 Data Analytics and Simulation Tools

The study incorporates data analytics and simulation tools to assess IoT's impact on energy conservation and natural ventilation. These tools analyze energy consumption patterns, indoor environmental quality, and ventilation effectiveness. The quantitative data from these tools contribute to a more objective evaluation of IoT's influence.

3.6 Comprehensive Evaluation

The research methodology aims to comprehensively evaluate IoT's influence on energy conservation and natural ventilation. This evaluation considers technical aspects (analyzing data and simulation results) and user-centered aspects (capturing stakeholder insights). This multifaceted approach ensures a well-rounded understanding of the topic.

3.7 Universal Perspective

The ultimate goal is to provide a universal perspective on the impact of IoT on sustainable building practices. By conducting case studies across various building categories and engaging with diverse stakeholders, the research aims to offer insights that can be applied broadly, considering the diversity of buildings and users.

4. Overview

Bringing Internet of Things (IoT) technology into everyday lives has brought about transformative changes across various sectors, including architecture and building management. This paper dives into the profound influence of IoT on energy conservation and natural ventilation within diverse building categories, shedding light on the innovative solutions and sustainable practices that IoT offers to construction and clients. The built environment significantly contributes to global energy consumption and greenhouse gas emissions. Addressing this challenge necessitates the development and implementation of intelligent, energy-efficient strategies. IoT emerges as a critical enabler, offering real-time monitoring, data analysis, and automation capabilities that enhance energy efficiency while maintaining occupant comfort and well-being.

This paper explores IoT applications within different building categories, encompassing residential, commercial, industrial, and institutional structures. A systematic review of case studies and emerging trends elucidates how IoT technologies transform building management systems, optimize energy usage, and promote sustainability at both micro and macro levels. It will also discuss the relationship between the IoT system and building energy consumption in creating categories and climates. There are many challenges when it comes to design for energy consumption and the IoT. Two questions need to be answered. Does the nature of a particular type present more intricate obstacles to efficient design? And do regulatory requirements limit creative possibilities? This question will be answered through the adaptability of double-skin façades and their materials without compromising performance or their fundamental nature. It also advocates an intelligent use of materials and IoT technology to realize energy savings potential and improved indoor comfort.

5. Key Topics Covered in This Paper Include

IoT-Enabled Building Automation: Investigating how

IoT sensors and actuators can control lighting, heating, cooling, and ventilation systems, resulting in significant energy savings.

5.1 Occupant Comfort and Well-being

It analyzes the role of IoT in creating responsive and personalized indoor environments that enhance occupant satisfaction while minimizing energy wastage.

5.2 Data-driven Decision-making

We highlight the importance of data analytics and machine learning in processing vast amounts of building performance data to inform energy conservation strategies.

5.3 Energy Management in Different Building Types

Delving into various building categories' unique challenges and opportunities, such as homes, offices, factories, and educational institutions.

5.4 Sustainability and Environmental Impact

Assessing the ecological benefits of IoT-driven energy conservation, including reduced carbon emissions, resource preservation, and alignment with global sustainability goals.

5.5 Challenges and Future Directions

Identifying current limitations, security concerns, and the potential for future advancements in IoT technology to revolutionize further building energy efficiency.

This paper serves as a valuable resource for architects, engineers, policymakers, and clients in the construction industry, providing insights into the transformative potential of IoT in fostering energy conservation and natural ventilation in diverse building categories. By harnessing the power of IoT, the environmental footprint of the built environment will be reduced, and more comfortable and sustainable spaces for occupants will be created.

6. Literature Review

In the pursuit of achieving greater energy efficiency and sustainability in the construction and operation of buildings, integrating innovative technologies and architectural solutions has become a paramount concern. This literature review delves into scholarly articles that contribute valuable insights into double-skin façades and the transformative potential of Internet of Things (IoT) technology in building design and energy conservation [1].

Su, 2016 is dedicated to exploring the thermal performance and optimization of double-skin façades across diverse climate zones in China. The paper utilizes a rich array of diagrams to vividly depict the efficiency of various double-skin façade configurations. Moreover, including meticulously calculated data bolsters the study's findings, offering readers a clear understanding of how this data is acquired and interpreted (Su et al., 2017). Importantly, this research is a valuable resource for comprehending the efficacy of double-skin façades in varying climates and the methodologies for constructing efficient designs [2].

Ahmed, 2016 comprehensively examines the rationale behind double-skin façades in building design. It delves deeply into the classification of different types of double-skin façades, establishing the criteria that categorize them into specific groups. Beyond merely extolling their virtues, this article also candidly discusses the potential drawbacks of these systems. Furthermore, it emphasizes the role of double-skin façades in contemporary architectural developments, highlighting their significance. Architects and designers will find this source invaluable for gaining a lucid and informative perspective on the various categories of double-skin façades and the challenges associated with their integration into architectural designs [3].

Ullah, 2022 focuses on introducing IoT systems to enhance energy efficiency within greenhouses. The authors propose an optimization scheme centered on IoT technology to automate greenhouse environment-related activities. The objective is to strike a balance between energy consumption and achieving the desired climate within the greenhouse, incorporating variables such as temperature, CO_2 levels, and humidity. The scheme's cyclic operation, involving sensors and actuators, offers a dynamic approach to greenhouse climate control. This source underscores the potential of IoT in improving energy efficiency, which can be extrapolated to building environments [4].

Andreeva, 2022 addresses the pressing need for energy conservation in buildings, acknowledging that they account for a significant share of global energy consumption. As buildings contribute to excessive carbon emissions, strategies for decarbonization and utilizing renewable resources have become imperative. With a focus on factors to consider during building design and usage, this paper underscores the importance of adopting sustainable design approaches. By referencing the European Commission's assertion that buildings can reduce their CO_2 emissions by 80%, the article highlights the potential for substantial environmental impact through sustainable building practices. This source reinforces the urgency of sustainable design and its contribution to mitigating climate change [5].

Wilmar, 2012 discusses the need for double-skin façades in high-tech buildings of today's world and to create an indoor environment that is thermally and visually comfortable, which are widely used and designed by architects these days. Designing these naturally ventilated double-skin façades is a good approach towards sustainability, but making them functional to save energy costs is complex. Computational Fluid Dynamics (CFD) can help double skin façades to obtain thermal comfort. However, an analysis is carried out using experimental data from the literature review to understand the critical factors and find out the strategies for CFD stimulation to provide accurate results [6].

Numerous previous inquiries have extensively expounded on the Energy Efficiency in the Building by Using AI in Sunlight Control. Many scholarly articles ponder Using IoT and emphasize Energy Conservation and Natural Ventilation. Several other research studies focus on the role of IoT in energy conservation [7].

7. Findings

Integrating the Internet of Things (IoT) system and double-skin façades can transform building design, energy conservation, and natural ventilation. This paper explores the current state of research in these areas through critical findings and further investigation. It presents a comprehensive overview of double skin façades, their types, and IoT's role in optimizing building performance [8].

The built environment plays a significant role in global energy consumption and environmental impact. Addressing this challenge necessitates innovative approaches to building design and operation. One such process involves the combination of IoT technology and double skin façades. This section introduces the research areas and the importance of their integration [8].

7.1 Double Skin Façades: Types and Functionality

Double skin façades are architectural elements consisting of two layers of building envelopes with a gap in between. This design offers several advantages, including improved thermal comfort and natural ventilation. The research findings in this area provide a fundamental understanding of double skin façades and their functionality. Double skin façades come in various types, each designed to address specific architectural and environmental needs. These types include sealed inner skin, openable inner and outer skins, open-able inner skin, sealed cavities, and acoustic barrier double skin façades. Each class has unique characteristics that impact its effectiveness in different building categories and climates. One notable research direction is the application of double skin façades in different environments to determine their efficiency in maintaining thermal comfort. Studies have explored how double skin façades configurations impact temperature regulation and energy consumption, yielding insights into their suitability for diverse environmental conditions.

7.2 Materials within Double Skin Façades

Materials used in the layers of double skin façades play a critical role in achieving desired thermal and environmental outcomes. Research in this area investigates how various materials can be strategically employed to enhance thermal comfort. Insulation materials are crucial in preventing heat transfer between the interior and exterior of a building. Different insulation materials have been tested to determine their effectiveness in double-skin façades, focusing on their impact on energy conservation. Emerging research delves into the use of intelligent materials within double-skin façades. These materials can dynamically respond to environmental conditions, allowing real-time adjustments to enhance thermal comfort. For example, self-tinting glass can adapt to sunlight exposure, reducing the need for artificial lighting and air conditioning [9].

7.3 IoT and Interior Mechanical Systems

IoT technology plays a pivotal role in optimizing interior mechanical systems within buildings. Research has explored how IoT can be integrated with double skin façades to create responsive and energy-efficient environments. One area of investigation involves IoT to control automated window systems. These systems can monitor factors like temperature, sunlight, and occupant presence, automatically adjusting window openings to maintain comfortable indoor conditions. HVAC systems are needed for indoor comfort. The IoT technology improves these systems by collecting temperature, humidity, and air quality data. Adjustments can be made in real-time to minimize energy consumption while ensuring occupants' well-being. Adequate natural ventilation is crucial for indoor air quality and energy conservation. IoT sensors can monitor outdoor air conditions and indoor air quality, allowing for the precise control of ventilation systems. This approach reduces the reliance on mechanical ventilation and lowers energy consumption [10].

7.4 IoT in Building Networks

IoT systems operate within intricate networks within a building, creating a web-like structure that connects various devices and sensors. Research in this area explores the functionality and efficiency of these networks. IoT relies on data flow and connectivity to ensure seamless communication between sensors, actuators, and central control systems. Understanding IoT networks' architecture and data pathways is crucial for optimizing building performance. Building networks must be reliable to guarantee uninterrupted operation. Redundancy and failover mechanisms are researched to ensure IoT systems continue functioning in case of sensor or connectivity failures [10].

7.5 Double Skin Façades Design Challenges

While double skin façades offer numerous benefits, they also present design challenges that must be addressed. Research in this area explores how double skin façades impact architectural design, structural considerations, and aesthetics. Double skin façades influence architectural design by introducing new elements and relations. Researchers investigate how architects can seamlessly integrate double-skin façades into their plans while maintaining the overall aesthetic and functionality of the building. The addition of double-skin façades can impact a building's structural load and stability. Studies focus on structural assessments and engineering solutions to ensure that double-skin façades do not compromise the building's integrity. Aesthetic considerations are essential in building design. Research explores how double skin façades can enhance the overall user experience visually and in terms of occupant comfort [11].

7.6 Materials Compatibility with IoT

Construction materials must be compatible with IoT systems to harness IoT's potential fully in the building. The research investigates the selection and integration of materials, allowing seamless IoT connectivity. Researchers identify building materials that enable the installation of IoT sensors and devices without compromising their functionality. This includes materials with minimal signal interference and those that can host embedded sensors. Fabrics must also be durable and long-lasting to support the extended operational lifespan of IoT systems. Research explores materials that can withstand environmental conditions and wear over time [11] (Table 1).

Table 1. A summary of findings.

Double Skin	Types	Functionality	
Category A	Sealed Inner Skin	Mechanically ventilated cavity with controlled flue intake	
Category B	Openable Inner and Outer Skins	Single-story cavity height versus full-building cavity height	7.1
Category C	Open-able Inner Skin	Mechanically ventilated cavity with cool flue intake	
Category D	Sealed Cavity	Zoned floor by floor or with a full-height cavity	
Category E	Acoustic Barrier	Either a massive exterior envelope or a lightweight outer envelope.	
Double Skin	Smart Materials Thermal Responses Light Responses Moisture Responses Shape Memory	Description Structure changes the material properties, which can be permanent or temporary. Material bringing about a color change alternately concerning illustration Sandwiched layers of fabric, a dainty novel into a film, and wood polish Versatility or Visco flexibility are likewise regularly seen under specific conditions.	7.2
IoT	Mechanical Window System Heating/Cooling Interior/Exterior air quality	Systems Description Close or open windows based on interior temperature Controls temperature, humidity, and air quality based on interior sensors Reduces the reliance on mechanical ventilation by sensors in both inter and exterior	7.3
IoT	Networks Application Layer Transmission Layer Perception Layer	Description Handheld devices, terminals, and user interface Connectivity establishment and information transmission Sensing, identification, actuation, and communication technologies	74
Double Skin	Design Challenges New elements Structure/ Stability	Description Using double skin façades and maintaining aesthetic and function Engineering solutions to ensure double skin façades are un-compromised	7.5
Compatibility with IoT	Materials Accelerometer senses Gyroscope Light sensor Proximity sensor	Description Motion and acceleration in mobile phones Detects the orientation of the phone Detects the intensity of ambient light Uses an infrared (IR) LED, which emits IR rays	7.6

7.7 IoT for Energy Conservation

One of the primary objectives of integrating IoT in building management is energy conservation. Research explores the strategies and mechanisms by which IoT can optimize energy usage within buildings. IoT enables real-time energy monitoring, allowing building managers to identify energy-intensive processes and areas of improvement. Studies showcase the benefits of continuous data collection and analysis in reducing energy consumption. IoT systems can facilitate demand response strategies by automatically adjusting energy usage during peak demand periods. Research investigates the effectiveness of demand response programs in reducing energy costs and grid stress. IoT technology can optimize the integration of renewable energy sources, such as solar panels and wind turbines, into building energy systems. Studies explore IoT and renewable energy synergies for sustainable building practices [12].

7.8 IoT Case Studies

Case studies offer valuable insights to validate IoT's practicality and effectiveness in building management. The research includes real-world examples of IoT implementation in new and existing buildings. Case studies of new building constructions showcase the seamless integration of IoT systems into the design and construction phases. These examples highlight the potential energy savings and enhanced occupant comfort achieved through IoT. Retrofitting existing buildings with IoT systems is a cost-effective approach to improving energy efficiency. Researchers examine successful retrofitting projects, quantifying the energy and cost savings achieved. Integrating IoT technology and double skin façades holds immense potential for enhancing energy conservation and natural ventilation in various building categories. Current research findings provide a solid foundation for understanding the fundamentals of double skin façades, materials compatibility, and the role of IoT in building management. However, significant research gaps remain, including further exploration of design challenges, materials selection, and real-world case studies. Continued research in these areas will undoubtedly contribute to more sustainable and efficient building practices, reducing energy consumption and environmental impact [13].

8. Discussion

8.1 Interrelationships and Future Research Directions

The intricate interrelationships between IoT and double-skin façades uncovered by this study offer profound implications for the future of sustainable building practices. As we delve into the nuanced connections between these findings, a clearer picture emerges of the transformative potential of integrating IoT into the design and management of double-skin façades.

8.2 Collaboration for Multifaceted Challenges

One of the key takeaways from this research is the need for collaboration across disciplines. Architects, engineers, materials scientists, and IoT specialists must work together to tackle the multifaceted challenges and opportunities associated with IoT-integrated double-skin façades. Future research should explore effective collaboration models and methodologies to ensure a seamless integration of expertise.

8.3 Materials Science and IoT Compatibility

The call for advancements in materials science underscores the pivotal role of innovative, IoT-compatible materials. Research in this domain should delve into developing materials that align with the structural demands of double-skin façades and optimize building performance, durability, and energy efficiency. Specific questions could revolve around the scalability and cost-effectiveness of these materials for widespread adoption.

8.4 Long-term Monitoring and Analysis

The emphasis on long-term monitoring and analysis highlights the dynamic nature of IoT-integrated buildings. Future research should address the challenges of continuous monitoring, focusing on refining data collection techniques and implementing robust analysis frameworks. Questions may arise regarding monitoring systems' scalability, real-time data integration into building management strategies, and optimizing long-term energy savings.

8.5 Sustainable Building Practices and Global Initiatives

The study aligns with the global push for sustainability, emphasizing the importance of research that contributes to reducing carbon emissions and mitigating climate change. Future investigations could explore specific strategies within IoT-integrated double-skin façades that align with global initiatives, which may involve assessing the lifecycle environmental impact, researching renewable energy integration, and optimizing resource efficiency.

8.6 Policy and Regulatory Frameworks

To facilitate widespread adoption, exploring policy and regulatory frameworks becomes paramount. Future research should delve into the development of policies that encourage the seamless integration of IoT technology in building management. Questions include balancing innovation with privacy concerns, ensuring data security, and crafting regulations that foster innovation without stifling it.

8.7 User Experience and Well-being

Investigating the impact on the overall user experience, occupant satisfaction, and health and well-being opens avenues for human-centric research. Future studies should explore the psychological and physiological effects of IoT-integrated double-skin façades, examining how innovative technologies influence the daily lives and well-being of building occupants.

9. Conclusions

From designing energy-efficient buildings to retrofitting existing structures, IoT can help migrate and track energy wastage throughout the envelope, helping reduce the structure's carbon footprint and cost of maintaining light and temperature. IoT can tackle many unique challenges in different double skin facade categories in different climates and prove that it can meet specific goals to better the building energy saving. After looking at case studies that show data, emerging trends, and the latest advancements, it is safe to say that this can be used more often in the future.

Author Contributions

Lachhman Das Khatri reviewed the literature on natural and adoptive ventilation in double-skin facades, designed the method of writing the paper, and edited the manuscript. Anakin Chalin reviewed the double-skin fronts and IoT literature and produced the summary table. Noah Anderson examined the role of double-skin masks and IoT in building energy conservation. Prashansa Sharma and Lamia Tasnim Ankon helped in reviewing the literature review, revising the manuscript and citation of the paper.

Conflict of Interest

The authors declare no conflict of interest.

Funding

This work received no external funding.

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