The Use of Artificial Intelligence in Building Energy Management Control Systems

November 2025

Note: This brief was written by ACEEE Senior Research Manager Rohini Srivastava. It is based on research conducted for the Industrial Technology Research Institute in Taiwan. Copyright Energy Administration, Taiwan.

Abstract

Building energy management and control systems (BEMCS) can provide energy services tailored to diverse user behaviors and changing environmental conditions by regulating heating, ventilation, air-conditioning, lighting, and energy consumption in buildings, but this often means that energy use within buildings is not fully optimized. Artificial intelligence (AI) is transforming BEMCS, making them more intelligent, adaptive, and efficient. Within the buildings sector, the application of AI, particularly in machine learning and automation, is becoming established. AI has shown its potential to improve energy efficiency in large buildings, particularly through enhancing energy audits, modeling changes in energy demand under different scenarios, and optimizing HVAC systems. AI-driven BEMCS use advanced analytics, predictive modeling, and automation to optimize building operations. By analyzing building data, AI-integrated BEMCS identify patterns and anomalies that traditional systems might miss, allowing dynamic responses to environmental changes, optimizing energy use, and enhancing safety. As additional use cases develop, AI is anticipated to play a crucial role in fostering innovation within the building industry and helping to achieve sustainability goals.

Integrating AI in BEMCS benefits various stakeholders. Building occupants gain optimized comfort, real-time sustainability data, and lower energy costs due to reduced waste. Owners and operators benefit from reduced expenses, lower carbon emissions, and improved comfort via load-shifting, with the potential to offset upgrade costs by marketing flexible loads. For grid operators, intelligent systems provide reliable flexible demand, aiding supply-demand balance as renewables increase. Documented advantages include 8–19% annual onsite energy savings and up to 40% carbon reduction through efficiency measures. While AI shows promise, it faces challenges such as funding limitations, complexities in implementation, data quality and accurate decision-making reliability, and interoperability hurdles.

Introduction

Commercial buildings are complex, with occupants who have varying behaviors and needs. Building energy management and control systems (BEMCS) can provide energy services tailored to diverse user behaviors and changing environmental conditions by regulating heating, ventilation, air-conditioning, lighting, and energy consumption in buildings, but this often means that energy use within buildings is not fully optimized. Artificial intelligence (AI) is transforming BEMCS, making them more intelligent, adaptive, and efficient.

The application of AI, particularly in machine learning and automation, is becoming established within the buildings sector (Esram 2024). AI has shown its potential to improve energy efficiency in large buildings, particularly through enhancing energy audits, modeling changes in energy demand under different scenarios, and optimizing heating, ventilating and air-conditioning system (HVAC) systems (Chow 2024). AI-driven BEMCS use advanced analytics, predictive modeling, and automation to optimize building operations. By analyzing building data, AI-integrated BEMCS identify patterns and anomalies that traditional systems might miss, allowing dynamic responses to environmental changes, optimizing energy use, and enhancing safety. However, challenges exist in combining AI into BEMCS including complexities in implementation, data quality, and accurate decision-making.

This paper explores AI integration in BEMCS across four areas: predictive analytics to optimize energy use based on data like weather and occupancy; fault detection and maintenance to identify inefficiencies and predict equipment issues; system optimization for improving performance through renewable integration and grid interaction; and human interaction, which is a newer focus using large language models to address behavioral, communication, and training challenges. While the first three areas are partially implemented through machine learning, AI can enhance accuracy and efficiency. The fourth area represents an emerging opportunity.

AI integration with BEMCS

AI is enabling owners and facility managers to make more informed, data-driven decisions for energy upgrades, while managing uncertainties related to cost effectiveness. Recent advances in AI now make it computationally feasible to generate digital twin models of buildings and produce detailed forecasts, including building-level simulations and hourly load shapes to optimize energy performance and keep the models up to date. Real-time data are used to train the AI model to provide insights into how much energy is being used and where, how much is being dispatched and when, and how much needs to be made available in the future. In this section we discuss how AI is being integrated with BEMCS across four areas—predictive analysis, fault detection and maintenance, renewable integration and utility grid interaction, and enhanced human interactions—to make buildings smarter and more efficient.

Predictive analytics to optimize energy use

AI-enabled BEMCS can integrate real-time and historical data from sensors, weather forecasts, energy systems, and occupancy patterns to predict energy demand and optimize energy consumption. By analyzing the data at a granular level, AI-enabled BEMCS can identify inefficiencies and automatically adjust HVAC settings based on occupancy and weather, turn off heating or cooling in unoccupied rooms, and reduce energy use during peak pricing periods, which can lead to significant energy and cost savings (Khan et al. 2025; Dong et al. 2023). For example, implementing AI to optimize a building's existing HVAC equipment can result in energy savings of over 30% of total HVAC energy consumption (BrainBox AI 2024; Evans and Gao 2016). While minimizing the environmental footprint and operational expenses, it also reduces occupant complaints, equipment alarms, and the frequency of periodic recommissioning.

The AI-algorithm can change based on the data it receives, allowing the BEMCS to make predictions for the building's energy use in advance based on the experiences in the past (Le et al. 2024; IEA 2019). This enables facility managers to proactively manage energy use, identify inefficiencies, and make improvements, supporting a more informed, data-driven strategy for implementing energy upgrades. Appendix A includes a list of products from companies such as Trane, Schneider Electric, Johnson Controls, Honeywell, and Siemens that are currently on the market. The list is expected to grow as more companies incorporate AI into their BEMCS.

To automate equipment control and achieve significant improvements in energy consumption and indoor air quality, certain AI algorithms leverage machine learning and energy modeling to create digital twins of the buildings (Zhao et al. 2025). These digital twins analyze operational patterns to understand how energy is used in the building, forecast future states, and evaluate the effects of various energy technologies, thereby identifying opportunities for energy optimization and addressing occupant comfort concerns (Aketi, Bozorgi, and Khan 2025). By simulating building energy demand under various scenarios, these models inform data-driven investments for individual buildings or entire portfolios, enabling owners to pursue decarbonization goals more effectively.

Table 1 presents use cases illustrating how AI integration within BEMCS enables effective energy management.

Table 1. Application of AI in predictive analytics function in BEMCS

Capabilities	Role of AI algorithms
HVAC control	Dynamically adjust HVAC systems to optimize comfort and minimize energy use.
Equipment scheduling	Schedule and adjust equipment like lighting, HVAC, elevators, and pumps in real time to run only when needed.
Occupancy detection	Use sensor data (e.g., motion, CO_2 levels) to adapt operations in real time to room or building occupancy.
Predictive analytics and demand forecasting	Machine learning algorithms forecast energy consumption based on weather, building occupancy, historical data, and other factors to adjust HVAC settings in real time.
Pattern recognition	Analyze occupant behavior to suggest energy-saving habits or automate adjustments. AI analyzes real-time data from sensors, smart meters, weather forecasts, and occupancy patterns to optimize energy use in buildings. This allows for dynamic adjustments of systems like HVAC, lighting, and ventilation, reducing unnecessary energy consumption and costs while maintaining occupant comfort.
Personalized comfort	Smart controls can learn individual or group preferences and adjust environments accordingly. Using building performance data, AI energy management systems can equip facility managers to adjust setpoints or schedules to maximize efficiency and comfort.

Fault detection and maintenance

By analyzing data from HVAC sensors and a building's existing energy management and control systems, AI algorithms can detect inefficiencies, predict equipment failure before it occurs, and schedule maintenance based on vibration, temperature, and power consumption patterns (Chen et al. 2023). AI is helping to build condition assessments by enabling more efficient and accurate analysis of building components and sensor data in real time. Facility managers and building maintenance staff can receive early warning notification when HVAC equipment like pumps, compressors, or chillers show signs of inefficiency or operate outside of normal parameters (Ali, Motuziene, and Džiugaitė-Tumėnienė 2024; IBM 2018). This helps reduce downtime by allowing for timely repairs or scheduling maintenance during off-peak hours to avoid disruptions and extend asset life by preventing major failures by addressing minor issues before they become worse.

Traditional facilities maintenance is manual and reactive, and it relies on scheduled inspections, which may miss potential equipment failures. AI algorithms can analyze sensor data and enable facilities management to become almost predictive. AI models leverage machine-learning modules to refine anomaly detection, predict when a piece of equipment is likely to fail or operate suboptimally, make maintenance schedules more precise based on occupancy patterns, and modify building environments (Yardi 2025). Predictive maintenance can help facilities reduce the time required to plan maintenance and equipment downtime duration by up to 50%, while extending equipment lifespan by 20–40% (Deloitte 2017; Coleman et al. 2017).

Table 2 illustrates the ways in which AI is improving the fault detection and maintenance functions of BEMCS.

Table 2. Application of AI in the maintenance and fault detection functions of BEMCS

Capabilities	Role of AI algorithms
Warning alerts and notifications	Monitor for signs of wear and inefficiency in equipment such as pumps, compressors, or chillers, and issue facility notifications when performance declines are detected.
Anomaly detection and data charting	Identify and track unusual patterns in energy use that may indicate equipment malfunctions or inefficiencies. Plot data from different devices and for any period of time.
Preventive maintenance	Predict when systems are likely to fail and help prioritize maintenance before breakdowns occur. AI can also help schedule maintenance during off-peak hours to avoid disruptions.
Extend asset or equipment life	Mitigate the risk of significant failures by proactively resolving minor issues before they escalate.

Renewable energy integration and utility grid interaction

AI algorithms in a BEMCS can align renewable energy production with building demand. Renewable sources such as wind and solar generate power supplies that vary over time, resulting in fluctuations. Buildings equipped with AI-based BEMCS can forecast building-level load variations, simulate and evaluate different distributed energy resources, and adjust energy usage or respond to utility price signals accordingly to meet demand response objectives. This approach can reduce grid strain during periods of high demand (Ali, Motuziene, and Džiugaitė-Tumėnienė 2024).

AI-integrated BEMCS can analyze historical pricing data, forecast price changes, connect with utility application programming interfaces (APIs) for real-time pricing or curtailment updates, and automate increased use of energy-intensive processes when rates decrease (Muniandi et al. 2024). This capability allows buildings to participate in demand response programs by dynamically adjusting energy consumption based on grid conditions and pricing signals.

Table 3 shows AI use cases for optimizing renewable integration and supporting grid interactivity.

Table 3. AI applications in optimizing renewable energy integration and utility grid interaction

Capabilities	Role of AI algorithms
Load balancing	Help match renewable energy production (e.g., from solar panels) with building demand.

Procurement guidance	Combine AI forecasting with energy procurement services to secure contracts.
Time-of-use optimization	Receive real-time price or curtailment notifications from the utility and temporarily adjust HVAC setpoints or lighting during demand response events. Automatically ramp up energy-intensive processes during low electricity rates.
Storage optimization	Manage batteries or other storage systems to reduce grid dependency and costs.

Enhanced human interactions by learning occupant preferences and improving communication

Beyond predictive analytics for optimizing building systems, AI-enabled BEMCS can assist facilities staff and technicians better manage building energy use and gain deeper insights into building operations by offering personalized insights, data-driven recommendations for optimization, and autonomous control (FacilityManagement 2025; Johnson Controls 2023b). AI models, including large language models (LLMs) and advanced generative AI (GenAI) algorithms, can synthesize extensive datasets collected from building sensors and meters, as well as documentation and manuals for equipment troubleshooting, to generate actionable insights and compliance documentation for facility managers, while also empowering tenants to monitor their energy use in real time and receive suggestions for optimizing consumption (Wang 2024; John 2023). Human oversight and supervision will, however, remain essential to ensure safe, efficient, and ethical implementation. Appendix A includes examples of BEMCS that use GenAI to generate insights and recommendations.

Natural language interfaces allow facility management teams to access data-driven insights and use conversational interfaces for navigating complex information (Chow 2024). These systems are trained on numerous scenarios, large building operations datasets, and factors that affect a building's energy consumption and emissions to deliver real-time AI-generated insights on energy use, along with capabilities for information retrieval and conversation.

GenAI can also enhance and expand facility staff knowledge and make domain-specific tools and technologies more easily accessible (Sreedhar Sistu, vice president, AI Offers, Schneider Electric, pers. comm., 2025). For example, language models can help upskill technicians who are not familiar with existing systems and technologies, or who need assistance with installing new equipment or troubleshooting maintenance issues.

Table 4 highlights how GenAI and other AI algorithms enhance BEMCS communication functionalities.

Table 4. GenAI applications in enhancing human interaction and communication

Capabilities	Role of AI algorithms
Reporting	Automate generation of energy audit report and compliance by accessing, downloading, and sharing buildings' data.
Building control and execution	Assign simple building management tasks such as adjusting HVAC schedules and setpoints.
Data visualization and insights	Use natural language interfaces for control (e.g., voice/text assistance for energy management) and live dashboard data to give insights about building energy use.

Decision support	Provide real-time insights and recommendations for smarter building decisions.

Using LLMs, AI-integrated BEMCS can customize their functionalities according to user interactions, preferences, and feedback. This allows for the generation of insights and recommendations tailored to building management staff, with ongoing adjustments aimed at improving accuracy and relevance. This adaptive learning enhances the user experience, helping optimize building operations.

Energy savings from AI-driven BEMCS

Studies show that AI can reduce building energy use and carbon emissions by 8% to 19%, with some applications achieving even greater reductions when supported by strong policies and low-carbon energy sources (Chow 2024; Ding et al. 2024; IEA 2019). AI-driven BEMCS also help avoid peak energy prices by shifting loads and optimizing schedules and can lower a building's carbon footprint throughout its life cycle, from design through maintenance. Additionally, these systems help predict HVAC failures to reduce downtime and repair expenses (Muniandi et al. 2024).

AI-powered systems decrease energy consumption by adapting to usage patterns, optimizing HVAC controls and equipment, and integrating low-carbon sources. A comprehensive meta-analysis of 87 education buildings across four years in Sweden found that integrating AI-based HVAC solutions resulted in total energy consumption reductions of 3.1% for district heating and 8.93% for electricity, and annual reduction of 64 tons of carbon dioxide equivalent (Paccou and Roussilhe 2024). Such systems dynamically adjust HVAC setpoints and airflow to balance occupant comfort with enhanced energy efficiency.

Challenges

A variety of challenges stand in the way of widespread use of AI-driven BEMCS:

- Financing the high initial investment in AI technologies and solutions (both in the infrastructure, programming, and integration) that enable optimization, development of recommendations, and autonomous control can impede implementation. Broader efforts are needed to engage all building stakeholders in AI adoption.
- Implementing and managing AI systems requires a workforce that is trained in relevant skills, as workflows may need to be reorganized to integrate an AI-based model. Allocating resources for training, education, and internal leadership can help involve all levels of the organization in the process.
- Interoperability issues could impede the effective deployment of AI technologies. Future systems must ensure interoperability across different building types and legacy systems to maximize the impact of AI and GenAI. Additionally, a lack of standardized protocols can delay adoption.
- Cybersecurity risks and ensuring data security are major concerns for organizations looking to integrate AI into their existing building energy management processes. Integrating disparate data sources and ensuring occupant privacy remain ongoing challenges for widespread AI and GenAI adoption in BEMCS.

- Lack of trust by building owners and occupants that the technology can reduce energy consumption without compromising occupant comfort poses a challenge in gaining industry acceptance.
- Thus far, the integration of AI into BEMCS has mostly been in large applications (large buildings or multiple smaller buildings controlled centrally); further development is needed to incorporate AI into BEMCS for medium and small buildings.
- GenAI data centers require significantly more energy than traditional ones. While AI can drive energy savings, the computational demands of large AI models must be managed to ensure net environmental benefits.

Projects to help address these challenges are discussed in the next section.

Project application and impact

Projects implementing a BEMCS with AI can expect short-to-moderate payback periods, with some achieving returns in as little as under a year to five years (John 2023; BrainBox AI 2025). However, actual payback periods will vary depending on factors such as building type, baseline performance, scope of control integration, and the available incentives. As AI-enabled BEMCS continue to demonstrate their effectiveness in improving energy efficiency in large buildings, the minimum building size for cost effectiveness is expected to decrease over time. Already, as shown by the BrainBox example, chains with many centrally controlled and similar small buildings can also use current AI-enhanced BEMCS. Advances in AI computation power and reductions in implementation costs will likely drive broader adoption of AI-enabled BEMCS in medium-sized buildings in the future, and eventually in non-chain small buildings. In this section we review several case studies of successful implementations of AI-driven BEMCS and detail outcomes, lessons learned, and best practices.

Dollar Tree stores optimize HVAC systems

Dollar Tree, a Fortune 500 retailer, operates over 16,000 stores across 48 U.S. states and five Canadian provinces. With a corporate goal to reduce Scope 1 and 2 greenhouse gas emissions by 50% by 2032, the company sought a scalable, cost-effective solution to improve energy efficiency across its vast portfolio (Dollar Tree 2025). BrainBox AI's autonomous HVAC optimization technology provided the flexibility and performance needed to meet these ambitious targets.

To accelerate its emissions reduction strategy, Dollar Tree aimed to retrofit 600 stores—spanning 6.6 million square feet—with an AI-driven solution that could integrate with existing rooftop HVAC rooftop units (RTUs) and operate across diverse climates (BrainBox AI n.d.). The company needed a system that would not disrupt daily operations or cause installation downtime, require minimal capital expenditure, and deliver measurable energy and emissions savings (Dorfman 2025).

BrainBox AI's autonomous HVAC optimization platform was deployed across 616 stores in 18 U.S. states, with each store averaging 11,000 square feet. The solution integrated seamlessly with Dollar Tree's existing RTUs and building energy management system (BEMS), leveraging on-premises servers with cloud connectivity to avoid additional capital expenditure. Within just two months, 400 stores were live and operating autonomously using real-time internal and external data inputs (BrainBox AI n.d.).

Each HVAC unit was labeled using industry-standard nomenclature, and BrainBox AI's advanced algorithms were tested at every store to determine the optimal configuration. The system used real-time data from Dollar Tree's BEMS, along with external data such as weather forecasts, to dynamically adjust HVAC runtimes and reduce energy consumption (Dorfman 2025). This resulted in fewer HVAC-related work orders and technician dispatches, which generally cost between $750 and $1,500 per visit, thereby reducing operational expenses and increasing maintenance efficiency.

In just one a year, Dollar Tree saved 7,980,916 kWh of electricity and $1,028,159 in costs by optimizing equipment runtimes, and reduced emissions by 5,632 metric tons CO_2 equivalent (BrainBox AI n.d.). Following the pilot's completion, Dollar Tree expanded the BrainBox AI deployment to over 2,000 additional stores. BrainBox AI's autonomous HVAC optimization system has significantly advanced Dollar Tree's energy efficiency and emissions reduction objectives, resulting in more than $1 million in annual savings and reducing emissions by more than 5,600 tCO_2e (BrainBox AI n.d.). The quick payback period of under 12 months highlights the ability of AI solutions integrated into existing HVAC systems to deliver substantial operational cost savings, thereby improving both environmental sustainability and financial performance on a large scale (BrainBox AI 2025).

Lippulaiva shopping center maximizes its microgrid system

Citycon is a leading owner and operator of urban hubs in Finland. Its Lippulaiva shopping center in the Helsinki metropolitan area is a large microgrid with solar generation, EV charge stations, batteries, back-up generation, air-conditioning, combined heat and power production, and many energy consumers (Schneider Electric 2025a). Citycon's goal was to make Lippulaiva Europe's first energy-self-sufficient, sustainable and carbon-neutral shopping center.

Citycon collaborated with Schneider Electric to deploy EcoStructure Building Operation software along with the EcoStructure Microgrid Advisor solution to manage the mall's energy system and lower CO_2 emissions, aiming to improve operational efficiency and sustainability (Weckesser 2025). The AI algorithms in the advisor continuously collect and analyze energy production, consumption, and energy storage data from energy assets across the mall and applies machine learning to optimize energy consumption (Schneider Electric 2025b). This helps ensure that renewable energy sources, such as solar and geothermal, are used at the maximum level, and excess energy is sold back to the grid.

The EcoStructure has a web-based user interface, predictive modeling capabilities, and the ability to automatically manage energy resources (Schneider Electric 2024). With the intuitive user interfaces, building operators can control energy use to reduce energy costs, lower CO_2 emissions, and improve operations (Schneider Electric 2025a). The advisor automatically determines the optimal use of energy storage, microgrid power, or grid power based on energy time-of-use (TOU) tariff rates and external factors like weather forecasts (Schneider Electric 2025a).

Lippulaiva is now an energy prosumer (consumers producing their own energy) with the AI-enhanced system optimizing when it consumes and generates energy. The energy optimization solution has reduced the mall's CO_2 emissions by 335 tons/year, annual energy costs by 14%, and its three-million-euro investment will be paid back in five years (Weckesser 2025; Schneider Electric 2025b).

Microsoft Beijing West Campus improves operational performance

Microsoft's Beijing Campus is home to over 3,200 full-time employees and serves as the company's headquarters in China. As part of its global sustainability mission, Microsoft sought to transform the nearly 150,000 square meter facility into an energy efficient workplace and enhance the indoor environment for employees and visitors (Johnson Controls 2023). By integrating cloud-based technologies and AI, the company has improved operational performance and indoor air quality.

Initially, the real estate and facilities team at Microsoft centralized data from different systems—power supply, building controls, energy management—onto Microsoft's Azure cloud platform. While this improved operational efficiency, the team recognized the need for more advanced tools to drive deeper efficiencies and reduce carbon emissions (Johnson Controls 2023).

Microsoft partnered with Johnson Controls to implement a suite of smart building technologies. The Metasys building automation system was deployed to monitor heating and cooling equipment, while OpenBlue Enterprise Manager—an AI-enabled platform—provided real-time data analysis capabilities and generated actionable insights (Johnson Controls 2023; Forrester Research, Inc. 2025). The integration allowed the team to measure the performance of critical infrastructure, such as cooling towers, and identify additional opportunities for optimization. OpenBlue collects and analyzes real-time data, allowing the team to monitor usage and improving building equipment performance through the application of AI to predict faults and optimize energy use.

Beyond energy efficiency, the team prioritized occupant well-being. Although Beijing's air quality has improved in recent years, pollution levels can still pose health risks. Hundreds of sensors were installed across the campus to monitor indoor and outdoor air quality, including particulate matter 2.5 (PM2.5) levels, carbon dioxide concentration, and humidity. OpenBlue provided real-time visibility into these metrics, enabling the team to respond proactively. For example, when outdoor pollution levels are high, the system initiates fresh air circulation at 6 a.m. to ensure a healthy environment by the time employees arrive (Johnson Controls 2023). This capability extends to specific zones within buildings, such as meeting rooms, allowing for targeted interventions.

The adoption of AI solutions has delivered measurable results, including up to a 10% reduction in energy costs and a 67% decrease in chiller maintenance expenses (Forrester Research, Inc. 2025). Microsoft achieved a 27.9% annual reduction in energy consumption and maintained over 98% uptime for key equipment (Johnson Controls 2023). The AI-driven insights have also increased the level of automation across operations, reducing manual oversight and enhancing system responsiveness.

Conclusions

AI and GenAI are transforming BEMCS by facilitating real-time, predictive, and adaptive control of building systems. These advancements are driving significant improvements in operational efficiency and fostering innovation within the building industry. And as additional use cases develop, AI is anticipated to play a crucial role in achieving sustainability goals.

Integrating AI in BEMCS benefits various stakeholders. Building occupants gain optimized comfort, real-time sustainability data, and lower energy costs due to reduced waste. Owners and operators benefit from reduced expenses, lower carbon emissions, and improved comfort via load-shifting, with the potential to offset upgrade costs by marketing flexible loads. For grid operators, intelligent systems provide reliable flexible demand, aiding supply-demand balance as renewables increase. Documented advantages include 8–19% annual onsite energy savings and up to 40% carbon reduction through efficiency measures. While AI shows promise, challenges such as funding limitations, biased data, and interoperability hurdles persist.

Although integrating artificial intelligence in BEMCS poses certain challenges, its significant potential to transform the building energy efficiency sector is clear. When developed and implemented responsibly, AI can play a critical role in advancing energy efficient buildings and supporting the transition toward a more sustainable future.

References

Aketi, P., A. Bozorgi, and H. Khan. 2025. "How AI Is Reshaping DER Potential Studies—Evolution of Potential Studies." ICF Insights/Energy. https://www.icf.com/insights/energy/how-ai-is-reshaping-der-potential-studies?utm_medium=emp-social&utm_source=thehub&utm_content=4875c49f-5b79-4d6f-af39-b5ec38a28247.

Ali, D. M. T. E., V. Motuzienė, and R. Džiugaitė-Tumėnienė. 2024. "AI-Driven Innovations in Building energy management systems: A review of potential applications and energy Savings." *Energies* 17 (17): 4277. https://www.mdpi.com/1996-1073/17/17/4277.

BrainBox AI. 2024. "Understanding Energy Efficiency as a Dynamic Resource in the Built Environment - Achieve Real Efficiency Gains by Modulating the Energy Flowing throughout Your Building." https://brainboxai.com/hubfs/20662219/White%20Papers/BrainBox%20AI_WhitePaper_Understanding%20Energy%20Efficiency.pdf.

———. n.d. "Dollar Tree Unlocks Major Energy and Emissions Savings with BrainBox AI." https://brainboxai.com/en/case-studies/dollar-tree-unlocks-major-energy-and-emissions-savings-with-brainbox-ai.

———. 2025. "How AI Optimizes Legacy HVAC Systems without Breaking the Bank." https://brainboxai.com/en/articles/how-ai-optimizes-legacy-hvac-systems-without-breaking-the-bank.

Chen, Z., F. Xiao, F. Guo, and J. Yan. 2023. "Interpretable Machine Learning for Building Energy Management: A State-of-the-Art Review." *Advances in Applied Energy* 9 (2023): 100123. https://doi.org/10.1016/j.adapen.2023.100123.

Chow, A. 2024." How AI Is Making Buildings More Energy -Efficient." *Time*. https://time.com/7201501/ai-buildings-energy-efficiency/.

Coleman, C., S. Damodaram, M. Chandramouli, and E. Deuel. 2017. "Making Maintenance Smarter —Predictive Maintenance and the Digital." Deloitte Insights. https://www.deloitte.com/us/en/insights/industry/manufacturing-industrial-products/industry-4-0/using-predictive-technologies-for-asset-maintenance.html.

Deloitte. 2017. "Predictive Maintenance Taking Pro-Active Measures Based in Advanced Data Analytics to Predict and Avoid Machine Failure." Deloitte Consulting GmbH. https://www.deloitte.com/content/dam/assets-zone2/de/de/docs/about/2024/Deloitte_Predictive-Maintenance_PositionPaper.pdf.

Ding, C., J. Ke, M. Levine, and N. Zhou. 2024. "Potential of Artificial Intelligence in Reducing Energy and Carbon Emissions of Commercial Buildings at Scale." *Nature Communications* 15 (1): 5916.

Dollar Tree. 2025. "Dollar Tree Working Toward a Healthier Planet—Sustainability—Creating Resilient and Responsible Operations." https://corporate.dollartree.com/values/environmental-stewardship.

Dong, J., J. Gao, J. Yu, L. Kong, N. Jiang, and Q. Wu. 2023. "Leveraging AI Algorithms for Energy Efficiency: A Smart Energy System Perspective." In *Advances in Artificial Intelligence, Big Data and Algorithms*, pp. 57–64. IOS Press. https://ebooks.iospress.nl/doi/10.3233/FAIA230792.

Dorfman, J. 2025. "AI Has Entered the Building: The Future of Energy Management is Here—The Moment Everything Clicked: How BrainBox AI Gives Buildings Brain." Supercool.

https://supercool.beehiiv.com/p/building-energy-management-brainbox-ai?utm_source=chatgpt.com.

Esram, N. 2024. "Can Artificial Intelligence Get Us to Net-Zero Buildings?" Washington, DC: ACEEE. https://www.aceee.org/blog-post/2024/11/can-artificial-intelligence-get-us-net-zero-buildings.

Evans, R., and J. Gao. 2016. "DeepMind AI Reduces Google Data Center Cooling Bill by 40%." Google DeepMind Blog. https://deepmind.google/discover/blog/deepmind-ai-reduces-google-data-centre-cooling-bill-by-40/.

FacilityManagement.com. 2025. "Optimizing Building Operations With AI-Powered Controls." FacilityManagement.com FM Articles. https://facilitymanagement.com/optimizing-ai-powered-controls/.

Forrester Research, Inc. 2025. "The Total Economic Impact of Johnson Controls OpenBlue. A Forrester Total Economic Impact Study Commissioned by Johnson Controls." https://www.johnsoncontrols.com/-/media/project/jci-global/johnson-controls/us-region/united-states-johnson-controls/open-blue/ob-tei-v2/the-tei-of-johnson-controls-openblue-april-2025_updated.pdf.

IBM. 2018. "Building Intelligence into Buildings - Integrating Artificial Intelligence into Building Ecosystems". IBM: New York. https://www.ibm.com/downloads/documents/us-en/10a99803faafdba2.

IEA (International Energy Agency). 2019. "Case Study: Artificial Intelligence for Building Energy Management Systems—Grid Edge." https://www.iea.org/articles/case-study-artificial-intelligence-for-building-energy-management-systems.

John, J. 2023. "These Startups Are Using AI to Cut Energy Waste from Buildings." Canary Media. https://www.canarymedia.com/articles/energy-efficiency/these-startups-are-using-ai-to-cut-energy-waste-from-buildings

Johnson Controls. 2023. "OpenBlue Pioneers Microsoft Beijing West Campus." Johnson Controls. https://www.johnsoncontrols.com/-/media/project/jci-global/johnson-controls/us-region/united-states-johnson-controls/open-blue/pioneers/documents/openblue-pioneers---microsoft-beijing-west-campus-case-study.pdf.

———. 2023b. "OpenBlue Enterprise Manager: Unlock the Performance of Your Building." brochure, www.johnsoncontrols.com/-/media/project/jci-global/johnson-controls/us-region/united-states-johnson-controls/open-blue/energy-efficiency-and-sustainability/documents/jciobemenergyefficiencysustainabilitybrochure1.pdf.[↩].

Khan, S., T. Mazhar, T. Shahzad, M. Amir Khan, A. Ur Rehman, M. M. Saeed, and H. Hamam. 2025. "Harnessing AI for Sustainable Higher Education: Ethical Considerations, Operational Efficiency, and Future Directions." *Discover Sustainability* 6 (1): 23. https://doi.org/10.1007/s43621-025-00809-6.

Le, T., J. Priya, H. Le, N. Le, M. Duong, and D. Cao. 2024. "Harnessing Artificial Intelligence for Data-Driven Energy Predictive Analytics: A Systematic Survey Towards Enhancing Sustainability." *International Journal of Renewable Energy Development* 13 (2): 270–293.

Muniandi, B., P. Kumar Maurya, C. Bhavani, S. Kulkarni, R. Reddy Yellu, and N. Chauhan. 2024. "AI-Driven Energy Management Systems for Smart Buildings." *Power System Technology* 48 (1). https://powertechjournal.com/index.php/journal/article/view/280.

Paccou, R., and G. Roussilhe. 2024. “AI-Powered HVAC in Education Buildings a Net Digital Impact Use Case.” Schneider Electric. https://www.se.com/ww/en/download/document/TLA_AI_Powered_HVAC/.

Schneider Electric. 2025a. “From Strategy to Action—EcoStruxure Delivers Sustainable Operations—Citycon Lippulaiva Case Study.” https://www.se.com/us/en/download/document/998-22354600_GMA/.

———. 2025b. “Schneider Electric—Lippulaiva Customer Story Key Figures.” https://www.se.com/us/en/work/campaign/life-is-on/case-study/lippulaiva/.

———. 2024. “Artificial Intelligence for Energy Transition How AI Can Support Sustainability Today.” Rueil-Malmaison, France : Schneider Electric:. https://enertic.org/wp-content/uploads/2024/12/PDF-Schneider-Electric.pdf.

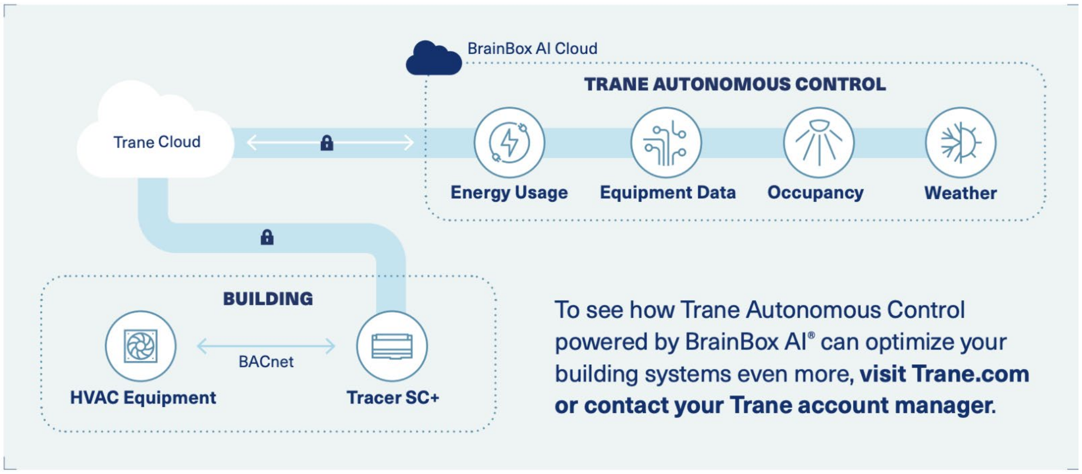
Weckesser, P. 2025. “Transforming Energy Systems with Artificial Intelligence Perspectives from Schneider Electric. The European Files Effective Work Tool for European Deciders.” https://www.europeanfiles.eu/non-classe/transforming-energy-systems-with-artificial-intelligence-perspectives-from-schneider-electric.

Yardi. 2025. “Facilities Management’s AI-Powered Revolution.” White paper. https://creative.endeavorb2b.com/ClientMarketing/BLD/Facility%20Manager%20AI%20White%20Paper.pdf?oly_id=%%0.2.110%%&oly_anon_id=2e22f82d-677b-4d13-8a1d-b2a53e6b62cc&oly_enc_id=6741H2555989E7K.

Zhao, L., H. Zhang, H. Wang, Y. Wang, and T. Li. 2025. “A Digital-Twin Evaluation Framework of Zero Carbon Buildings for Existing Residential Buildings Based on Scan-to-BIM.” *Alexandria Engineering Journal* 124: 204–213.

Appendix A. Example of AI-Enhanced BEMCS

-Trane's BrainBox AI system uses real-time data from building sensors—such as temperature, humidity, sun angle, wind speed, and occupancy—to autonomously control HVAC systems. Currently deployed in 4,000 buildings worldwide, including convenience stores, Dollar Trees, and airports, BrainBox also developed Aria, a generative AI assistant that enables facility managers to operate HVACs via text or voice. Aria is expected to launch widely in 2025.



-Honeywell's Connected Building Management is an AI-powered building management platform that integrates critical building software and technologies into a single interface for more efficient operations. Early adopters include Verizon Communications and Vanderbilt University, both already using the solution in their buildings.

-Johnson Control's OpenBlue digital platform focuses on energy optimization, occupant experience, and sustainability. It is cloud-based, modular, and scalable, and can be layered on existing building systems, making it a good option for retrofits and upgrades. Key quantified benefits include energy savings of up to 10%, reduced chiller maintenance costs by 67%, real estate savings of 21.9%, and rental premiums of a combined 7%.

-Siemens' Desigo CC is building management software designed for a range of building types and sizes. Its open architecture and multidisciplinary features allow for customization and integration across multiple sites. Native connectivity with Building X supports further scalability and enables unified multisite building management systems.

-Schneider Electric's EcoStruxure Resource Advisor Copilot is a conversational AI tool designed to help business leaders interact with their enterprise energy and sustainability data. Using large language model (LLM) technology, Schneider Electric has securely built Copilot as a convenient digital companion embedded inside Resource Advisor. Copilot equips energy and sustainability teams with enhanced data analysis, visualization, decision support, and performance optimization, and gives them the ability to seamlessly process intricate industry knowledge and Resource Advisor system information.

-JLL's Hank leverages machine learning, energy modeling, and external data sources to implement real-time microadjustments, continuously optimizing all HVAC equipment and achieving a 30% reduction in energy consumption and costs.