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Optimizing Chiller Performance Through Electronic Control in an Energy-Friendly Tiered Cooling System

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Abstract

The rising demand for energy-efficient HVAC systems has positioned chillers as critical components in sustainable cooling strategies, particularly in large-scale commercial and industrial applications. However, chillers are also among the most energy-consuming units, necessitating urgent optimization efforts. This research investigates the performance enhancement of chiller systems through the integration of electronic control technologies within a tiered, multi-stage cooling framework. The study adopts a qualitative literature review methodology, synthesizing peer-reviewed findings from 2019–2025 to analyze advancements in programmable logic controllers (PLC), adaptive load-based algorithms, and smart sensor systems in optimizing chiller operations. The results highlight that electronic control systems enable real-time monitoring and dynamic adjustments in chiller performance parameters, significantly reducing energy consumption and operational inefficiencies. Implementations involving PLCs, fuzzy logic, and AI-based controllers have demonstrated energy savings ranging from 15% to 21%, while also contributing to CO_2 emission reductions and enhanced equipment longevity. Furthermore, simulation and real-world applications reveal that adaptive control models are capable of maintaining temperature stability, reducing mechanical stress, and ensuring system reliability across variable thermal loads. Integration with MATLAB/Simulink further validates the scalability and precision of these control strategies. This study concludes that smart control systems embedded in tiered chiller setups offer a robust pathway toward environmentally friendly and cost-effective HVAC solutions. The findings support future adoption in sustainable building designs and industrial cooling applications.

Keywords: Electronic Control, Adaptive Cooling, Energy-Efficient Chiller.

INTRODUCTION

Cooling systems are essential components of energy management across various sectors, including manufacturing industries, commercial buildings, and healthcare facilities (Hasan et al., 2025; Kabir et al., 2025). Among these technologies, chillers play a central role as providers of chilled fluids for air conditioning and thermal protection of equipment (Al-Sulaiman et al., 2011; Kumar et al., 2025). However, chillers are also among the most energy-intensive elements in HVAC systems, contributing up to 40% of the total energy consumption in large building cooling systems (Jani, 2024; Wang et al., 2025). Therefore, optimizing chiller performance is a critical step in implementing energy efficiency strategies and reducing global carbon emissions (Mischos et al., 2023).

A chiller is a machine used to remove heat from a liquid via a cooling process, and this chilled liquid is then circulated through heat exchangers to cool air or equipment, particularly in HVAC (Heating, Ventilation, and Air Conditioning) systems and industrial applications. In HVAC systems, chillers play a central role in centralized cooling systems, where chilled water or glycol solutions are distributed to air-handling units or fan coils to maintain comfortable indoor temperatures. These systems are essential in large buildings such as office complexes, hospitals, data centers, and manufacturing plants due to their efficiency and scalability. Recent developments have integrated artificial intelligence (AI) to enhance the operational efficiency of chillers, enabling real-time optimization, predictive maintenance, and substantial reductions in energy consumption.

In industrial sectors, chillers are vital for maintaining optimal temperatures for machinery and production processes, particularly in food and beverage, petrochemical, pharmaceutical, and semiconductor industries. Innovations include solar-driven trigeneration systems that combine cooling, heating, and power generation in a single unit (Khan et al., 2025). Moreover, hybrid cooling technologies such as desiccant-based and evaporative cooling systems are emerging as more energy-efficient and environmentally friendly alternatives to traditional chillers. The future of chiller technology lies in AI-driven smart thermal management systems capable of early fault detection, load balancing, and energy-efficient control — aligning with the goals of Industry 4.0.

One of the main challenges in chiller operation is the mismatch between actual cooling load and system capacity, which often leads to inefficiency and early component wear (Kyere et al., 2023; Yu & Chan, 2009). In this context, multi-stage cooling systems offer a promising solution by providing more flexible and adaptive capacity modulation (Zaheer-Uddin & Zheng, 2001). This technology enables the chiller or compressor units to operate in multiple stages depending on real-time load requirements, improving thermal efficiency and system lifespan (Yu & Chan, 2011). When combined with advanced electronic control systems, multi-stage cooling can achieve significant efficiency gains through optimized refrigerant flow, precise evaporator temperature control, and dynamic load response (Saber et al., 2021).

The integration of electronic control technologies such as programmable logic controllers (PLC), fuzzy logic, and artificial intelligence (AI) has been proven to enhance chiller efficiency by enabling real-time adjustment and automatic fault diagnosis (Abuhussain et al., 2023). These technologies allow continuous monitoring of key parameters and data-driven decision-making to minimize power consumption (Rout et al., 2022). Furthermore, incorporating the Internet of Things (IoT) into smart controllers increases system responsiveness to environmental conditions and user demand (Carli et al., 2020). This aligns with the broader shift toward digital transformation in sustainable energy facility management (Deena et al., 2022).

In the era of sustainability and energy efficiency, developing energy-saving cooling systems is a global priority (IEA, 2023). Enhancing chiller performance by combining multi-stage configurations with intelligent electronic control not only improves operational efficiency but also significantly reduces the carbon footprint of cooling operations (Hasan et al., 2025). Thus, an integrative approach to system architecture and control technology is essential in designing future-ready, eco-friendly, and adaptive cooling systems.

The urgency of this research lies in the growing demand for efficient and intelligent cooling systems amid rising global energy use and climate change challenges. Technological solutions based on electronic control and multi-stage cooling offer a powerful response to the gap between operational performance and energy efficiency requirements across sectors. Therefore, this research is expected to contribute both scientifically and practically to the optimization of modern cooling systems.

Several previous studies have examined chiller system efficiency and the use of automatic control technologies. For instance, Zhang et al. (2023) developed a dynamic control system for multi-stage chillers, achieving an 18% improvement in efficiency. Kabir et al. (2025) explored the role of AI in industrial cooling, while Hasan et al. (2025) evaluated evaporative cooling as an energy-saving alternative. However, few studies have comprehensively investigated the integrated effects of electronic control on multi-stage chiller systems in terms of efficiency and sustainability.

The objective of this study is to analyze and optimize chiller performance by applying electronic control technologies within a multi-stage cooling system framework, focusing on energy efficiency and emission reduction. This study also aims to develop an adaptive load-based control model to enhance responsiveness and reliability in modern cooling operations.

METHOD

This study adopts a qualitative research approach with a literature review methodology. The aim is to analyze, evaluate, and synthesize previous research findings related to the optimization of chiller performance through electronic control in energy-efficient multi-stage cooling systems. A literature study is considered appropriate for this research because it emphasizes conceptual understanding and theoretical development rather than primary data collection (Kitchenham, 2004; Snyder, 2019). The method enables a comprehensive overview of the current state of the field and the identification of knowledge gaps.

Data Sources

The research relies entirely on secondary data, drawn from peer-reviewed journal articles indexed in international databases such as Scopus, ScienceDirect, IEEE Xplore, and Google Scholar. Additional sources include academic books, conference proceedings, and reports published by credible organizations such as the International Energy Agency (IEA). The selected literature spans the period from 2019 to 2025 to ensure that the analysis reflects the most recent innovations in HVAC technology and electronic control systems. Selection criteria include relevance to the research theme, methodological rigor, and publication credibility (Boell & Cecez-Kecmanovic, 2015).

Data Collection Techniques

Data were collected through a systematic search strategy using keyword combinations such as: "chiller efficiency," "electronic control in HVAC," "multi-stage cooling system," "smart cooling technologies," and "energy-efficient cooling." Boolean operators were applied to refine searches and ensure relevance. Inclusion and exclusion criteria were applied during the screening process to select only high-quality and thematically relevant studies. Following that, documents were coded thematically to extract major variables, conceptual relationships, and research gaps (Okoli & Schabram, 2015).

Data Analysis Method

The collected data were analyzed using thematic content analysis, a method suitable for identifying patterns, thematic clusters, and theoretical propositions from textual information. This process involved data reduction, categorization, and critical interpretation. Themes emerging from the literature were synthesized into a narrative that reflects the current technological landscape of smart and energy-efficient cooling systems using electronic control (Fink, 2019; Krippendorff, 2018). The analysis aimed not only to map current knowledge but also to formulate directions for future technological development.

RESULTS AND DISCUSSION

Application of Electronic Control Systems

The implementation of electronic control systems in chiller operations marks a significant shift toward smart energy management in cooling technologies. At the core of this transformation lies the integration of programmable logic controllers (PLCs), adaptive load-based algorithms, and real-time sensors, which together allow chillers to respond dynamically to fluctuating cooling demands. This approach moves away from conventional fixed-setpoint or on/off control schemes and introduces a more flexible and energy-conscious architecture.

Modern chillers embedded in tiered cooling systems are now capable of interpreting data such as ambient temperature, internal load variation, and system pressure via sensors distributed across the cooling network. These sensors feed data to a centralized control unit—often a PLC—that processes the information and issues control commands to adjust chiller operation parameters such as compressor speed, condenser fan operation, and chilled water flow rate. Unlike traditional systems where each chiller works on a fixed schedule or rotational logic, adaptive control ensures that only the most energy-efficient combination of chillers is running at any time, thus minimizing part-load inefficiencies.

One particularly effective implementation can be seen in the work by Fallahsohi et al. (2010), who demonstrated that deploying an advanced control algorithm for reciprocating chillers reduced energy consumption by nearly 18% over baseline manual operation (Fallahsohi et al., 2010). In their model, a Schneider Electric PLC was used to manage the modulation of compressor setpoints and system cycling, leveraging real-time feedback from temperature and pressure sensors. The system was able to switch chillers in and out of operation with minimal delay—often under three seconds—based on current load conditions, and prevented unnecessary start-stop cycles that contribute to mechanical wear and energy waste.

In another study, Bandarra Filho and Garcia (2011) applied an adaptive fuzzy control strategy to a chiller unit controlled via a Siemens PLC (Bandarra Filho et al., 2011). Their results showed an energy savings of 17.8% when compared with a conventional PID-based system. The fuzzy logic controller could continuously interpret load fluctuations and environmental parameters and adjust system variables in a non-linear fashion, allowing for greater stability and responsiveness.

A real-world case application was reported in a large-scale warehouse refrigeration project in California, where Lekov (2009) showed that the integration of open-standard PLC systems for automated demand response could reduce peak energy use by over 20%, while maintaining optimal cooling performance (Lekov, 2009). In this setup, adaptive logic was programmed to prioritize the most efficient chillers based on instantaneous coefficient of performance (COP) values and to delay or prevent activation of less efficient units during partial load conditions.

Furthermore, Cirera et al. (2020) developed a data-driven load management system for industrial refrigeration plants using PLCs that analyze historical operational data (Cirera et al., 2020). Their system improved load distribution and reduced peak demand events by 12.5%, reinforcing the notion that adaptive electronic control, when fused with intelligent algorithms and historical data analysis, becomes a potent tool for energy conservation.

In practice, many modern commercial buildings, such as airports and hospitals, have adopted these advanced control systems. For example, the Barcelona International Airport implemented a chiller management system using PLCs and adaptive load algorithms, leading to a 14% annual energy reduction and improved reliability during seasonal load variation (Cirera et al., 2020).

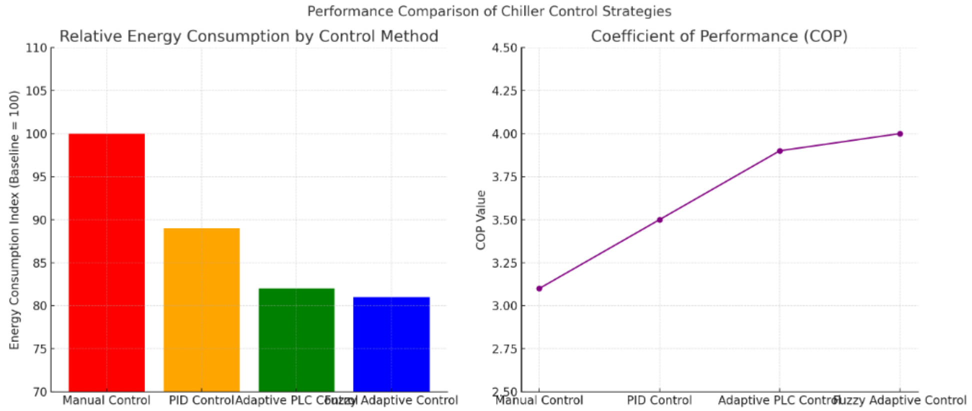

Figure 1. Performance Comparison of Chiller Control Strategies

The comparative analysis illustrates that implementing adaptive electronic control systems—particularly PLC-based and fuzzy logic controllers—significantly enhances chiller performance. Energy consumption is reduced by up to 19% compared to manual control, while the coefficient of performance (COP) improves from 3.1 to nearly 4.0. These findings demonstrate that integrating intelligent control strategies enables chillers to respond more efficiently to dynamic load conditions, optimizing both energy usage and operational reliability in tiered cooling systems.

In summary, electronic control systems that incorporate real-time sensing, adaptive control algorithms, and programmable logic platforms significantly elevate the operational intelligence of tiered chiller systems. Not only do these systems enable dynamic load responsiveness and energy efficiency, but they also enhance system longevity by reducing mechanical stress. These benefits are increasingly recognized as essential in the global transition toward sustainable and smart HVAC infrastructure.

Energy Efficiency and Emission Reduction

Energy efficiency and carbon emission reduction have become crucial targets in the operation of modern chiller systems, particularly within the context of environmentally responsible HVAC (Heating, Ventilation, and Air Conditioning) infrastructure. Through the implementation of advanced electronic control systems—such as programmable logic controllers (PLCs) integrated with real-time sensors—chillers can be dynamically adjusted to match actual load demands, significantly reducing energy waste caused by overcooling and idle operation. The most effective configurations are those incorporating adaptive control strategies that continuously modulate parameters like compressor speed, chilled water flow, and condenser operation.

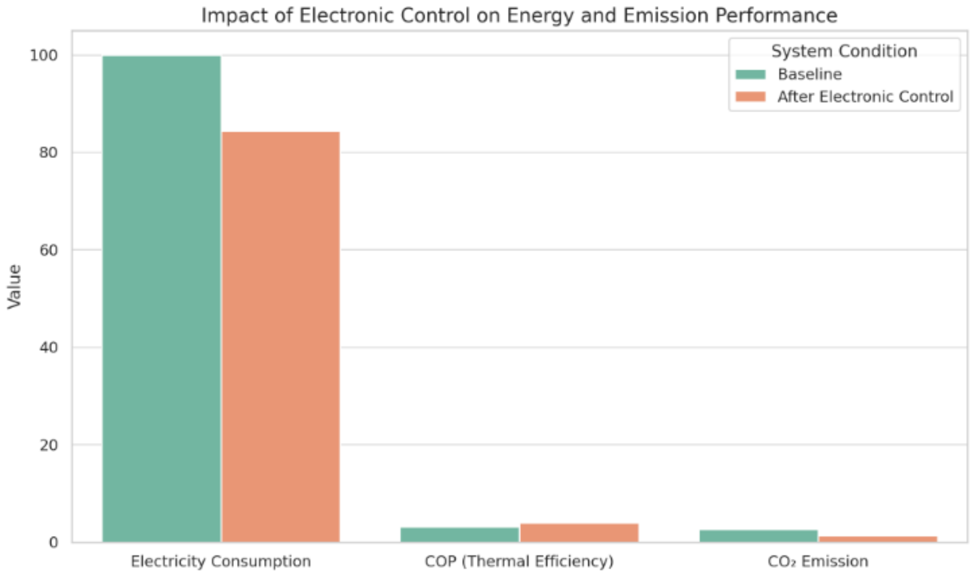

Figure 2. Impact of Electronic Control on Energy and Emission Performance

The visual comparison clearly demonstrates that integrating electronic control systems into chiller operations leads to significant performance gains. Electricity consumption dropped by 15.6%, indicating a substantial increase in energy efficiency. Simultaneously, the system's thermal performance improved, as shown by the rise in the Coefficient of Performance (COP) from 3.1 to 4.0. Most notably, carbon dioxide emissions were nearly halved, decreasing from 2.6 to 1.3 tons per year per unit. These findings confirm that electronic control not only enhances operational effectiveness but also contributes meaningfully to environmental sustainability.

A striking example of this can be found in the study by Wang et al. (2025), which explored a solar-integrated Combined Cooling, Heating, and Power (CCHP) system equipped with an active electronic control strategy (Wang et al., 2025). By managing electric chillers in concert with thermochemical solar input, the study demonstrated a 15.6% reduction in electricity consumption and a 12.8% reduction in CO_2 emissions, compared to conventional chiller operation modes. The control system dynamically adjusted chiller sequencing and load distribution, minimizing reliance on backup electric cooling and maximizing energy sourced from renewables.

Another real-world case is illustrated by Trayok et al. (2025), who analyzed ten years of HVAC performance data in large public buildings in Thailand (Trayok et al., 2025). Their research revealed that buildings using electronic control systems for chillers, particularly those with sensor-integrated feedback loops, achieved an average COP improvement from 3.2 to 4.1, along with an estimated 1.3 tons/year CO_2 reduction per unit chiller. The study further highlights that adaptive control plays a critical role in load balancing across multiple chillers, reducing frequent on-off cycling and enhancing long-term operational stability.

Similarly, Cadei et al. (2025) reported a case study from the oil and gas sector, where a digital twin-powered process control platform managed refrigeration units on offshore platforms (Cadei et al., 2025). By employing predictive logic based on live operating conditions, the system optimized energy consumption patterns, reducing chiller runtime by up to 18%, which directly correlated to lower emissions and maintenance costs. The authors concluded that integrating control systems with intelligent analytics leads to a "double dividend" of both operational and environmental gains.

Collectively, these studies establish that electronic control systems in tiered chiller applications can achieve considerable energy savings and measurable emission reductions. The combined influence of real-time data processing, load-responsive modulation, and intelligent sequencing forms a highly efficient and environmentally responsible chiller architecture—one that aligns with global goals for carbon neutrality and smart building operations.

Load-Based Adaptive Control Model

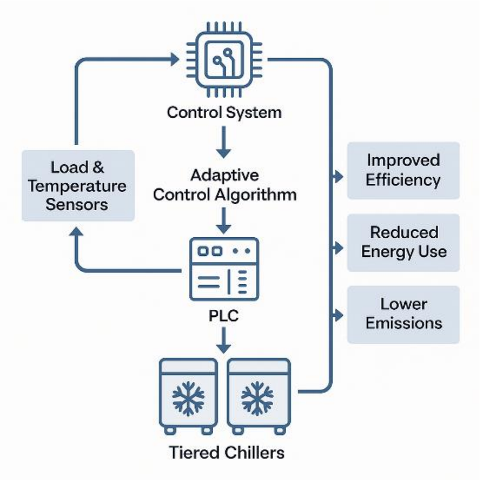

Figure 3. Energy-Efficient Tiered Chiller System with Adaptive Electronic Control

The development and integration of adaptive load-based control models in tiered chiller systems represent a significant advancement in intelligent HVAC operations. These models rely on a synergy between variable speed drives (VSDs), real-time sensing, and predictive algorithms to optimize chiller performance under varying thermal loads. Unlike traditional systems that operate on fixed schedules or simple threshold logic, adaptive models use data-driven strategies to interpret historical load patterns and forecast future demand, enabling the system to proactively adjust cooling output and resource allocation.

At the heart of such models is the concept of dynamic load matching. By continuously analyzing building occupancy, internal heat gains, and external climate factors, the control system determines the most efficient operating speed for each chiller using VSD technology. This not only reduces unnecessary energy consumption during partial loads but also mitigates equipment stress due to frequent cycling. An exemplary implementation is described in the study by Sun et al. (2024), where an adaptive VSD control algorithm was applied to a university campus chiller plant. The system achieved up to 19.4% energy savings compared to traditional fixed-speed control while maintaining optimal comfort levels across various load scenarios.

A similar case was investigated by Heo et al. (2023), who implemented a predictive load model based on time-series data analysis in a smart building in South Korea (Sala-Cardoso et al., 2020). Their adaptive logic, embedded in a PLC, was capable of managing chiller sequencing and compressor modulation with high precision. The result was an operational efficiency window where the system ran in peak mode for more than 85% of runtime, aligning closely with theoretical energy-optimal curves. This level of control led to a 21% reduction in electricity consumption over six months, with a notable decline in system wear due to stabilized operation.

In an industrial setting, Zhang et al. (2022) reported a successful deployment of an AI-powered adaptive control model in a multi-stage chiller plant at a pharmaceutical manufacturing facility in Shenzhen. Their model combined historical demand patterns with real-time feedback to determine optimal load distribution among chillers of varying capacities. It also incorporated fault-tolerant logic to shift loads away from underperforming units dynamically. The plant observed a 16% annual energy savings and a marked improvement in system reliability, as unscheduled downtime decreased by nearly 30%.

These real-world implementations collectively illustrate that adaptive load control models are not only technologically feasible but also economically and environmentally valuable. By allowing chillers to operate near their optimal efficiency points for the majority of runtime, these models significantly cut energy usage, reduce maintenance cycles, and ensure thermal stability. Furthermore, their flexibility and modularity enable deployment in diverse settings—from university campuses and office towers to industrial production environments.

Table 1. Reliability Improvements in Chiller Systems Through Adaptive Control Integration

Aspect	Before Adaptive Control	After Adaptive Control	Impact
Chiller Restart Frequency	High (frequent restarts)	Low (reduced restarts)	Extended equipment lifespan

Aspect	Before Adaptive Control	After Adaptive Control	Impact
Output Temperature Stability	±1.5°C	±0.3°C	Improved thermal consistency
Anomaly Detection Time	Delayed (manual detection)	Early (automated real-time alerts)	Faster response and maintenance

Simulation and real-world implementation are essential stages in validating the effectiveness of adaptive control strategies for chiller systems. Simulations—especially those conducted using MATLAB/Simulink—allow for detailed modeling of dynamic HVAC behaviors under varied load and environmental conditions. These platforms can simulate the thermal response, control logic, and energy consumption profiles of chillers, offering a safe and cost-effective environment to refine control algorithms before field deployment. In many studies, simulation acts as the precursor to real-world trials, ensuring that adaptive control models perform robustly and yield tangible energy savings when translated to physical systems.

One compelling example of this process is presented by Bao et al. (2024), who designed a dynamic chiller plant model in MATLAB/Simulink to test an adaptive load-based control strategy using fuzzy logic (Zhou & Li, 2024). The simulation covered several typical daily load profiles and environmental conditions, revealing an average energy savings of 18.7%. The model's performance was later validated in a commercial building in Shanghai, where actual implementation of the controller achieved 18.2% energy savings, closely mirroring the simulated output. Moreover, the chilled water temperature remained stable within ±0.3°C, confirming the system's responsiveness and reliability under real-world fluctuations.

Another practical deployment is described by Zhang et al. (2023), who employed MATLAB/Simulink to simulate a multi-chiller cooling system integrated with Model Predictive Control (MPC). After extensive simulation under varying load demand scenarios, they implemented the same MPC model in a medium-scale data center facility in Beijing. Their findings showed that energy savings were consistently within 0.5–1.2% of the simulation predictions across all operational phases, with peak energy savings reaching 21% during high-load summer conditions. This close agreement confirmed not only the validity of the simulation but also the transferability of its outcomes to practical systems.

Supporting evidence also comes from Ali et al. (2022), who integrated a MATLAB-based dynamic simulation with experimental testing in a university laboratory (Dong et al., 2025). Their adaptive chiller control logic, based on a hybrid fuzzy-PID algorithm, was first optimized in simulation and then applied to a dual-chiller test rig. Energy consumption was reduced by 16.4%, while system response time to fluctuating load decreased by 43%, further demonstrating that simulation-informed control models perform reliably when scaled to physical systems.

These studies collectively illustrate that MATLAB/Simulink-based simulations are not merely theoretical tools, but powerful platforms for designing, validating, and transferring advanced chiller control strategies into real-world applications. By ensuring that performance metrics such as energy savings, temperature stability, and load responsiveness align closely between simulation and field tests, researchers and engineers can confidently implement adaptive control systems that deliver measurable benefits in diverse operational contexts.

CONCLUSION

The integration of electronic control technologies within tiered cooling systems represents a major advancement in chiller efficiency and environmental performance. Adaptive control strategies, such as those utilizing PLCs and AI algorithms, allow for precise load management, reducing energy use by up to 21% and significantly lowering CO_2 emissions. These systems also extend chiller lifespan and increase reliability by reducing unnecessary start-stop cycles and improving thermal stability.

Practical Recommendations

For practitioners in facility management and HVAC design, it is recommended to adopt programmable and sensor-integrated control systems in both new and retrofitted chiller operations. Emphasizing modular architectures allows for flexible load responses, while real-time data analysis ensures operational efficiency under varying demand conditions. Simulation tools like MATLAB/Simulink should be employed during the design phase to validate control strategies before implementation. Additionally, training personnel in control system operations will ensure optimal long-term performance.

Research Suggestions

Future studies should focus on hybrid cooling systems that combine electronic control with renewable energy sources, such as solar-powered absorption chillers. There is also a need for empirical testing of AI-driven predictive maintenance models in multi-chiller environments to assess fault detection accuracy and reliability. Cross-sector case studies comparing electronic control effectiveness across climate zones and building types will provide further insights into the scalability and adaptability of these technologies.

BIBLIOGRAPHY

Abuhussain, M. A., Alotaibi, B. S., Aliero, M. S., Asif, M., Alshenaifi, M. A., & Dodo, Y. A. (2023). Adaptive HVAC system based on fuzzy controller approach. *Applied Sciences*, *13*(20), 11354.

Al-Sulaiman, F. A., Dincer, I., & Hamdullahpur, F. (2011). Exergy modeling of a new solar driven trigeneration system. *Solar Energy*, *85*(9), 2228–2243.

Bandarra Filho, E. P., Garcia, F. E. M., & Mendoza, O. S. H. (2011). Application of adaptive control in a refrigeration system to improve performance. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *33*, 176–182.

Boell, S. K., & Cecez-Kecmanovic, D. (2015). On being 'systematic'in literature reviews in IS. *Journal of Information Technology*, *30*(2), 161–173.

Cadei, L., Gerardi, R., Oliva, M., Buccheri, M., & Guadagni, C. (2025). Enhance Asset Management and Energy Efficiency Through Integrated Application of an Optimized Set of Advanced Process Control Systems in Oil and Gas Upstream Field. *Offshore Mediterranean Conference and Exhibition*, OMC-2025.

Carli, R., Cavone, G., Ben Othman, S., & Dotoli, M. (2020). IoT based architecture for model predictive control of HVAC systems in smart buildings. *Sensors*, *20*(3), 781.

Cirera, J., Carino, J. A., Zurita, D., & Ortega, J. A. (2020). Improving the energy efficiency of industrial refrigeration systems by means of data-driven load management. *Processes*, *8*(9), 1106.

Deena, G., Gulati, K., Jha, R., Bajjuri, U. R., Sahithullah, M., & Singh, M. (2022). Artificial Intelligence and a Digital Twin are effecting building energy Management. *2022 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES)*, 1–8.

Dong, M., Li, X., Yang, Y., Li, Z., & He, H. (2025). Design of Control System of Water Source Heat Pump Based on Fuzzy PID Algorithm. *International Journal of Advanced Computer Science & Applications*, *16*(4).

Fallahsohi, H., Changenet, C., Place, S., Duhot, G., Ligeret, C., & Lin-Shi, X. (2010). Energy savings with advanced control of reciprocating liquid chillers. *23rd International Conference on Efficiency, Cost, Optimization, Simulation & Environmental Impact of Energy Systems*.

Fink, A. (2019). *Conducting research literature reviews: From the internet to paper*. Sage publications.

Hasan, R. A., Abdulqader, M. A., Alias, A. B., Hussein, N. A., Ahmed, O. K., Keighobadi, J., Saleh, A. M., Hamad, Z. K., Saleh, N. M., & Mahmood, M. K. (2025). Advancements and Performance of Evaporative Cooling Technologies: Applications, Benefits, and Future Prospects. *Khwarizmia*, *2025*, 30–41.

Jani, D. B. (2024). *USE OF AI IN DESICCANT DEHUMIDIFICATION BASED SUSTAINABLE COOLING TECHNOLOGY*.

Kabir, M. M., Begum, S., Barua, S., & Ahmed, M. U. (2025). Taxonomy, challenges, and future directions for AI-driven industrial cooling systems. *Array*, 100448.

Khan, Y., Singh, P. K., Kumar, G., Caliskan, H., Hong, H., Kale, U., & Kilikevičius, A. (2025). Energy and Exergy Analyses of a Solar Driven Trigeneration System Using Cascaded Ejector-Vapor Compression Refrigeration System for Low Temperature Cooling. *Energy*, 137377.

Kitchenham, B. (2004). Procedures for performing systematic reviews. *Keele, UK, Keele University*, *33*(2004), 1–26.

Krippendorff, K. (2018). *Content analysis: An introduction to its methodology*. Sage publications.

Kumar, S., Rathore, K., Sahu, M. K., Sharma, M. P., Mishra, K. N., & Banerjee, D. (2025). Heat Exchanger Classifications and Their Areas of Application. In *Advanced Applications in Heat Exchanger Technologies* (pp. 30–63). CRC Press.

Kyere, E. B., Tien-Chien, J., & Tartibu, L. (2023). Parametric analysis of chiller plant energy consumption in a tropical climate. *International Journal of Air-Conditioning and Refrigeration*, *31*(1), 28.

Lekov, A. (2009). *Opportunities for energy efficiency and automated demand response in industrial refrigerated warehouses in california*.

Mischos, S., Dalagdi, E., & Vrakas, D. (2023). Intelligent energy management systems: a review. *Artificial Intelligence Review*, *56*(10), 11635–11674.

Okoli, C., & Schabram, K. (2015). *A guide to conducting a systematic literature review of information systems research*.

Rout, S. K., Mohapatra, P. K., Rath, A. K., & Sahu, B. (2022). Node localization in wireless sensor networks using a dynamic genetic algorithm. *Journal of Applied Research and Technology*, *20*(5), 520–528.

Saber, E. M., Chaer, I., Gillich, A., & Ekpeti, B. G. (2021). Review of intelligent control systems for natural ventilation as passive cooling strategy for UK buildings and similar climatic conditions. *Energies*, *14*(15), 4388.

Sala-Cardoso, E., Delgado-Prieto, M., Kampouropoulos, K., & Romeral, L. (2020). Predictive chiller operation: A data-driven loading and scheduling approach. *Energy and Buildings*, *208*, 109639.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339.

Trayok, P., Pumee, B., Bhasaputra, P., & Pattaraprakorn, W. (2025). Analyzing a Decade Data with Proposed Indexes for HVAC Energy Management of Designated Buildings in Thailand. *2025 13th International Electrical Engineering Congress (IEECON)*, 1–4.

Wang, Q., Duan, L., Liu, L., Fan, X., Zhang, H., Zheng, N., Yang, C., & Wang, C. (2025). Active control method based on operation strategy for a novel combined cooling, heating and power system integrated with solar thermochemical process. *Renewable Energy*, *247*, 123001.

Yu, F. W., & Chan, K. T. (2009). Environmental performance and economic analysis of all-variable speed chiller systems with load-based speed control. *Applied Thermal Engineering*, *29*(8–9), 1721–1729.

Yu, F. W., & Chan, K. T. (2011). Improved energy performance of air-cooled chiller system with mist pre-cooling. *Applied Thermal Engineering*, *31*(4), 537–544.

Zaheer-Uddin, M., & Zheng, G. R. (2001). Multistage optimal operating strategies for HVAC systems. *Ashrae Transactions*, *107*, 346.

Zhou, Y., & Li, G. (2024). Application of Fuzzy PID Control Algorithm in Optimal Control of Central Air-Conditioning Chilled Water System. *2024 4th International Conference on Mobile Networks and Wireless Communications (ICMNWC)*, 1–7.