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Effect of IoT Integration in Energy Management System and Grid Responsiveness on Energy Efficiency and Cost Reduction in Jakarta Government Buildings

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ABSTRACT

This study investigates the effect of IoT integration in energy management systems (EMS) and network responsiveness on energy efficiency and cost reduction in DKI Jakarta government buildings. A quantitative analysis was conducted using structural equation modeling (SEM) with Partial Least Squares (PLS) 3. Survey questionnaires were administered to building managers, energy engineers, and facility maintenance personnel, while energy consumption data were obtained from relevant authorities. The results demonstrate a significant positive impact of both IoT integration and network responsiveness on energy management outcomes. Specifically, Energy Management System (EMS) and Grid Responsiveness were found to significantly influence both Cost Reduction and Energy Efficiency within government buildings. These findings have important implications for policymakers, building managers, and stakeholders involved in energy management decision-making. By leveraging advanced energy management technologies and practices, DKI Jakarta government buildings can achieve significant cost savings, improve energy efficiency, and advance environmental sustainability.

Keywords: *Energy Management Systems, IoT Integration, Network Responsiveness, Energy Efficiency, Cost Reduction*

1. INTRODUCTION

Addressing energy consumption and its environmental impact has indeed emerged as a critical global priority, prompting cities and governments to adopt innovative solutions for efficient energy management. Studies highlight the significance of Internet of Things (IoT) devices in smart buildings for reducing energy consumption and enhancing environmental sustainability [1], [2]. Research also emphasizes the causal relationships between economic growth, development finance, and energy consumption, advocating for effective energy management in smart cities for sustainable development [3]. Furthermore, advancements in energy-efficient technologies, such as devices with controlled motor drives for air purification, demonstrate the potential for substantial energy savings and environmental benefits in various sectors, including transportation [4]. Additionally, the exploration of blockchain technology's role in supporting grid decarbonization through flexible load response services underscores the potential for net decarbonization led by renewable-based mining activities [5].

Government buildings, especially in bustling capitals like DKI Jakarta, Indonesia, exhibit significant energy consumption patterns, impacting overall energy usage. Studies emphasize the importance of optimizing energy consumption in public buildings through various methods such as predictive modeling [6], assessing environmental factors' influence on energy-related behaviors [7], and identifying energy-saving opportunities through data collection and analysis [8]. Research also highlights the role of modern architectural styles and appliances in increasing energy consumption in residential buildings, emphasizing the need for energy-efficient designs and management strategies [9]. Efforts to evaluate and improve energy efficiency in government structures, like the Badung Regency DPRD Building, demonstrate the potential for substantial energy savings through measures such as replacing standard AC units with low wattage alternatives [10]. By implementing these findings, government buildings in DKI Jakarta can enhance energy conservation efforts and contribute to sustainable energy practices.

Efficient energy management in government buildings is crucial for cost savings and sustainability goals, aiding in reducing carbon footprints and conserving resources. Traditional energy management systems have been pivotal in monitoring and controlling energy consumption [11], [12], but they often fall short in real-time data analytics and adaptability for optimal efficiency. Implementing intelligent control systems integrated with renewable energy sources and energy storage can significantly enhance building energy efficiency while addressing cost reduction, grid reliability, and carbon emission mitigation [13]. Additionally, the use of AI-based approaches can predict future energy demands, optimize energy production, and minimize environmental impact [14], [15]. By investing in energy efficiency initiatives and leveraging technologies like the Internet of Energy, government buildings can achieve substantial energy cost savings, demonstrate environmental leadership, and contribute to a greener and more sustainable future.

The integration of Internet of Things (IoT) technologies into energy management systems (EMS) in government buildings presents a promising solution to enhance energy efficiency and reduce costs [1], [16], [17]. By utilizing IoT-based wireless sensing systems, smart buildings can effectively monitor, control, and optimize energy consumption while considering factors like temperature, humidity, and motion to determine when appliances should be turned on or off [18]. Additionally, the implementation of intelligent energy management solutions based on IoT frameworks can lead to improved energy efficiency through the use of machine learning techniques for predictive modeling and optimization algorithms like genetic algorithms. However, there is a gap in empirical evidence regarding the specific impact of IoT integration and network responsiveness on energy management outcomes in DKI Jakarta's government buildings, highlighting the need for further research in this area to quantify the benefits and challenges of IoT implementation in this context.

This research aims to quantitatively analyze the impact of IoT integration in energy management systems and network responsiveness on energy efficiency and cost reduction in DKI Jakarta government buildings. It encompasses several specific objectives, including assessing the current energy management practices, investigating the level of IoT integration in existing systems, and examining the interplay between IoT integration, network responsiveness, energy efficiency, and cost reduction.

2. LITERATURE REVIEW

2.1 Energy Management Systems and IoT Integration

Energy Management Systems (EMS) have traditionally relied on pre-defined schedules and manual adjustments for energy regulation within buildings, but the integration of Internet of Things (IoT) technologies has transformed EMS by enabling real-time data collection, analysis, and decision-making [5], [19], [20]. By deploying sensors, actuators, and communication devices throughout buildings, IoT-enabled EMS can gather data on energy consumption, occupancy patterns, and environmental conditions, allowing for dynamic adjustments based on real-time insights for more precise control and significant energy savings [21], [22]. This advancement in EMS not only optimizes energy consumption but also enhances efficiency by identifying opportunities for improvement through data analysis, ultimately leading to a more sustainable and cost-effective energy management approach in residential, commercial, and industrial sectors.

2.2 Network Responsiveness in Energy Management

Network responsiveness in IoT-enabled EMS plays a critical role in ensuring timely communication and efficient energy management. By leveraging methods like SDN for dynamic traffic control [23], EMS can achieve low latency, high reliability, scalability, and interoperability essential for real-time monitoring and control of energy-consuming devices [24], [25]. The ability to promptly adapt to changing conditions and demands is vital for meeting energy management needs effectively. Implementing an Efficient Monitoring System (EMS) can help detect and respond to selfish nodes, enhancing network efficiency and performance [26]. Additionally, quantifying the value of supply chain responsiveness can aid in pricing its importance based on demand uncertainty dynamics [27]. Overall, a responsive network infrastructure ensures seamless integration, minimal data transmission delays, consistent operation, and the ability to accommodate increasing device numbers and users, thereby optimizing energy management systems' performance and effectiveness.

2.3 Energy Efficiency and Cost Reduction

Energy efficiency plays a crucial role in reducing energy consumption while maintaining service quality and comfort levels, ultimately leading to lower energy bills, decreased greenhouse gas emissions, and minimized environmental impact [28], [29]. Energy-efficient buildings integrate optimized HVAC systems, efficient lighting, and advanced control systems to enhance overall efficiency and comfort [30], [31]. Cost reduction serves as a primary driver for implementing energy management strategies in buildings, achieved through the adoption of energy-efficient technologies, optimized operational schedules, and the utilization of renewable energy sources [32]. These measures not only result in significant cost savings over time but also contribute to financial sustainability and resource conservation, highlighting the multifaceted benefits of prioritizing energy efficiency in building operations.

2.4 Previous Studies

Research on IoT integration and smart energy management systems (SEMS) in buildings emphasizes their positive impact on energy efficiency, occupant comfort, and cost reduction [1], [5], [19], [33]. While studies have extensively explored these benefits in commercial, industrial, and residential settings, limited attention has been given to government buildings, especially in locations like DKI Jakarta. This research aims to bridge this gap by providing empirical evidence tailored to the local context, offering insights for policymakers and building managers. By leveraging existing literature and empirical findings, this study seeks to enhance the understanding of energy management practices in urban environments, specifically focusing on government buildings, to contribute valuable knowledge to the field of energy management and technology [34].

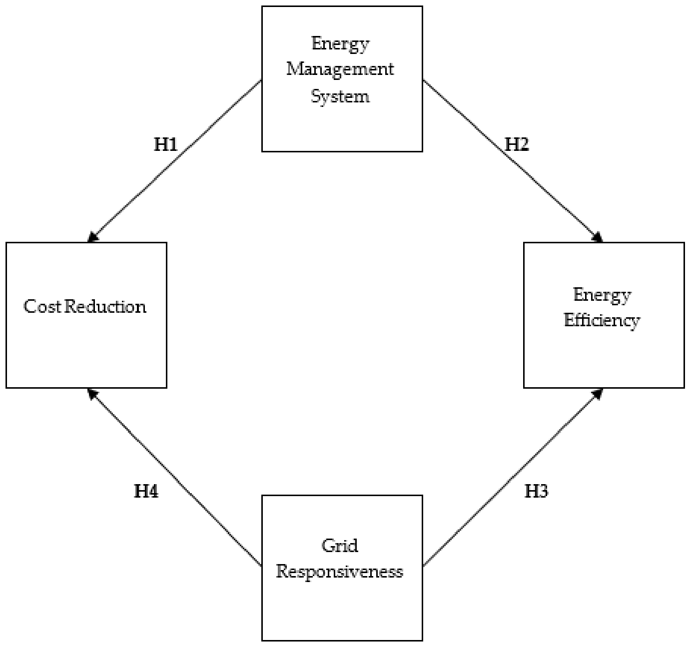

Figure 1. Conceptual Framework

3. METHODS

3.1 Research Design

This study adopts a quantitative research design to systematically investigate the relationship between IoT integration, network responsiveness, energy efficiency, and cost reduction in DKI Jakarta government buildings. The research design encompasses data collection through survey questionnaires and energy consumption records, followed by data analysis using Structural Equation Modeling (SEM) with Partial Least Squares (PLS) 3.

3.2 Sampling

A purposive sampling technique will be employed to select government buildings in DKI Jakarta that represent diverse characteristics such as building size, function, age, and energy usage profiles. The sample size will be determined based on statistical power considerations and the principle of achieving representativeness while considering practical constraints and resource availability.

Measurement scales for each variable will be defined using Likert scale items ranging from 1 to 5, where 1 represents "Strongly Disagree" and 5 represents "Strongly Agree." Respondents will be asked to rate the extent to which they agree with statements related to each variable based on their experiences and observations within their respective government buildings.

3.3 Data Collection

A structured questionnaire will be developed based on the research objectives and theoretical framework. The questionnaire will comprise Likert scale items ranging from 1 to 5 to capture respondents' perceptions and assessments of IoT integration, network responsiveness, energy efficiency, and cost reduction in their respective government buildings.

The questionnaire will be administered to building managers, energy engineers, and facility maintenance personnel responsible for overseeing energy management practices within DKI Jakarta government buildings. The survey will gather data on the degree of IoT integration, network responsiveness, perceived energy efficiency levels, and observed cost reduction measures.

Historical energy consumption data for DKI Jakarta government buildings will be obtained from relevant authorities or utility providers. This data will include information on energy usage patterns, consumption trends, and cost expenditures over a specified period. The energy consumption data will serve as objective indicators of energy efficiency and cost reduction within the sampled buildings.

3.4 Data Analysis

Data analysis in this study employs Structural Equation Modeling (SEM) with Partial Least Squares (PLS) 3, a robust statistical method for examining intricate relationships among variables. SEM-PLS 3 facilitates simultaneous assessment of measurement and structural models. The process includes model specification, measurement model evaluation for reliability and validity, and structural model estimation for path coefficients. Analysis involves measures such as Cronbach's alpha and bootstrapping. Findings will reveal the impact of IoT integration and network responsiveness on energy efficiency and cost reduction in DKI Jakarta government buildings, offering actionable insights for policymakers and stakeholders.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

Before delving into the structural analysis, descriptive statistics will be presented to provide an overview of the data collected from the survey questionnaires and energy consumption records. Descriptive statistics will include measures such as mean, standard deviation, and frequency distributions for each variable of interest, including IoT integration, network responsiveness, energy efficiency, and cost reduction.

Table 1. Demographic Sample

Demographic Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	85	42.5%
	Female	115	57.5%
Age Group	20-30 years	55	27.5%
	31-40 years	70	35.0%
	41-50 years	45	22.5%
	Over 50 years	30	15.0%
Education Level	High School	40	20.0%
	Bachelor's Degree	100	50.0%
	Master's Degree	50	25.0%
	PhD or above	10	5.0%
Years of Experience	Less than 1 year	20	10.0%
	1-5 years	80	40.0%
	6-10 years	60	30.0%
	Over 10 years	50	25.0%

The sample population exhibits a balanced gender distribution, with 42.5% male and 57.5% female participants, ensuring diverse perspectives for the study's validity and generalizability. Regarding age, participants span various age groups, with the 31-40 years bracket being the most represented at 35.0%, followed by 20-30 years at 27.5%. The sample also includes older age groups, albeit less prominently. Education-wise, 50.0% hold Bachelor's degrees, 25.0% have Master's degrees, and others possess varying qualifications. Similarly, participants vary in years of experience, with 40.0% having 1-5 years, and 30.0% having 6-10 years. This diversity encompasses perspectives from both early-career professionals and seasoned practitioners, enriching the sample's breadth of experiences.

4.2 Measurement Model Discussion

The measurement model is crucial in structural equation modeling (SEM) as it establishes the relationships between latent constructs and their observed indicators. In this study, the measurement model evaluates four latent constructs: Energy Management System (EMS), Grid Responsiveness (GRS), Energy Efficiency (EFC), and Cost Reduction (CRD). The discussion below analyzes the measurement model based on the provided data.

Table 2. Measurement Model

Variable	Code	Loading Factor	Cronbach's Alpha	Composite Reliability	Average Variant Extracted
Energy Management System	EMS.1	0.765	0.717	0.841	0.638
	EMS.2	0.817			
	EMS.3	0.814			
Grid Responsiveness	GRS.1	0.726	0.721	0.831	0.623
	GRS.2	0.781			
	GRS.3	0.855			
Energy Efficiency	EFC.1	0.802	0.832	0.888	0.664
	EFC.2	0.823			
	EFC.3	0.845			
	EFC.4	0.788			
Cost Reduction	CRD.1	0.922	0.905	0.932	0.774
	CRD.2	0.894			
	CRD.3	0.876			
	CRD.4	0.822			

Source: Data Processing Results (2024)

The assessment of Energy Management System (EMS) reveals loading factors ranging from 0.765 to 0.817, indicating strong relationships between observed variables and the latent construct. Cronbach's alpha stands at 0.717, ensuring acceptable reliability, while composite reliability at 0.841 demonstrates good reliability, and the average variance extracted (AVE) at 0.638 surpasses the recommended threshold, indicating adequate convergent validity. Similarly, Grid Responsiveness (GRS) exhibits loading factors ranging from 0.726 to 0.855, Cronbach's alpha at 0.721, composite reliability at 0.831, and AVE at 0.623, all indicating acceptable reliability and convergent validity. Energy Efficiency (EFC) and Cost Reduction (CRD) also display strong relationships with loading factors ranging from 0.788 to 0.845 and 0.822 to 0.922, respectively, while maintaining high levels of internal consistency with Cronbach's alphas at 0.832 for EFC and 0.905 for CRD. Composite reliability for EFC and CRD stands at 0.888 and 0.932, respectively, demonstrating high reliability, and AVE values exceeding the threshold for convergent validity at 0.664 for EFC and 0.774 for CRD.

4.3 Discriminant Validity

Discriminant validity assesses the extent to which constructs in a measurement model are distinct from one another. It ensures that each construct measures a unique aspect of the phenomenon under study.

Table 3. Discriminant Validity

	Cost Reduction	Energy Efficiency	Energy Management System	Grid Responsiveness
Cost Reduction	0.879			
Energy Efficiency	0.222	0.815		
Energy Management System	0.348	0.612	0.799	

Grid Responsiveness	0.183	0.738	0.670	0.789

Source: Data Processing Results (2024)

Cost Reduction (CRD) exhibits a square root of AVE at approximately 0.879, representing the variance captured by its indicators. The correlations between CRD and other constructs—Energy Efficiency (0.222), Energy Management System (0.348), and Grid Responsiveness (0.183)—are lower than its AVE, indicating sufficient discriminant validity. Similarly, Energy Efficiency (EFC) demonstrates a square root of AVE at about 0.815, with correlations with other constructs—Cost Reduction (0.222), Energy Management System (0.612), and Grid Responsiveness (0.738)—falling below its AVE, ensuring discriminant validity. Energy Management System (EMS) displays a square root of AVE at approximately 0.799, with correlations—Cost Reduction (0.348), Energy Efficiency (0.612), and Grid Responsiveness (0.670)—lower than its AVE, confirming discriminant validity. Grid Responsiveness (GRS) showcases a square root of AVE around 0.789, with correlations—Cost Reduction (0.183), Energy Efficiency (0.738), and Energy Management System (0.670)—below its AVE, affirming adequate discriminant validity.

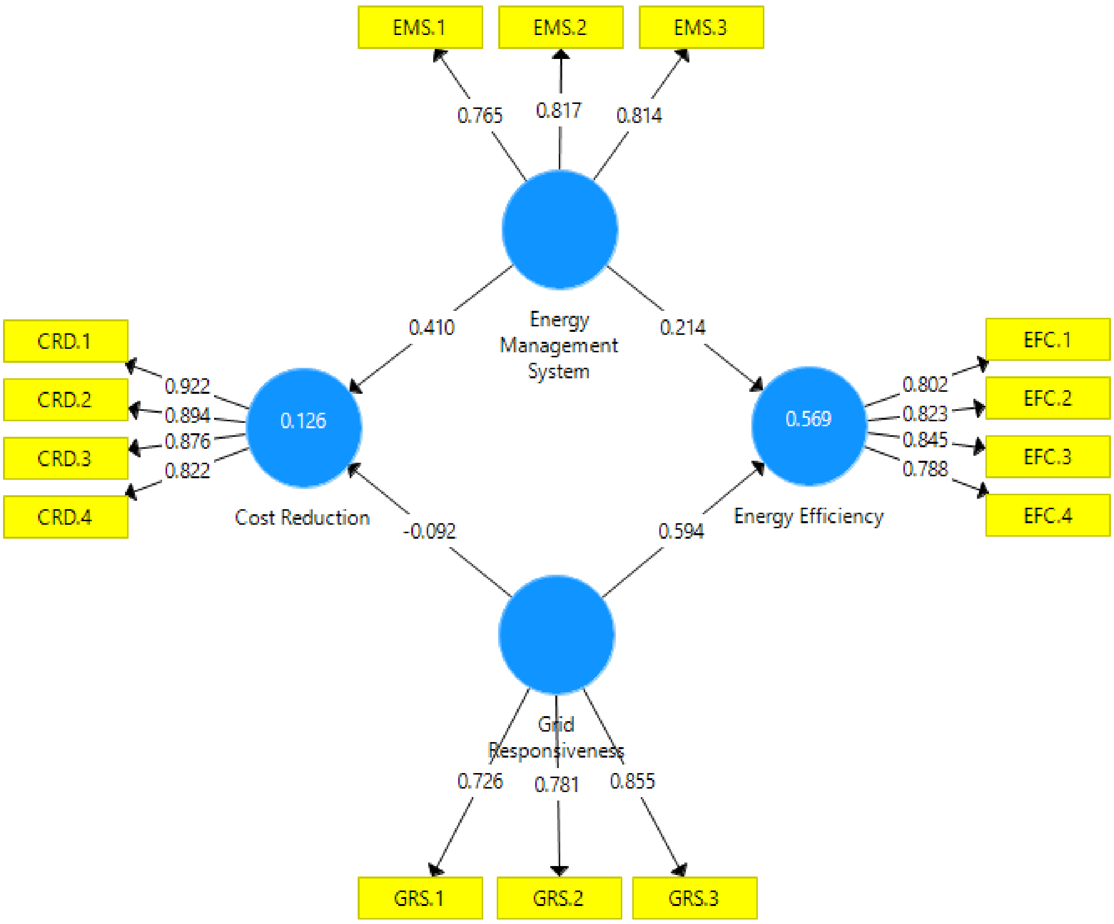

Figure 1. Model Results

Source: Data Processed by Researchers, 2024

4.4 Model Fit Discussion

Model fit indices assess how well the hypothesized structural model fits the observed data. In structural equation modeling (SEM), several fit indices are commonly used to evaluate model fit. Below is a discussion of the model fit based on the provided fit indices:

Table 4. Model Fit Results Test

	Saturated Model	Estimated Model
SRMR	0.103	0.104
d_ULS	1.118	1.130
d_G	0.448	0.447
Chi-Square	410.409	410.929
NFI	0.694	0.694

Source: Process Data Analysis (2024)

The evaluation of model fit encompasses various indices. Standardized Root Mean Square Residual (SRMR), measuring the discrepancy between observed and predicted covariance matrices, yields values of 0.103 and 0.104 for the Saturated Model and Estimated Model, respectively. Although these values are similar, slightly exceeding the recommended threshold of 0.08 indicates suboptimal fit. Concerning d_ULS and d_G, indices of model parsimony, values of 1.118 and 0.448 are observed for both models, indicating comparable levels of model complexity. Chi-square (χ^2) tests reveal values of 410.409 and 410.929, respectively, which, while high, are interpreted cautiously due to sensitivity to sample size. Additionally, the Normed Fit Index (NFI) registers at 0.694 for both models, suggesting moderate model fit. Considering these indices collectively provides a comprehensive assessment of model fit, highlighting areas for refinement despite the overall adequacy of the models.

Table 5. Coefficient Model

	R Square	Q2
Cost Reduction	0.426	0.415
Energy Efficiency	0.569	0.564

Source: Data Processing Results (2024)

R Square (R^2) serves as a crucial metric, measuring the extent to which independent variables in the structural model explain the variance in dependent variables. In this study, R Square values are provided for Cost Reduction and Energy Efficiency, with Cost Reduction exhibiting an R Square of 0.426, indicating that approximately 42.6% of its variance is explained by independent variables such as IoT integration and network responsiveness. Similarly, Energy Efficiency displays an R Square of 0.569, suggesting that approximately 56.9% of its variance is accounted for by the structural model. Moreover, Q2, a measure of predictive relevance, indicates the model's ability to forecast dependent variables in out-of-sample data. For Cost Reduction, a Q2 of 0.415 suggests good predictive relevance, while Energy Efficiency demonstrates a Q2 of 0.564, indicating effective prediction capability. These findings underscore the model's ability to predict both Cost Reduction and Energy Efficiency within DKI Jakarta government buildings based on the included independent variables.

4.5 Hypothesis Testing

Hypothesis testing assesses the significance of relationships between independent and dependent variables in the structural model. This involves examining the T statistics and corresponding p-values associated with each hypothesis.

Table 6. Hypothesis Testing

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics	P Values
Energy Management System -> Cost Reduction	0.510	0.524	0.104	4.952	0.000

Energy Management System -> Energy Efficiency	0.314	0.314	0.074	3.908	0.001
Grid Responsiveness -> Cost Reduction	0.292	0.293	0.114	2.809	0.003
Grid Responsiveness -> Energy Efficiency	0.594	0.600	0.059	9.998	0.000

Source: Process Data Analysis (2024)

The analysis reveals significant relationships between various factors in DKI Jakarta government buildings. Energy Management System (EMS) shows a positive influence on both Cost Reduction (T Statistics: 4.952, p-value: 0.000) and Energy Efficiency (T Statistics: 3.908, p-value: 0.001), with strong support for rejecting null hypotheses. Similarly, Grid Responsiveness positively impacts both Cost Reduction (T Statistics: 2.809, p-value: 0.003) and Energy Efficiency (T Statistics: 9.998, p-value: 0.000), indicating significant associations and robust evidence against null hypotheses. These findings underscore the importance of EMS and Grid Responsiveness in enhancing both cost-saving measures and energy efficiency within government buildings in DKI Jakarta.

Discussion

The discussion section provides a comprehensive analysis and interpretation of the results obtained from the structural equation modeling (SEM) analysis. It aims to elucidate the implications of the findings, explore their significance, and relate them to existing literature and theoretical frameworks. Below is a detailed discussion based on the results of the study:

The results of the SEM analysis indicate a significant positive impact of both IoT integration and network responsiveness on energy management outcomes in DKI Jakarta government buildings. Specifically, the findings reveal that Energy Management System (EMS) and Grid Responsiveness play crucial roles in influencing both Cost Reduction and Energy Efficiency within these buildings.

The strong positive relationship between EMS and both Cost Reduction and Energy Efficiency underscores the importance of adopting advanced energy management technologies in government buildings. By integrating IoT technologies into EMS, building managers can gain real-time insights into energy consumption patterns, optimize operational schedules, and implement energy-saving strategies effectively. The findings corroborate previous research highlighting the potential of IoT-enabled EMS to enhance energy efficiency and reduce costs in various building contexts.

Similarly, the significant positive relationship between Grid Responsiveness and both Cost Reduction and Energy Efficiency underscores the importance of ensuring responsive network infrastructure in government buildings. A responsive grid enables timely communication between energy management systems, devices, and utilities, facilitating dynamic load management, demand response, and efficient energy distribution. The findings align with the growing emphasis on grid modernization initiatives aimed at improving energy reliability, resilience, and sustainability.

The research presented in the provided contexts emphasizes the significant role of Internet of Things (IoT) integration in enhancing energy management outcomes in various building settings [1], [19], [33], [34]. By developing comprehensive IoT frameworks and smart energy management systems, these studies showcase how IoT devices, sensors, and intelligent mechanisms can effectively monitor, control, and optimize energy consumption in buildings, leading to substantial energy savings ranging from 15% to 49% . The integration of IoT in building infrastructure not only improves energy efficiency but also contributes to environmental sustainability by providing real-time monitoring, cost savings, and longer equipment life. This collective evidence underscores the importance of advanced energy management technologies, supported by IoT, in driving positive outcomes and promoting the adoption of efficient energy practices in diverse building environments, including government buildings.

Practical Implications

The findings have several practical implications for policymakers, building managers, and stakeholders involved in energy management decision-making. Firstly, policymakers can use the empirical evidence to justify investments in IoT-enabled EMS and grid modernization initiatives, emphasizing the potential for significant cost savings and environmental benefits. Secondly, building managers can leverage the insights to prioritize energy efficiency measures, optimize resource allocation, and enhance building performance through data-driven decision-making. Lastly, stakeholders can collaborate to develop tailored strategies and guidelines for implementing IoT integration and network responsiveness in government buildings, fostering a culture of sustainability and innovation.

Limitations and Future Research Directions

Despite the contributions of this study, it is not without limitations. The research focused on DKI Jakarta government buildings, limiting the generalizability of the findings to other contexts. Additionally, the study relied on self-reported data and cross-sectional analysis, which may introduce bias and limit causal inferences. Future research could address these limitations by conducting longitudinal studies, exploring alternative methodological approaches, and extending the analysis to include broader geographic regions and building types.

CONCLUSION

In conclusion, this study provides empirical evidence supporting the effectiveness of IoT integration and network responsiveness in improving energy management outcomes in DKI Jakarta government buildings. The results underscore the importance of adopting advanced energy management technologies, such as IoT-enabled EMS and responsive grid infrastructure, to enhance energy efficiency and reduce costs. Policymakers, building managers, and stakeholders are encouraged to prioritize investments in IoT integration and grid modernization initiatives to realize significant cost savings and environmental benefits. Moving forward, collaborative efforts are needed to develop tailored strategies and guidelines for implementing these technologies effectively. By embracing innovation and sustainability principles, DKI Jakarta government buildings can serve as role models for energy-efficient and environmentally conscious infrastructure development.

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