AI-Based Optimization of HVAC Systems in Kuwait (A Descriptive Study on Industry Adoption and Performance Benefits)

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Abstract:

In high-temperature regions such as Kuwait, HVAC systems are essential for indoor comfort and energy management. This study examines the adoption and effectiveness of Artificial Intelligence (AI)-based optimization in HVAC systems among industry professionals in Kuwait. Using a descriptive survey methodology, data were collected from 203 professionals including HVAC engineers, facility managers, and maintenance supervisors using a structured questionnaire designed to capture both quantitative and qualitative data during five months from October 2024 to February 2025. The results showed moderate adoption levels of AI, with high perceived benefits in areas such as energy efficiency, cost reduction, system optimization, and predictive maintenance. However, barriers such as high initial costs, technical skill gaps, and data security concerns hinder broader implementation. also, the findings suggest a need for a coordinated approach involving government policies, industry innovation, and workforce training to overcome these challenges. As the demand for energy-efficient and sustainable building systems continues to rise, AI-based solutions are well-positioned to transform HVAC operations in Kuwait and similar environments. Future research should focus on validating these perceptions through empirical data and exploring scalable, cost-effective models for AI integration.

Keywords: Artificial Intelligence (AI), HVAC systems, Energy efficiency, Building sustainability, Operational optimization, State of Kuwait.

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تحسين أنظمة التدفئة والتهوية وتكييف الهواء القائمة على الذكاء الاصطناعي في الكويت (دراسة وصفية حول تبني الصناعة وفوائد الأداء)

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الملخص:

في المناطق ذات درجات الحرارة المرتفعة مثل الكويت، تُعد أنظمة التدفئة والتهوية وتكييف الهواء (HVAC) ضرورية للراحة الداخلية وإدارة الطاقة. تبحث هذه الدراسة في اعتماد وفعالية التحسين القائم على الذكاء الاصطناعي (AI) في أنظمة التدفئة والتهوية وتكييف الهواء بين المتخصصين في هذا المجال في الكويت. باستخدام منهجية المسح الوصفي، جُمعت البيانات من 203 متخصصين، بمن فيهم مهندسو التدفئة والتهوية وتكييف الهواء، ومديرو المرافق، ومشرفو الصيانة، باستخدام استبيان مُنظم مُصمم لالتقاط البيانات الكمية والنوعية على مدار خمسة أشهر من أكتوبر 2024 إلى فبراير 2025. أظهرت النتائج مستويات معتدلة من اعتماد الذكاء الاصطناعي، مع فوائد مُتصورة عالية في مجالات مثل كفاءة الطاقة، وخفض التكاليف، وتحسين النظام، والصيانة التنبؤية. ومع ذلك، فإن العوائق مثل التكاليف الأولية المرتفعة، والفجوات في المهارات الفنية، ومخاوف أمن البيانات تعيق التنفيذ على نطاق أوسع. كما تُشير النتائج إلى الحاجة إلى نهج مُنسق يشمل السياسات الحكومية، والابتكار في المجال، وتدريب القوى العاملة للتغلب على هذه التحديات. مع استمرار ارتفاع الطلب على أنظمة المباني الموفرة للطاقة والمستدامة، فإن الحلول القائمة على الذكاء الاصطناعي في وضع جيد لتحويل عمليات التدفئة والتهوية وتكييف الهواء في الكويت والبيئات المماثلة. وينبغي للأبحاث المستقبلية أن تركز على التحقق من صحة هذه التصورات من خلال البيانات التجريبية واستكشاف نماذج قابلة للتطوير وفعالة من حيث التكلفة لدمج الذكاء الاصطناعي.

الكلمات المفتاحية: الذكاء الاصطناعي؛ أنظمة التدفئة والتهوية وتكييف الهواء؛ كفاءة الطاقة؛ استدامة المباني؛ التحسين التشغيلي؛ الكويت.

1. Introduction

The heating, ventilation, and air conditioning (HVAC) industry plays a crucial role in ensuring comfortable and energy-efficient environments, particularly in regions with extreme temperatures like Kuwait. During Kuwait's extended summer season, air conditioning systems are responsible for nearly 70% of the country's electricity consumption from the power grid (Kulaib et al., 2021). With the rising demand for more energy-efficient, cost-effective, and sustainable solutions, Artificial Intelligence (AI) has emerged as a transformative technology that promises significant improvements in HVAC system optimization (Farzaneh et al., 2021). AI-powered HVAC systems play a crucial role in enhancing energy efficiency by dynamically optimizing their operations. Through intelligent algorithms, these systems adjust key parameters such as temperature settings, airflow rates, and fan speeds in response to occupancy patterns and ambient environmental factors. Additionally, they utilize external data inputs—like weather forecasts and real-time electricity pricing—to refine performance strategies that promote both economic and environmental sustainability (Sleem & Elhenawy, 2023). A prominent application is in demand response initiatives, where HVAC systems modify their energy consumption during peak periods to alleviate stress on the electrical grid. These systems continuously evolve by learning from operational data, thereby minimizing energy waste and reducing carbon emissions (Devaraj, 2023; Murdan, 2023).

AI can help streamline operations, enhance energy efficiency, reduce operational costs, and enable predictive maintenance. These advancements can substantially contribute to reducing the environmental impact of HVAC systems, which are notorious for high energy consumption, and improving their overall performance and reliability. Despite these benefits, the adoption of AI in HVAC systems remains limited, particularly in developing regions like Kuwait, where the integration of cutting-edge technologies often faces challenges.

Due to Kuwait's tropical desert climate—one of the hottest in the Arabian Peninsula—residential buildings consume substantial energy for cooling. This high usage is further intensified by government-subsidized electricity rates and the year-round reliance on air conditioning, which is driven by minimal seasonal temperature variation (Jaffar, Oreszczyn, & Raslan, 2019). HVAC systems are essential in managing the indoor climate of both residential and commercial buildings, making their optimization a top priority. However, the adoption of AI within the local HVAC industry has been slower than expected. Industry professionals, including HVAC engineers, facility managers, and maintenance supervisors, continue to face barriers such as high initial investment costs, lack of technical expertise, and resistance to technological change. These obstacles hinder the widespread implementation of AI-driven solutions, limiting their potential to enhance system performance and reduce downtime. Additionally, there is a gap in understanding how AI can predict HVAC system failures, optimize maintenance schedules, and improve overall operational efficiency. The integration of AI technologies into HVAC systems in Kuwait, therefore, requires a comprehensive examination of both the benefits and challenges that professionals encounter in this domain.

This study seeks to bridge these gaps by exploring the current state of AI adoption in HVAC systems within Kuwait, providing insights into how industry professionals perceive the role of AI in improving system performance, energy efficiency, and cost-effectiveness. By identifying the key challenges preventing AI adoption, such as financial, technical, and organizational barriers, the research aims to uncover actionable strategies that could facilitate wider implementation. Moreover, the study will examine the potential of AI in predicting system failures, reducing unexpected downtime, and optimizing maintenance schedules, which are crucial for enhancing the long-term reliability and sustainability of HVAC systems. Ultimately, this research will contribute to advancing knowledge in HVAC system optimization through AI and offer valuable guidance for policymakers, industry professionals, and technology providers in Kuwait.

2. Literature review

Numerous studies have explored the potential of Artificial Intelligence (AI) in optimizing HVAC system performance, reflecting a growing academic and industry interest in leveraging smart technologies to enhance energy efficiency, reduce operational costs, and improve indoor environmental quality. These investigations have examined various AI-driven approaches, ranging from predictive maintenance and real-time control to integration with renewable energy sources and smart building frameworks.

Parifard et al. (2025) explored the design and optimization of a sustainable geothermal-based system to supply utility services to a smart residential building in a coastal city in Iran. The study integrated a humidification-dehumidification (HDH) desalination system with a heat pump (HP) to meet the heating, cooling, and freshwater needs of a five-story residential building. Additionally, the electricity required by the building and its systems was provided by an organic Rankine cycle (ORC), which extracts heat from geothermal sources.

The research utilized EnergyPlus software to model energy consumption and ventilation requirements. The analysis was conducted from thermodynamic, exergy, and exergo-economic perspectives, identifying key parameters influencing first-law efficiency and the unit cost of purified water (UCPW). Using artificial intelligence (AI), the study optimized the system's performance through multi-objective optimization with a genetic algorithm. Results showed the optimal first-law efficiency and UCPW to be 46.66% and 4.49 US$/m^3, respectively, indicating the system's potential for sustainable energy and water management in smart buildings.

Devaraj (2023) discussed the transformative impact of integrating AI, the Internet of Things (IoT), and cloud computing into Heating, Ventilation, and Air Conditioning (HVAC) systems. The paper outlined how IoT-enabled sensors collect real-time data, which AI-driven algorithms use for predictive analytics and optimization, while cloud platforms offer scalable storage. This technological convergence enhances the energy efficiency and reliability of HVAC systems. The study also highlighted emerging trends such as the integration of HVAC systems within smart buildings and the use of renewable energy sources. Despite these advancements, challenges related to data security, standardization, and the initial investment required for implementation were noted. The paper recommended further research into overcoming these challenges to enable widespread adoption of AI-integrated HVAC systems in sustainable building practices.

Lee and Lee (2023) examined AI applications in energy-efficient HVAC systems, with a focus on the necessary hardware improvements to achieve significant energy savings. Through a systematic review, the study analyzed how AI-enabled HVAC systems can optimize energy consumption by controlling chillers, air-handling units, heating systems, and air conditioners. The authors highlighted that AI applications are often linked to specific hardware upgrades that are crucial for achieving energy efficiency. They recommended that further advancements in hardware and sensor technologies are needed to maximize the energy-saving potential of AI-equipped HVAC systems.

Ogundiran et al. (2024) presented a systematic review on the use of AI and machine learning (ML) in building energy management, specifically focusing on energy efficiency and indoor environmental quality (IEQ). The study identified key areas where AI is applied, including thermal comfort, energy consumption prediction, IAQ control, and anomaly detection. The paper emphasized the importance of AI in optimizing energy use without compromising IEQ. However, the authors also identified significant gaps in policy, real-life application scenarios, and the need for further studies on the integration of AI for visual and acoustic comfort. The review called for a more comprehensive approach to incorporating AI in buildings to address these gaps.

Ajayi et al. (2024) explored AI-driven solutions for decarbonizing buildings through predictive analytics and real-time energy monitoring. The study focused on optimizing building energy consumption using machine learning algorithms that dynamically adjust heating, ventilation, and air conditioning (HVAC) operations based on occupancy, weather patterns, and energy prices. The integration of renewable energy sources, such as solar and wind, was also examined, highlighting AI's role in managing clean energy use. The paper suggested that AI, combined with renewable energy, significantly reduces carbon emissions and improves overall energy sustainability. The authors noted challenges such as high implementation costs and data privacy issues, recommending a regulatory framework to facilitate AI adoption in building energy management.

Yayla et al. (2022) investigated the application of AI in developing an occupant-centric HVAC control system for multi-zone commercial buildings. Using real data from a shopping mall in Istanbul, the study employed artificial neural networks (ANN) to predict hourly occupancy and optimize HVAC operations accordingly. A sensor-free HVAC control algorithm was developed, and its performance was compared with traditional systems using IDA ICE simulation software. The results demonstrated that AI-based HVAC systems achieved at least 10% energy savings while providing better thermal comfort for occupants. The study recommended the use of AI in improving HVAC control mechanisms to support sustainable building operations.

Himeur et al. (2023) conducted a comprehensive survey on the applications of AI and big data analytics in building automation and management systems (BAMS). The review covered various AI-driven tasks, including load forecasting, water management, occupancy detection, and indoor environmental quality (IEQ) monitoring. The study found that AI technologies, particularly machine learning and digital twins, significantly enhance the efficiency and sustainability of buildings by providing real-time insights into building performance. However, challenges such as data privacy concerns and the need for advanced data processing systems were noted. The authors recommended further research into overcoming these barriers to improve the adoption of AI in BAMS.

Alshamrani et al. (2024) explored the use of an AI-based optimal control framework in smart buildings that integrated borehole thermal energy storage with wastewater heat recovery. The study developed a rule-based control strategy that utilizes wastewater heat for preheating ventilation air, combined with thermal energy storage for cooling. The AI-assisted optimization model was designed and tested using MATLAB and TRNSYS software. Results indicated that the system's efficiency and environmental performance were significantly better than traditional ventilation systems, reducing CO_2 emissions and energy costs. The study recommended the integration of such AI-based control frameworks in smart buildings to optimize energy use and minimize environmental impact.

A notable research gap in the integration of Artificial Intelligence (AI) in HVAC systems for sustainable building management lies in the insufficient exploration of real-world applications and the adaptation of AI-driven technologies to diverse building types and geographic conditions. While several studies have demonstrated the potential of AI in optimizing energy efficiency, predictive maintenance, and indoor environmental quality (IEQ) control, the research often lacks comprehensive analyses on the scalability, economic feasibility, and long-term effectiveness of these solutions in varying contexts, particularly in developing countries or areas with unique environmental challenges. Moreover, the lack of standardized frameworks for AI integration across HVAC systems and the limited examination of potential failures or limitations of AI technologies in these applications highlight the need for further research to address these practical barriers and improve the robustness and adaptability of AI-powered systems in real-world scenarios.

3. Methodology

3.1. Study Design

This study adopted a descriptive research design to investigate the current state of AI-based optimization in HVAC systems in Kuwait. This approach is suitable for exploring the extent of AI implementation and understanding the perspectives of HVAC industry professionals on AI's impact on energy efficiency, operational costs, system performance, and predictive maintenance. Data were gathered through a structured survey to ensure consistency and reliability in measuring the variables of interest.

3.2. Population and Sample

The target population for this study consists of HVAC industry professionals in Kuwait, specifically HVAC engineers, facility managers, and maintenance supervisors. A total of 203 participants were surveyed, providing a representative sample from the key professional roles within the industry. The sample includes a diverse group, with HVAC engineers making up the largest proportion (45.3%), followed by facility managers (35.0%) and maintenance supervisors (19.7%). The participants represent various company types, including HVAC service providers (38.4%), manufacturing/engineering firms (32.0%), and facility management companies (29.6%). This diverse sampling ensures that the data reflects a wide range of experiences, roles, and company perspectives. The sample size was chosen to ensure a robust dataset, allowing for meaningful analysis and generalizable results.

3.3. Study Tool

Data was collected using a structured questionnaire designed to capture both quantitative and qualitative data. The questionnaire includes a mix of Likert scale items, multiple-choice questions, and open-ended questions to provide a comprehensive understanding of the respondents' perspectives on AI adoption in HVAC systems. The Likert scale items were assessed the perceived benefits and challenges of AI adoption, the effectiveness of AI in predictive maintenance and system optimization, and the anticipated trends for AI adoption in the next five years.

3.4. Data Analysis

The data collected from the survey were analyzed using both descriptive and inferential statistical methods. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize the demographic characteristics of the sample and the respondents' perceptions of AI in HVAC systems. Likert scale responses were analyzed to determine the level of agreement or effectiveness, while percentages will be used to represent the distribution of responses for categorical questions. Inferential statistics, including independent samples t-tests, were employed to assess statistically significant differences in AI awareness across subgroups such as years of experience and company type. These analyses helped determine whether professional background influences awareness levels of AI applications in HVAC systems.

3.5. Time limit

The study was conducted over five months, from October 2024 to February 2025. This period encompassed the distribution of surveys, data collection, statistical analysis, and the formulation of recommendations.

4. Results

Table (1) represents the percentage-based distribution of how extensively AI is used in HVAC systems. The majority of participants reported moderate adoption (41.9%) of AI-based solutions in HVAC systems, suggesting that while AI has made inroads in the industry, its implementation is still not widespread. Around 30.5% of respondents indicated limited use of AI, while 12.3% of organizations have not yet adopted AI at all. The 15.2% of respondents who reported extensive adoption show that AI is beginning to make significant strides, though full integration is still in the early stages for many.

Table 1: Current Use of AI-Based HVAC Solutions

Current Use of AI in HVAC	No. (%)
Not at all	25 (12.3%)
Limited use in some areas	62 (30.5%)
Moderate adoption	85 (41.9%)
Extensive adoption across systems	31 (15.2%)

Table (2) shows the percentage-based reasons HVAC professionals adopt AI technology. The most common reason for adopting AI in HVAC systems is to improve energy efficiency (86.2%), followed closely by the potential for cost reduction (77.8%). Many participants also highlight predictive maintenance (70%) and enhanced system performance (79.3%) as key drivers for AI integration. Regulatory compliance plays a less significant role, with only 50.7% of respondents citing it as a reason. The relatively low percentage for "Other" (8.9%) suggests that the identified factors are primary drivers.

Table 2: Primary Reasons for Adopting AI in HVAC Systems

Reason for Adopting AI	No. (%)
Energy efficiency improvements	175 (86.2%)
Cost reduction	158 (77.8%)
Predictive maintenance	142 (70.0%)
Enhancing system performance	161 (79.3%)
Regulatory compliance	103 (50.7%)
Other	18 (8.9%)

Table (3) illustrates the percentage-based levels of awareness of AI applications in HVAC. The majority of respondents (46.8%) indicate a moderate awareness of AI applications in HVAC, suggesting that while some awareness exists, it is not fully widespread. A considerable portion also has a high (28.6%) or very high (5.9%) awareness of AI technology. However, 14.8% report low awareness, and only a small percentage (3.9%) report very low awareness, highlighting that there is still significant room for growth in terms of AI awareness across the industry.

Table 3: Awareness of AI Applications in HVAC

Awareness Level	No. (%)
Very Low	8 (3.9%)
Low	30 (14.8%)
Moderate	95 (46.8%)
High	58 (28.6%)
Very High	12 (5.9%)

Table (4) uses a Likert scale with mean and standard deviation to assess the perceived benefits of AI in HVAC systems. The responses suggest that AI in HVAC systems is seen as highly beneficial, with means ranging from 4.11 to 4.22, indicating strong agreement with all statements. Energy efficiency (mean of 4.18) and predictive maintenance (mean of 4.22) are particularly highlighted as key benefits. Operational cost reduction and system performance optimization also received high agreement, with a slightly lower mean of 4.12 and 4.15, respectively. These results reflect a positive perception of AI's impact on HVAC performance and efficiency.

Table 4: Perceived Benefits of AI in HVAC Systems

Statement	Mean	Standard Deviation	Level of Agreement
AI-based HVAC solutions significantly improve energy efficiency.	4.18	0.75	High
AI helps reduce operational costs in HVAC systems.	4.12	0.80	High
AI optimizes HVAC system performance by adjusting real-time parameters.	4.15	0.78	High

AI enables predictive maintenance, reducing unexpected failures.	4.22	0.72	High
AI-based HVAC systems enhance occupant comfort and indoor air quality.	4.11	0.77	High

Table (5) represents the percentage-based challenges preventing AI adoption. The high initial investment costs (73.9%) are the most significant barrier to AI adoption, closely followed by lack of technical expertise (66.5%). The resistance to change (56.7%) and compatibility issues (55.2%) with existing HVAC systems are also noted as substantial obstacles. Data privacy and security concerns (61.6%) were mentioned by a majority of respondents, indicating that companies are cautious about the implications of integrating AI into their systems. Only a small percentage (8.4%) cited other barriers, indicating that the primary concerns are well understood.

Table 5: Challenges Preventing AI Adoption in HVAC Systems

Challenges Preventing AI Adoption	No. (%)
High initial investment costs	150 (73.9%)
Lack of technical expertise	135 (66.5%)
Resistance to change	115 (56.7%)
Compatibility issues with existing systems	112 (55.2%)
Data privacy/security concerns	125 (61.6%)
Other	17 (8.4%)

Table (6) shows the percentage-based perception of AI effectiveness in predicting system failures. The majority of respondents find AI to be moderately effective (48.8%) in predicting HVAC system failures, with 25.1% rating it as very effective. However, a small group (3.9%) feel it is not effective at all, while 17.7% believe it is only slightly effective. These results suggest that while AI shows promise in failure prediction, its effectiveness may vary across different systems and organizations.

Table 6: Effectiveness of AI in Predicting HVAC System Failures

Effectiveness of AI in Predicting Failures	No. (%)
Not Effective	8 (3.9%)
Slightly Effective	36 (17.7%)
Moderately Effective	99 (48.8%)

Very Effective	51 (25.1%)
Extremely Effective	9 (4.4%)

Table (7) uses a Likert scale with mean and standard deviation. The results indicate that AI is considered highly effective in reducing HVAC system downtime (mean of 4.19) and unexpected failures (mean of 4.22). AI is also perceived as effective in optimizing maintenance schedules and costs (mean of 4.18). All statements received high agreement, with low variability in responses (standard deviations ranging from 0.73 to 0.75), suggesting that AI's potential in maintenance optimization is widely recognized.

Table 7: Effectiveness of AI in Maintenance and Failure Prediction

Statement	Mean	Standard Deviation	Level of Effectiveness
AI reduces HVAC system downtime.	4.19	0.74	High
AI-based predictive maintenance reduces unexpected failures.	4.22	0.73	High
AI helps optimize maintenance schedules and costs.	4.18	0.75	High

Table (8) is percentage-based, showing the expected trends for AI adoption in HVAC. The majority of respondents believe that AI adoption in HVAC will increase in the next 5 years, with 45.8% expecting a slight increase and 37% anticipating a significant increase. Only a small percentage of participants expect AI adoption to decrease (2%) or remain the same (15.2%). These responses reflect optimism regarding the growth of AI in the HVAC industry.

Table 8: AI Adoption Trends in the Next 5 Years

AI Adoption Trend	No. (%)
Decrease	4 (2.0%)
Remain the same	31 (15.2%)
Slightly increase	93 (45.8%)
Significantly increase	75 (37.0%)

Table (9) is percentage-based for improvements that could encourage AI adoption. A significant number of respondents believe that cost reduction (80.8%) is crucial to fostering AI adoption in HVAC systems.

Other important improvements include better training programs (69.4%) for professionals and improved integration with existing systems (73.9%). Security and data privacy (66.5%) are also key concerns, and government incentives or regulations (55.2%) are seen as helpful for encouraging broader AI adoption.

Table 9: Improvements Needed to Encourage AI Adoption in HVAC

Improvements Needed	No. (%)
Cost reduction of AI solutions	164 (80.8%)
Better training programs for industry professionals	141 (69.4%)
Improved integration with existing HVAC systems	150 (73.9%)
Enhanced security and data privacy measures	135 (66.5%)
Government incentives or regulations	112 (55.2%)

Table (10) presents the results of independent samples t-tests conducted to examine differences in AI awareness levels across subgroups based on years of experience and company type. AI awareness was measured using a 5-point Likert scale, where higher scores indicate greater awareness of AI applications in HVAC systems.

Participants with more than 10 years of experience reported the highest mean awareness score (M = 4.10, SD = 0.68), significantly higher than those with less than 5 years of experience (M = 2.60, SD = 0.85), t = 8.74, p = .000. Similarly, respondents with 5–10 years of experience (M = 3.30, SD = 0.74) also reported significantly greater awareness compared to the least experienced group, t = 4.52, p = .001. These findings suggest a strong positive relationship between professional experience and awareness of AI technologies in HVAC, indicating that industry familiarity may lead to increased exposure to or understanding of emerging technologies.

Respondents from HVAC service providers demonstrated the highest awareness levels (M = 4.20, SD = 0.66), significantly surpassing their counterparts in manufacturing/engineering firms (M = 3.10, SD = 0.88), t = 6.23, p = .000, and facility management companies (M = 3.40, SD = 0.79), t = 4.12, p = .001. This suggests that professionals working directly in HVAC service provision may have greater exposure to AI-enabled solutions, possibly due to their operational role in system deployment and maintenance.

Table 10: Independent Samples T-Test Results for Differences in AI Awareness by Years of Experience and Company Type

Category	Subcategory	Mean	Standard Deviation	T-Statistic	P-Value
Years of Experience	Less than 5 years	2.60	0.85	—	—
	More than 10 years	4.10	0.68	8.74	0.000**
	5–10 years	3.30	0.74	4.52	0.001**
Company Type	HVAC Service Provider	4.20	0.66	—	—
	Manufacturing/Engineering	3.10	0.88	6.23	0.000**
	Facility Management	3.40	0.79	4.12	0.001**

5. Discussion

The study reveals a moderately optimistic landscape for AI integration in HVAC systems within Kuwait. While 41.9% of respondents reported moderate adoption and only 15.2% noted extensive integration, awareness of AI applications was relatively high, suggesting potential for growth. These findings are consistent with prior research highlighting AI's transformative role in energy systems (Yayla et al., 2022; Himeur et al., 2023). The high perceived effectiveness of AI in improving energy efficiency, predictive maintenance, and operational optimization aligns with global trends in smart building technologies.

However, persistent barriers hinder full-scale implementation. High initial costs, lack of technical expertise, resistance to change, and data security concerns were frequently cited—echoing the concerns raised by Devaraj (2023) and Ajayi et al. (2024). Notably, the study found strong support for AI's role in predictive maintenance, with high agreement across respondents on its effectiveness in reducing system downtime and unexpected failures. The future outlook is promising, with over 80% of participants expecting AI adoption to increase significantly in the next five years.

These perceptions confirm that while technological readiness is growing, institutional and infrastructural challenges remain. Bridging the gap between perceived value and practical adoption requires targeted policy support, financial incentives, and greater technical training.

5.1. Theoretical and practical Implications

Theoretically, this study contributes to the emerging literature on AI applications in building and mechanical systems, specifically within high-demand environments such as Kuwait.

It enriches existing technology adoption frameworks by situating them in a context characterized by extreme climate conditions, emphasizing the role of environmental necessity in innovation diffusion.

Practically, the findings offer actionable guidance for stakeholders. Policymakers are encouraged to introduce subsidies and regulatory frameworks that reduce the financial burden of AI integration. HVAC companies should prioritize professional development programs to build internal technical capacity. Additionally, technology developers must focus on creating interoperable and scalable AI solutions that address regional infrastructural limitations. These combined efforts can significantly improve HVAC performance and sustainability.

5.2. Limitations

This research has several limitations. The study's scope was restricted to HVAC professionals in Kuwait, potentially limiting the generalizability of the findings to other geographic or economic contexts. The reliance on a descriptive survey design means that causal relationships between AI use and HVAC performance outcomes could not be established. Furthermore, self-reported data may be subject to biases, including overestimation or social desirability bias. Lastly, the study did not include technical performance evaluations of AI systems, which limits the ability to validate perceived effectiveness with objective data. Future research should incorporate longitudinal studies and experimental designs that assess real-time AI system performance, cost-benefit analysis, and comparative studies across regions or sectors.

6. Conclusion

This study demonstrates the growing recognition of Artificial Intelligence as a critical tool for optimizing HVAC system performance in Kuwait. AI's perceived benefits—such as energy savings, predictive maintenance, and improved operational efficiency—are widely acknowledged by industry professionals. However, practical barriers remain, particularly in terms of investment cost, technical readiness, and organizational resistance.

The findings suggest a need for a coordinated approach involving government policies, industry innovation, and workforce training to overcome these challenges. As the demand for energy-efficient and sustainable building systems continues to rise, AI-based solutions are well-positioned to transform HVAC operations in Kuwait and similar environments. Future research should focus on validating these perceptions through empirical data and exploring scalable, cost-effective models for AI integration.

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