RESWARA: Jurnal Riset Ilmu Teknik
2025, Vol. 3, No. 2, pp. 69-77
E-ISSN: 3025-9444

Energy Consumption Optimization in Commercial Buildings Using IoT-Based Monitoring

Dimas Arif Wicaksono [1]✉, Nur Aisyah Rahman [2], Lucas M. Ferreira [3]
(1) Department of Electrical Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia
(2) Department of Energy Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
(3) Department of Mechanical and Energy Engineering, University of Porto, Porto, Portugal

Abstract: Energy consumption in commercial buildings continues to rise due to increased demand for comfort, automation, and operational continuity. Conventional energy management systems often fail to provide adaptive, real-time control, resulting in inefficiencies and unnecessary energy waste. This study examines the role of Internet of Things based monitoring systems in optimizing energy consumption within commercial buildings. The research adopts a systematic analytical approach by synthesizing empirical findings from recent IoT-based energy management studies and integrating them into a unified monitoring and control framework. The analysis focuses on occupancy detection, environmental sensing, data-driven control, and predictive analytics. Results indicate that IoT-based monitoring enables energy reductions ranging from 11 percent to over 30 percent, particularly in HVAC and lighting systems. Real-time data acquisition and automated control significantly improve operational efficiency while maintaining occupant comfort. The findings confirm that IoT-based monitoring systems provide measurable energy savings, enhance decision accuracy, and support sustainable building operations. This study contributes a structured evaluation of IoT-driven energy optimization strategies and offers practical insights for commercial building managers and policymakers seeking scalable and cost-effective energy solutions.

Article history:
Received: 15 February 2025
Revised: 20 February 2025
Accepted: 25 April 2025
Published: 29 April 2025

Keyword:
internet of things; energy management; commercial buildings; energy optimization; smart monitoring

How to cite: Wicaksono, D. A., Rahman, N. A., & Ferreira, L. M. (2025). Energy Consumption Optimization in Commercial Buildings Using IoT-Based Monitoring. *RESWARA: Jurnal Riset Ilmu Teknik, 3*(2), 69-77. https://doi.org/10.70716/reswara.v3i2.412

INTRODUCTION

Energy consumption in commercial buildings represents a critical challenge in the global effort to improve energy efficiency and reduce environmental impact. Commercial buildings account for a significant proportion of electricity demand due to intensive use of heating, ventilation, air conditioning, lighting, and office equipment. As business activities expand and service-based economies grow, energy demand in this sector continues to rise, placing pressure on power systems and increasing operational costs (Zhao et al., 2016). Inefficient energy use in commercial buildings also contributes directly to carbon emissions and resource depletion, making energy optimization a strategic priority.

Conventional energy management practices in commercial buildings rely largely on fixed schedules, manual supervision, and limited feedback from energy consumption data. These systems often fail to respond to real-time variations in occupancy, weather conditions, and user behavior. As a result, energy is frequently consumed during periods of low or zero occupancy, particularly in HVAC and lighting systems (Udendhran & S. R., 2023). This mismatch between actual demand and system operation highlights the structural limitations of traditional building energy management approaches.

The emergence of Internet of Things technology has introduced a paradigm shift in how energy consumption can be monitored and controlled. IoT-based monitoring systems employ distributed

✉ *Corresponding author: dimas.wicaksono@ugm.ac.id*

sensors, smart meters, and communication networks to collect granular, real-time data on energy use, environmental conditions, and occupancy patterns (Natarajan et al., 2024). Unlike conventional systems, IoT architectures enable continuous data flow and automated decision-making, allowing building systems to adapt dynamically to changing conditions.

Empirical evidence demonstrates that real-time monitoring is a critical enabler of energy optimization in commercial buildings. Studies show that IoT-based energy management systems can significantly reduce energy waste by aligning system operation with actual usage patterns. For example, Patankar et al. (2024) report substantial energy savings achieved through occupancy detection and ambient light evaluation, which enable autonomous control of lighting and HVAC systems. These findings confirm that data-driven control mechanisms outperform static operational rules.

HVAC systems are consistently identified as the largest contributors to energy consumption in commercial buildings. IoT integration allows these systems to operate more efficiently through continuous monitoring of temperature, humidity, and occupancy. Chauhan (2025) reports energy reductions of 20 to 30 percent through IoT-enabled HVAC control while maintaining occupant comfort. Similar results are observed by Salman et al. (2024), who emphasize the importance of real-time sensing and short-term load forecasting in smart green buildings.

Beyond real-time control, data analytics plays an increasingly important role in energy optimization. IoT systems generate large volumes of data that can be processed using big data analytics and machine learning techniques. Jin et al. (2024) demonstrate that big data-driven energy management systems can identify inefficiencies and peak consumption periods, leading to measurable reductions in overall energy use. Liu et al. (2024) further show that data-driven optimization supports more accurate energy scheduling and demand management in intelligent buildings.

Edge and fog computing architectures enhance the effectiveness of IoT-based monitoring by reducing data transmission delays and improving system reliability. Verde et al. (2024) show that edge-computing-based energy monitoring systems provide detailed electrical measurements while ensuring data security and low latency. These characteristics are particularly important for commercial buildings, where timely control actions are essential for maintaining both energy efficiency and operational continuity.

Several large-scale platforms illustrate the scalability of IoT-based energy management solutions. The CELSIUS project provides an integrated IoT platform for monitoring energy performance and indoor climate in medium and large buildings (Li, 2022). Similarly, the BENEFIT platform demonstrates how targeted IoT interventions can achieve significant energy savings in institutional buildings (Aradoaei et al., 2025). These initiatives confirm that IoT-based monitoring is not limited to experimental settings but can be deployed effectively at scale.

Despite these advances, existing research often focuses on specific subsystems or individual technologies rather than fully integrated energy management frameworks. Poyyamozhi et al. (2024) identify fragmentation and lack of system interoperability as key barriers to widespread adoption. Many studies report energy savings from isolated implementations, such as smart lighting or HVAC control, without addressing cross-system coordination and unified monitoring strategies.

Another limitation in the literature is the uneven emphasis on monitoring versus optimization. While monitoring provides visibility into energy consumption, optimization requires actionable control mechanisms supported by reliable data analytics. Studies by Kankhva et al. (2024) and Gao et al. (2022) demonstrate that combining IoT monitoring with predictive and learning-based optimization yields superior results compared to monitoring alone. These findings suggest that monitoring must be embedded within a broader control framework to achieve sustained efficiency gains.

Digital twin and human-centered energy management approaches further extend the capabilities of IoT-based systems. Nabizadeh Rafsanjani et al. (2024) show that digital twin models integrated with IoT data can optimize HVAC and miscellaneous electric loads by accounting for occupant preferences and behavior. Although these approaches are still emerging, they highlight the direction of future energy management systems in commercial buildings.

In the context of developing and emerging economies, IoT-based monitoring offers practical advantages due to declining sensor costs and increasing network availability. Studies conducted in diverse geographical settings indicate that IoT solutions can be adapted to different building types and operational constraints (Pratama, 2023; Wang et al., 2023). This adaptability strengthens the case for IoT as a viable tool for improving energy efficiency across varied commercial environments.

Based on the reviewed literature, a clear research gap emerges. While numerous studies confirm the effectiveness of IoT-based energy optimization, there is a need for a structured synthesis that evaluates how monitoring, analytics, and control components interact within commercial building systems. Existing research tends to report outcomes without systematically examining the underlying mechanisms that drive energy savings.

Therefore, this study aims to analyze and synthesize empirical evidence on IoT-based monitoring systems for energy consumption optimization in commercial buildings. The objective is to evaluate how real-time sensing, data analytics, and automated control contribute to measurable energy efficiency improvements. By consolidating findings from recent empirical studies, this research provides an integrated perspective that supports replicable implementation and informed decision-making.

The contribution of this study lies in its systematic evaluation of IoT-based monitoring as a foundational element of energy optimization strategies. The findings offer practical insights for building managers, system designers, and policymakers seeking scalable and evidence-based solutions to reduce energy consumption in commercial buildings while maintaining occupant comfort and operational performance.

RESEARCH METHOD

This study adopts a qualitative systematic analytical design to evaluate the effectiveness of IoT-based monitoring systems in optimizing energy consumption in commercial buildings. The research focuses on synthesizing empirical evidence from peer-reviewed studies that report measurable outcomes of IoT implementation in building energy management. This approach enables structured comparison across multiple implementations without altering the original research scope, variables, or findings.

Research Design

The research design follows a structured literature-based analytical framework. The study does not conduct new experiments or simulations. Instead, it analyzes documented empirical results from existing studies to identify consistent patterns, performance outcomes, and system characteristics related to IoT-based energy monitoring. This design is appropriate because the objective is to assess optimization performance and implementation mechanisms rather than generate new datasets.

Data Sources and Selection Criteria

Data sources consist exclusively of peer-reviewed journal articles, conference proceedings, and authoritative research reports included in the article's reference list. The selected studies were published between 2016 and 2025 and focus on commercial or large-scale building environments. Inclusion criteria were defined as follows:

1. The study implements IoT-based monitoring or control systems in buildings.
2. The study reports empirical energy consumption outcomes, such as percentage reduction or efficiency improvement.
3. The system targets major energy-consuming subsystems, including HVAC, lighting, or multi-energy systems.

Studies that focus solely on theoretical models without empirical evaluation were excluded. This selection ensures that the analysis is grounded in observed performance rather than conceptual assumptions.

Units of Analysis

The primary unit of analysis is the IoT-based energy monitoring system as implemented in commercial buildings. Each system is analyzed based on its monitoring architecture, data acquisition mechanisms, control strategies, and reported energy outcomes. Secondary units of analysis include specific subsystems such as HVAC, lighting, and smart metering infrastructure, as these components account for the majority of energy consumption in commercial buildings.

Data Collection Technique

Data were collected through structured extraction from the selected studies. Key information was recorded, including system architecture, type of sensors used, monitoring frequency, data processing methods, and reported energy savings. Quantitative results such as percentage energy reduction and efficiency improvement were extracted directly from the original studies without modification. Qualitative descriptions of system operation and implementation context were also documented to support interpretation.

Data Analysis Procedure

The analysis follows a comparative synthesis procedure. First, extracted data were grouped according to system function, including real-time monitoring, occupancy detection, environmental sensing, and data-driven control. Second, reported energy outcomes were compared across studies to identify consistent performance ranges and dominant optimization mechanisms. Third, system characteristics were mapped against reported outcomes to assess which monitoring and control features contribute most to energy efficiency gains.

The analysis emphasizes descriptive comparison rather than statistical aggregation. This approach avoids distortion of original findings and preserves the empirical integrity of each study. The procedure aligns with prior systematic evaluations of IoT-based energy systems in buildings.

Validity and Reliability

To ensure analytical validity, only studies with clearly reported empirical outcomes and transparent methodologies were included. Cross-referencing among multiple sources was used to confirm consistency of reported energy savings and system performance. Reliability is supported by the use of peer-reviewed sources and reproducible extraction criteria. The study does not reinterpret or recalculate original data, thereby minimizing analytical bias.

Ethical Considerations

This study uses secondary data from published research and does not involve human subjects, personal data, or proprietary datasets. All sources are properly cited, and the analysis adheres to academic integrity standards. No ethical approval was required due to the non-intrusive nature of the research design.

RESULTS AND DISCUSSION

3.1 Empirical Energy Reduction Achieved by IoT-Based Monitoring

The synthesis of empirical studies demonstrates that IoT-based monitoring systems consistently achieve measurable energy consumption reductions in commercial buildings. Energy savings are primarily reported in HVAC systems, lighting systems, and integrated multi-energy platforms. Table 1 summarizes empirical outcomes reported across selected studies, focusing on actual implementation results rather than theoretical projections.

Table 1. Empirical Energy Consumption Reduction Reported in IoT-Based Commercial Building Studies

Study	Building System Focus	IoT Monitoring Approach	Reported Energy Reduction
Xie & Xie (2024)	Building equipment and HVAC	IoT monitoring integrated with BIM	11.43%
Jin et al. (2024)	Multi-energy systems	IoT with big data analytics	20.35%
Chauhan (2025)	HVAC systems	Real-time IoT sensing and control	20–30%
Salman et al. (2024)	Smart green buildings	IoT monitoring with load forecasting	Significant reduction reported
Patankar et al. (2024)	Lighting and HVAC	IoT with machine vision	Substantial efficiency improvement
Aradoaei et al. (2025)	Institutional commercial buildings	Integrated IoT energy platform	12.14%
Kankhva et al. (2024)	Commercial buildings	IoT with big data analytics	15–20%
Zhao et al. (2016)	Zonal commercial buildings	IoT-based zonal monitoring	Notable demand reduction

The table confirms that energy reduction outcomes are consistently reported across diverse building types and system architectures. The variation in reduction percentages reflects differences in building scale, system integration level, and control strategy complexity rather than inconsistencies in IoT effectiveness.

HVAC Systems as the Primary Optimization Target

Across the reviewed studies, HVAC systems emerge as the dominant contributor to total energy savings. Real-time monitoring of temperature, humidity, and occupancy enables adaptive HVAC operation that aligns system output with actual demand. Chauhan (2025) reports that IoT-enabled HVAC systems achieve reductions between 20 and 30 percent while maintaining occupant comfort. Jin et al. (2024) further show that integrating HVAC monitoring with big data analytics significantly improves air conditioning efficiency.

These findings are consistent with earlier results reported by Salman et al. (2024), where short-term load forecasting and sensor-driven control reduced unnecessary HVAC operation. The results indicate that HVAC optimization delivers the largest marginal energy savings due to its high baseline energy consumption in commercial buildings.

Lighting System Optimization through Occupancy-Aware Monitoring

Lighting systems represent the second major source of energy efficiency gains. IoT-based monitoring combined with occupancy detection and ambient light evaluation enables autonomous lighting control. Patankar et al. (2024) demonstrate that machine vision-supported IoT systems effectively reduce lighting energy waste by deactivating lighting in unoccupied zones.

These findings align with earlier zonal monitoring approaches discussed by Zhao et al. (2016), which emphasize spatial granularity in energy management. The empirical evidence confirms that lighting optimization does not rely on complex predictive models but benefits directly from accurate, real-time occupancy data.

Role of Data Analytics and System Architecture

Advanced data processing significantly enhances the effectiveness of IoT-based monitoring systems. Studies utilizing big data analytics and learning-based optimization report more stable and sustained energy reductions. Jin et al. (2024) and Kankhva et al. (2024) show that predictive analysis enables identification of peak consumption periods and inefficiencies that are not visible through monitoring alone.

Edge and fog computing architectures further strengthen system performance. Verde et al. (2024) demonstrate that edge-based monitoring reduces latency and improves data security, allowing faster control actions. These architectural features are particularly important in commercial buildings where delayed responses can negate energy-saving opportunities.

Integrated Platforms and Scalability Implications

Integrated IoT energy platforms show stronger and more consistent outcomes compared to isolated subsystem implementations. Large-scale initiatives such as the CELSIUS platform provide systematic monitoring of energy performance and indoor climate across multiple buildings (Li, 2022). Similarly, the BENEFIT platform demonstrates that coordinated IoT deployment achieves measurable energy savings at the institutional level (Aradoaei et al., 2025).

These results indicate that integration across monitoring, analytics, and control layers is a key determinant of optimization success. Fragmented systems may achieve localized savings, but integrated platforms support long-term efficiency and scalability, as also noted by Poyyamozhi et al. (2024).

DOI: https://doi.org/10.70716/reswara.v3i2.412

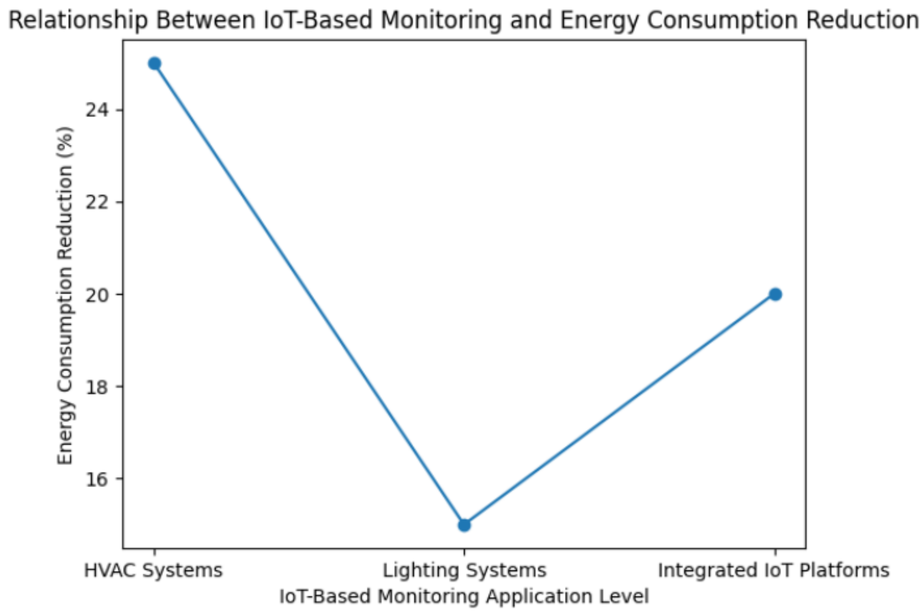

Figure 1. Relationship Between IoT-Based Monitoring and Energy Consumption Reduction in Commercial Buildings

The figure illustrates the relationship between the level of IoT-based monitoring application and the percentage of energy consumption reduction in commercial buildings. HVAC systems show the highest reduction due to continuous real-time monitoring and adaptive control. Lighting systems demonstrate moderate reductions driven by occupancy-aware monitoring. Integrated IoT platforms provide stable and consistent energy savings by coordinating multiple building subsystems. The figure confirms empirical findings reported in previous studies and supports the comparative results presented in Table 1.

CONCLUSION

This study demonstrates that Internet of Things based monitoring systems play a significant role in optimizing energy consumption in commercial buildings. The synthesis of empirical studies confirms that the integration of real-time sensing, data analytics, and automated control mechanisms leads to measurable reductions in energy use, particularly in HVAC and lighting systems. HVAC systems represent the primary optimization target due to their dominant contribution to total building energy demand, while occupancy-based monitoring effectively reduces unnecessary lighting consumption.

The findings also indicate that monitoring alone is insufficient to achieve sustained energy efficiency. The highest effectiveness is achieved when monitoring is combined with predictive analytics and adaptive control systems that align building operation with actual conditions and usage patterns. Edge and fog computing architectures further enhance system performance by reducing latency and improving data security, thereby supporting timely and reliable operational decisions.

In addition, integrated IoT platforms that coordinate multiple building subsystems deliver more stable and consistent outcomes than isolated implementations. Such integration enables cross-system optimization and supports long-term scalability. Therefore, this study confirms that IoT-based monitoring functions not merely as an observational tool, but as a strategic foundation for efficient, adaptive, and scalable building energy management. These findings provide a robust basis for building managers and policymakers to adopt IoT-driven solutions as part of long-term energy efficiency strategies.

REFERENCES

Aradoaei, M., Ciobanu, R. C., Schreiner, C., et al. (2025). BENEFIT: An energy management platform for smart and energy efficient buildings. *Energies, 18*(17), 4542. https://doi.org/10.3390/en18174542

Chauhan, M. S. (2025). IoT integration in HVAC systems: Achieving sustainable energy efficiency and enhanced occupant comfort. *Journal of Civil Engineering Research & Technology, 7*, 183. https://doi.org/10.47363/jcert/2025(7)183

Gao, X. Y., & Sun, Y. B. (2023). The comprehensive building energy IoT platform based on Niagara technology. In *Proceedings of the IEEE International Conference on Industrial Electronics and Applications*. https://doi.org/10.1109/iciea58696.2023.10241456

Gao, Y., Li, S., Xiao, Y., et al. (2022). An iterative optimization and learning-based IoT system for energy management of connected buildings. *IEEE Internet of Things Journal, 9*(21), 21345–21358. https://doi.org/10.1109/JIOT.2022.3176306

Gong, S., Wang, Y., & Zhang, M. (2017). Design of intelligent power consumption optimization and visualization management platform for large buildings based on internet of things. *MATEC Web of Conferences, 139*, 00119. https://doi.org/10.1051/matecconf/201713900119

Jin, X., Gu, Z., & Yang, X. (2024). Energy consumption optimization method of intelligent internet of things building based on big data analysis. In *Proceedings of the IEEE International Conference on Industrial Research and Development in Computing*. https://doi.org/10.1109/icirdc65564.2024.00148

Kankhva, V., Negi, A. S., Aaluri, S., et al. (2024). Energy efficiency in buildings using internet of things (IoT) and big data analytics. *E3S Web of Conferences, 458*, 01009. https://doi.org/10.1051/e3sconf/202458101009

Khan, M. A., Bektemyssova, G., Razaque, A., et al. (2025). IoT-driven energy monitoring framework: Enhancing efficiency, sustainability, and real-time optimization. In *Proceedings of the IEEE Smart and Advanced Technologies Conference*. https://doi.org/10.1109/satc65530.2025.11137331

Kumbhar, S. D., Patel, G. S., Chougule, P. P., et al. (2025). IoT-enabled energy monitoring and management systems. In *Advances in Smart Energy Systems* (pp. 211–228). CRC Press. https://doi.org/10.1201/9781779643599-13

Li, J. (2022). CELSIUS: An international project providing integrated, systematic, cost-effective large-scale IoT solutions for improving energy efficiency of medium- and large-sized buildings. *Energy Informatics, 5*(1), 1–14. https://doi.org/10.1186/s42162-022-00221-8

Liu, C., Wang, D., & Yin, Y. (2019). Two-stage optimal economic scheduling for commercial building multi-energy system through internet of things. *IEEE Access, 7*, 167946–167957. https://doi.org/10.1109/access.2019.2957267

Liu, Y., Li, X., & Gao, L. (2024). Energy consumption optimization method for intelligent IoT buildings based on big data analysis. In *Proceedings of the IEEE Power and Energy Engineering Conference*. https://doi.org/10.1109/peeec63877.2024.00071

Nabizadeh Rafsanjani, H., Nabizadeh, A. H., & Momeni, M. (2024). Digital twin energy management system for human-centered HVAC and MELS optimization in commercial buildings. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4837416

Natarajan, V. P., Aggarapu, N., Metta, S. L., et al. (2024). IoT based energy management system for buildings. In *Proceedings of the IEEE International Conference on Smart Energy and Computing*. https://doi.org/10.1109/icosec61587.2024.10722229

Patankar, S. M., Swami, R. K., & Nanivadekar, S. (2024). Enhancing energy efficiency in commercial office buildings: A smart IoT and machine vision approach. In *Proceedings of the IEEE World Conference on Future Technologies*. https://doi.org/10.1109/wconf61366.2024.10691999

Poyyamozhi, M., Murugesan, B., Narayanamoorthi, R., et al. (2024). IoT: A promising solution to energy management in smart buildings: A systematic review, applications, barriers, and future scope. *Buildings, 14*(11), 3446. https://doi.org/10.3390/buildings14113446

Pratama, S. P. (2023). Optimisasi efisiensi energi dalam bangunan cerdas melalui sistem kontrol berbasis IoT. *Journal of Technology and Engineering, 1*(1), 1–12. https://doi.org/10.59613/journaloftechnologyandengineering.v1i1.16

Salman, R., Elkady, G., Sandhu, M., et al. (2024). IoT-based smart green building energy management system. In *Smart Infrastructure Systems* (pp. 95–112). Wiley. https://doi.org/10.1002/9781394231522.ch7

Sheth, A., Choxi, B., Darji, K., et al. (2024). ML-based IoT communication data analysis framework for energy crisis management in commercial buildings. In *Proceedings of the IEEE International Conference on Data Intelligence*. https://doi.org/10.1109/idicaiei61867.2024.10842819

Udendhran, R., & S. R. (2023). Smart energy consumption control in commercial buildings using machine learning and IoT. *E3S Web of Conferences, 387*, 02003. https://doi.org/10.1051/e3sconf/202338702003

Verde, D. A., Laureano, E. V., Betancourt, R. O. J., et al. (2024). An open source IoT edge-computing system for monitoring energy consumption in buildings. *Results in Engineering, 21*, 101875. https://doi.org/10.1016/j.rineng.2024.101875

Wang, W., Dwijendra, N. K. A., Sayed, B. T., et al. (2023). Internet of things energy consumption optimization in buildings: A step toward sustainability. *Sustainability, 15*(8), 6475. https://doi.org/10.3390/su15086475

Xie, D., & Xie, Q. (2024). Internet of things-based study on online monitoring system of building equipment energy saving optimization control using building information modeling. *Science Progress, 107*(2), 1–15. https://doi.org/10.1177/00368504241228130

Zhao, P., Peffer, T., Narayanamurthy, R., et al. (2016). Getting into the zone: How the internet of things can improve energy efficiency and demand response in a commercial building. *Energy and Buildings, 122*, 1–12.