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System Integration Architectures for Building Management Systems in HVAC, Electrical, and Fire-Life Safety Environments

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Abstract

Building management systems now connect HVAC, electrical, fire and life safety, security, lighting, metering, and ELV subsystems within a single operational environment. In commercial high-rise buildings, this connection affects equipment control, alarm traceability, emergency sequences, maintenance planning, and long-term serviceability. The study examines BMS integration architectures through an analytical review of ten recent scholarly sources and technical standards issued from 2021 to 2025. The source base covers BACnet communication, building automation functions, IoT-enabled energy management, smart building adoption, data-driven BMS models, BAS integration, and emergency control interfaces. The article identifies three architectural priorities: layered control separation, multi-vendor interoperability, and commissioning-based validation of HVAC, electrical, and fire-life safety interfaces. The resulting model links protocol selection, point governance, cause-and-effect testing, alarm management, trend review, and maintenance feedback. The proposed logic suits commercial buildings operating under high temperature, dust, humidity, and long operating hours, where BMS performance depends on traceable integration.

Keywords: *Building Management Systems, BMS Integration, HVAC Automation, BACnet, Fire-Life Safety, Electrical Systems, ELV Interfaces, Smart Buildings, Commissioning, Multi-Vendor Architecture.*

INTRODUCTION

Building management systems have developed from supervisory panels into integration environments where mechanical, electrical, safety, security, lighting, metering, and ELV subsystems exchange operational signals. In commercial high-rise buildings, this development changes the engineering task. The team must define how controllers, gateways, alarms, interlocks, meters, and operator workstations exchange information during normal operation, fault conditions, and emergency events.

In buildings where HVAC equipment runs for long hours, electrical distribution feeds high-dependency loads, and fire alarm logic interacts with smoke control, lifts, dampers, fans, access control, public address, and emergency shutdown functions. Hot, dusty, and humid operating conditions place extra pressure on HVAC and electromechanical equipment. Under such conditions, BMS integration has to support preventive maintenance, alarm traceability, trend review, and performance validation. A screen showing connected devices provides limited operational value if the team cannot verify commands, feedback, alarm states, and cause-and-effect sequences.

The article aims to develop an analytical interpretation of system integration architectures for BMS environments connecting HVAC, electrical, fire-life safety, and ELV interfaces in complex commercial buildings. The first research objective is to identify the architectural layers through which BMS platforms connect field devices, equipment controllers, subsystem panels, supervisory workstations, and operational analytics. The second objective is to clarify how interoperability standards and communication protocols shape multi-vendor integration in buildings where different manufacturers supply HVAC, electrical, fire alarm, lighting, access control, and metering equipment. The third objective is to define how commissioning, cause-and-effect testing, and operational feedback convert integration design into reliable building performance.

The novelty of the article lies in treating BMS architecture as a problem of operational authority, safety logic, and maintainability. The proposed hypothesis states that BMS performance depends on interface ownership, protocol governance, emergency logic segregation, and post-commissioning feedback loops more than on the total number of connected devices.

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MATERIALS AND METHODS

The study draws on ten recent scholarly sources and technical standards selected through narrative screening. The selection covered publications from 2021 to 2025 dealing with BMS, BACS, IoT-enabled building energy management, BACnet communication, smart building adoption barriers, data-driven BMS architectures, BAS in green buildings, and emergency control interfaces. Review papers cover IoT applications in buildings and cities [1], smart building adoption challenges [3], real-time smart building management requirements [4], IoT-enabled energy management barriers [8], BAS integration in green buildings [9], and data-driven BMS architecture classification [10]. Technical standards and codes cover BACnet communication for building automation [2], building automation functions contributing to energy performance [5], BACS data communication protocol principles [6], and fire alarm emergency control interfaces [7]. The source map follows the article's three tasks: architectural layering, multi-vendor interoperability, and commissioning-based validation.

The study uses source analysis to extract architectural concepts, comparative analysis to distinguish protocol-based, gateway-based, and supervisory integration models, conceptual synthesis to connect HVAC, electrical, and fire-life safety requirements, typologization to classify integration risks, and analytical generalization to formulate an implementation logic suitable for multi-vendor commercial buildings.

RESULTS

Recent BMS studies describe smart buildings as heterogeneous technical environments where mechanical, electrical, safety, information, and user-facing systems interact through layered digital infrastructures. A systematic review of data-driven BMS research links current BMS development to information and communication technologies. It describes smart buildings as heterogeneous systems comprising data flows, computing architectures, and elements [10]. For the first research objective, this means that the BMS functions as a layered architecture in which field devices, equipment controllers, network protocols, supervisory software, and operational analytics serve distinct engineering purposes.

The basic integration architecture contains five layers. The field layer includes sensors, actuators, meters, damper-end switches, fan-status contacts, pressure switches, thermostats, relays, variable-frequency drives, and local equipment signals. The equipment controller layer contains packaged controls for chillers, AHUs, FCUs, pumps, switchgear, lighting panels, fire alarm panels, access control panels, CCTV servers, and lift interfaces. The protocol and interface layer contains BACnet IP, BACnet MS/TP, Modbus gateways, dry contacts, relays, hardwired interlocks, and selected middleware links. The supervisory layer contains BMS servers, operator workstations, alarm management, trend logging, scheduling, graphics, user permissions, and event records. The operational layer connects trend data, alarm history, fault detection, asset history, maintenance planning, and performance reporting. Prior research on smart building management systems frames building control in terms of indoor conditions, comfort, security, safety, costs, operating constraints, and design requirements [4]. That framing supports a layered architecture because each domain demands a different control depth and validation path.

BACnet-oriented standards provide the strongest technical basis for multi-vendor BMS integration. ASHRAE defines BACnet as a building automation and control networking protocol designed for HVAC control, fire and life safety systems, security, energy management, lighting control, physical access control, and elevator monitoring [2]. ISO 16484-5 defines data communication services, protocols, and an object-oriented information representation for monitoring and control of HVAC&R and other building systems [6]. These standards matter for the second research objective because multi-vendor buildings often combine chillers, VFDs, meters, fire alarm panels, access control, lighting controls, and packaged equipment from different manufacturers. Without a shared object structure and documented communication services, the BMS integrator receives inconsistent point names, proprietary variables, dry contacts with unclear states, and gateway registers that require manual interpretation.

Figure 1 presents the integration logic derived from BACnet and ISO BACS communication principles [2; 6]. The figure adapts the communication hierarchy into a BMS architecture for HVAC, electrical, fire-life safety, and ELV environments without adding quantitative data.

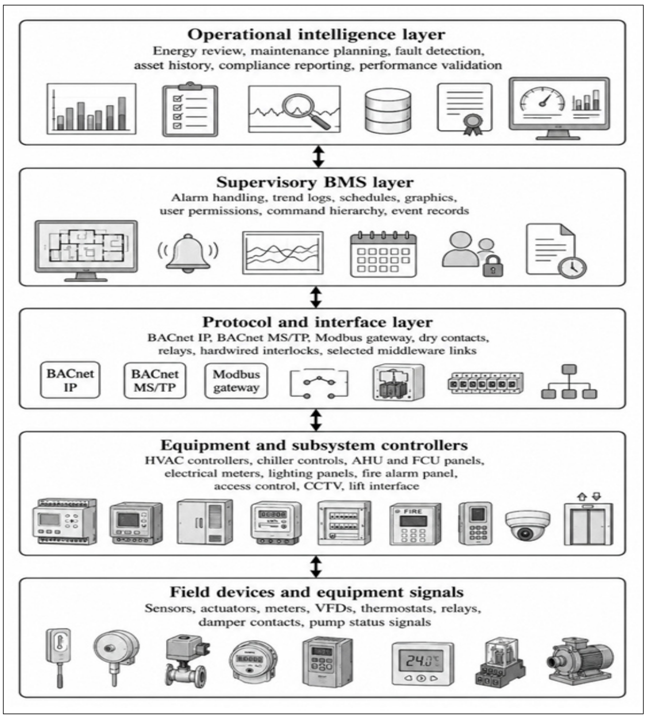

Figure 1. Layered BMS integration architecture for multi-vendor building environments. Adapted from BACnet and ISO BACS communication principles [2; 6]

The layered model separates communication from authority. HVAC control normally accepts BMS schedules, setpoint resets, start-stop commands, and trend logging within approved equipment limits. Electrical systems usually require BMS visibility for meter values, breaker status, generator readiness, UPS alarms, panel faults, and abnormal conditions. In contrast, electrical protection and switching logic remain inside approved electrical systems. Fire-life safety integration follows a stricter boundary. The BMS may display fire events, record emergency states, and help operators understand system status. Fire alarm panels and dedicated emergency control interfaces retain primary authority over life-safety actions. NFPA 72:2025 assigns a dedicated chapter to Emergency Control Function Interfaces [7]. For BMS design, this creates a clear rule: emergency shutdown, smoke control activation, lift recall, door release, and related cause-and-effect functions require code-governed interface design and documented testing.

Several sources approach BMS performance through different lenses. IoT-oriented reviews discuss sensors, connectivity, real-time monitoring, and remote management for building energy performance [1; 8]. BACS and BAS sources focus on control functions, comfort, energy use, sustainability, and the gap between design intention and operation [5; 9]. Data-driven BMS research classifies computing architectures and methods used for smart building operation [10]. Fire alarm codes define emergency interfaces where safety logic cannot be treated as an ordinary data point [7]. Together, these positions show that BMS architecture contains at least three integration modes. HVAC and energy systems need control integration. Electrical and ELV systems often need supervisory visibility and alarm escalation. Fire-life safety systems need verified interface integration with authority preserved in dedicated safety systems.

Fragmentation remains a recurring barrier. A built-environment review of IoT applications reports that professionals need clearer strategies for applying IoT in energy-efficient buildings [1]. A study of smart building technology adoption identifies integration across HVAC, power management, lighting, security, safety, and shared networks as part of smart building practice. At the same time, technical and organizational barriers still affect implementation [3]. A review of IoT in smart buildings reports obstacles such as initial cost, data security, and system integration complexity [8]. These findings directly support the second objective. Multi-vendor integration fails most often at the boundary between equipment packages and operational responsibility. Each supplier may deliver a working subsystem, while the BMS still lacks consistent point naming, alarm priorities, protocol exposure, trend intervals, command permissions, and cause-and-effect documentation.

HVAC, electrical, and fire-life safety interactions make the multi-vendor problem more visible. HVAC systems require stable sequences, modulating control, demand-based operation, and fault detection. Electrical systems require monitoring of availability, abnormal status, energy consumption, and standby source readiness. Fire-life safety systems require deterministic response, signal priority, supervised circuits, emergency control interfaces, and documented retesting. Engineers can use BACnet and ISO BACS principles to structure information exchange across these domains [2; 6]. Protocol compatibility alone gives limited assurance. Each imported point still needs engineering definitions for normal state, alarm state, fail state, command direction, override permission, trend retention, and responsibility during abnormal operation.

ISO 52120-1 adds a functional grading logic. The standard organizes building automation, controls, and technical building management functions according to their contribution to energy performance [5]. This helps project teams distinguish shallow monitoring from deeper automation. A specification that asks the contractor to "connect the AHU to BMS" leaves the integration depth unclear. A graded specification identifies whether the BMS will monitor only run and trip status, command schedules, adjust setpoints, trend filter pressure, supervise damper feedback, log valve position, display mode status, and classify alarms. The same logic applies to chillers, pumps, FCUs, lighting panels, meters, and selected electrical status points.

Research on BAS in green buildings indicates that current efforts focus heavily on energy efficiency and occupant comfort. At the same time, broader integration remains uncertain, with long-term prediction and control issues, sustainability requirements, privacy, and security concerns [9]. This finding has direct relevance for BMS integration in high-dependency buildings. Energy optimization cannot stand apart from emergency priorities, electrical availability, access control release, smoke extract fans, stair pressurization, generator status, and operator workflows during abnormal events. The BMS architecture requires a control hierarchy that prevents comfort or energy commands from overriding emergency states.

Real-time smart building management literature adds another layer to the argument. Research on smart building management systems links performance specifications to indoor conditions, comfort criteria, security and safety, costs, and environmental adaptation [4]. In high-temperature, dusty, humid environments with long operating hours, adaptation has a practical maintenance meaning. HVAC equipment accumulates runtime, filtration loads increase, coils and outdoor units require closer attention, and electromechanical components depend on preventive maintenance schedules. The BMS needs trend data to help the facility team act. Supply and return temperatures, chilled water valve positions, differential pressures, compressor status, fan speeds, filter alarms, pump run hours, and repeated resets gain value when technicians review them and connect them to maintenance tasks.

Comparing IoT, BEMS, and BMS sources clarifies the third objective. IoT reviews describe how connected sensors and devices support monitoring, energy management, and remote control [1; 8]. Data-driven BMS research explains computing architectures and digital methods used in smart buildings [10]. Smart building management research links performance to safety, comfort, operating constraints, and adaptation [4]. Commissioning receives less attention than design and analytics in much of this literature. In actual BMS delivery, commissioning decides whether the architecture works. Point-to-point testing, graphics verification, alarm-priority checks, trend validation, BACnet object mapping, gateway-failure tests, emergency interlock tests, and cause-and-effect demonstrations provide the operator with evidence that the BMS reflects field reality.

Fire-life safety integration provides the clearest example. NFPA 72:2025 lists Emergency Control Function Interfaces in its chapter structure [7]. BMS design should preserve the authority of fire alarm and dedicated emergency systems while providing operators with accurate visibility. HVAC shutdown, smoke control fan activation, damper position confirmation, pressurization fan status, lift recall, access door release, and public address interaction require sequence testing. A BMS screen that displays “smoke extract fan running” is of limited value unless commissioning verifies the command path, feedback path, power availability, damper state, fault condition, and operator indication.

The reviewed sources support three findings. The BMS integration architecture requires a layered separation between field control, equipment ownership, protocol mediation, supervisory management, and operational analytics [2; 6; 10]. Multi-vendor interoperability requires open communication principles and project-level information governance, including point naming, object definitions, command permissions, alarm priorities, cybersecurity limits, and maintenance responsibility [1; 3; 8]. Operational performance depends on commissioning and feedback loops that test HVAC control sequences, ensure visibility of electrical status, verify fire-life safety cause-and-effect logic, and support trend-based maintenance under actual operating conditions.

DISCUSSION

A BMS integration architecture for commercial high-rise buildings should start from a control philosophy. The control philosophy defines what each connection can read, command, alarm, trend, override, and record. This document protects the building from a common integration failure: many connected points with unclear authority. HVAC controllers, electrical protection equipment, fire alarm panels, access control, CCTV servers, lighting controls, meters, and packaged plant controllers carry different risk levels. A single BMS graphic can display them together, but the engineering rules behind each connection must remain distinct.

The proposed implementation model uses five decisions. The project team assigns a subsystem owner to each function. It defines the interface type, such as BACnet object, Modbus register, dry contact, relay interlock, hardwired shutdown, or vendor gateway. It defines control authority, including read-only monitoring, limited setpoint adjustment, scheduled command, operator command, or emergency sequence outside BMS authority. It defines validation evidence through point-to-point testing, trend verification, alarm simulation, cause-and-effect testing, or integrated systems testing. It defines operational use after handover through alarm review, preventive maintenance triggers, periodic retesting, and performance reporting.

Table 1 compares integration layers and decision priorities. The purpose of the table is to show how each layer requires a different engineering decision. The comparison links connected elements, failure routes, and practical controls.

Table 1. Integration layers and decision logic for BMS architectures

Integration layer	Typical connected elements	Primary integration risk	Recommended decision logic
Field device layer	Sensors, actuators, meters, relays, damper feedbacks, and status contacts	Wrong signal type, failed feedback, missing calibration, weak environmental protection	Verify wiring, calibration, physical location, normal state, fail state, and maintenance access before software mapping
Equipment controller layer	Chiller controls, AHU panels, FCU controllers, VFDs, lighting panels, and electrical meters	Hidden proprietary logic, incomplete point exposure, vendor dependency	Define minimum point lists, protocol objects, writable points, alarm classes, and vendor documentation before procurement closure
Interface and protocol layer	BACnet IP, BACnet MS/TP, Modbus, gateways, dry contacts, hardwired interlocks	Translation errors, network instability, inconsistent point naming, and weak command traceability	Use open protocols where feasible, document gateways, standardize naming, test communication loss, and restrict write permissions
Supervisory BMS layer	Graphics, alarms, schedules, trends, operator commands, reports	Alarm overload, misleading graphics, excessive overrides, weak user permissions	Apply alarm priority rules, command hierarchy, user authorization, trend retention, and operator training
Operational intelligence layer	Energy dashboards, fault detection, maintenance reports, and asset history	Data without maintenance action, misplaced confidence in analytics, and weak technician feedback	Convert trends into maintenance triggers, verify recurring alarms, review seasonal behavior, and record corrective actions

A correct BACnet object cannot correct a poorly located sensor. A clean graphic cannot correct a missing feedback contact. A dashboard cannot correct undocumented override behavior. Multi-vendor buildings need an interface responsibility matrix before final procurement. Late coordination places the integrator in a repair position after vendors have already fixed controller selections, software versions, point exposure, and gateway capacity.

Table 2 translates the same logic into subsystem validation. It compares BMS involvement across HVAC, electrical, fire and life safety, and ELV domains. The comparison separates active control, supervisory monitoring, emergency interface authority, and operational follow-up.

Table 2. Subsystem integration logic for HVAC, electrical, fire-life safety, and ELV environments

Subsystem domain	BMS function	Control boundary	Commissioning evidence	Operational monitoring focus
HVAC	Scheduling, setpoint reset, start-stop, valve and damper monitoring, fan speed visibility, alarms, trends	BMS commands comfort and energy functions within approved equipment limits	Point-to-point test, sequence test, trend review, alarm simulation, seasonal recommissioning	Runtime, temperatures, pressures, valve positions, filter alarms, repeated trips, abnormal overrides
Electrical	Metering, breaker status, generator and ATS status, UPS alarms, panel alarms, and power quality indicators, where available	BMS monitors and reports, while electrical systems retain protection and switching logic	Meter validation, status simulation, alarm priority checks, loss-of-power behavior review	Load patterns, generator readiness, battery alarms, breaker trips, repeated abnormal states
Fire-life safety	Fire alarm status, smoke control interface visibility, HVAC shutdown status, damper feedback, emergency event indication	Fire alarm and dedicated emergency control systems retain authority over safety sequences	Cause-and-effect testing, supervised interface checks, smoke control sequence validation, and emergency graphic verification	Emergency event traceability, trouble states, interface faults, status mismatch, periodic retest records
ELV and security	Access control status, CCTV health, public address interface, lift status, selected door release feedback	BMS provides selected visibility, while security systems retain event logic and access decisions	Interface test, alarm mapping, operator workflow test, failure mode review	Device health, communication loss, door status anomalies, server or network faults

The comparison prevents a uniform template from being applied across all systems. HVAC benefits from active BMS control because comfort and energy performance require continuous adjustment. Electrical integration creates value through visibility, alarm escalation, and metering review. Fire-life safety integration requires traceability and verified cause-and-effect behavior, while safety authority stays with dedicated systems. ELV integration improves operator awareness, but access rights, cybersecurity, and event records require separation from general BMS users.

Implementation should follow a controlled sequence. The team prepares a system integration matrix for every subsystem, data point group, protocol, command type, alarm priority, and commissioning method. The team defines naming rules before controller programming begins. It classifies points as monitoring, alarm, trend, writable command, emergency interface, or maintenance indicator. It requires bench verification for high-risk gateways and packaged equipment interfaces. Field technicians perform point-to-point testing before graphics approval. Integrated sequence testing starts with HVAC operating modes and then moves to fire-life safety cause-and-effect scenarios. Operational validation continues after occupancy, when trends reveal whether equipment behavior matches the intended sequence.

Performance monitoring should avoid broad claims about savings without measured data. A review article can define auditable indicators instead. HVAC monitoring can use runtime distribution, setpoint override frequency, valve saturation, differential pressure stability, filter alarm recurrence, and repeated trips. Electrical monitoring can use metered load profiles, generator readiness, UPS alarms, breaker trip frequency, and abnormal status duration. Fire-life safety interface monitoring can use cause-and-effect retest completion, status mismatch records, trouble signal duration, and emergency interface documentation. ELV monitoring can use communication loss frequency, server health, access control fault states, and public address interface readiness.

Harsh operating environments strengthen the case for trend-based integration. Heat, dust, humidity, and long operating hours increase equipment runtime and maintenance demand. A BMS that records AHU filter alarms but does not feed maintenance planning leaves actionable information unused. A BMS that trends chilled-water valve positions but does not flag persistent full-open operation leaves an unnoticed diagnostic pattern. A BMS that displays fire events without preserving interface test records weakens post-event traceability. The system architecture should connect commissioning evidence, alarm history, trend review, and maintenance response.

Multi-vendor buildings require vendor-neutral governance. Proprietary packaged controls will remain in many projects because manufacturers use them for warranty, plant optimization, and product support. The facility team still needs documented interface access to operate and maintain the building without relying on a single supplier for every adjustment. Open protocols, gateway schedules, editable graphics, exported trend data, alarm logic records, and tested failure modes give the building owner practical control over the installed system.

The proposed model reduces BMS integration to a disciplined engineering sequence: assign ownership, standardize communication, define authority, segregate safety logic, validate sequences, and connect operational data to maintenance action. This model suits high-rise commercial buildings because they combine continuous HVAC loads, dense electrical infrastructure, fire-life-safety interlocks, and multiple ELV interfaces. It suits multi-vendor environments because it treats integration as information governance and as a responsibility-allocation mechanism.

CONCLUSION

System integration architectures for BMS environments require a layered structure that distinguishes field devices, equipment controllers, protocol interfaces, supervisory functions, and operational analytics. HVAC, electrical, fire-life safety, and ELV systems differ in control depth, risk level, and validation requirements. A functional architecture needs defined ownership, command hierarchy, point classification, alarm logic, trend strategy, and commissioning evidence.

Multi-vendor integration depends on protocol-based interoperability and project-specific information governance. BACnet and ISO BACS principles support standardized communication and object-oriented representation, while ISO 52120-1 helps classify automation functions according to building performance. These standards gain practical value when engineers define point lists, writable objects, gateway rules, alarm priorities, cybersecurity limits, and maintenance responsibilities before commissioning.

Fire-life safety integration confirms the hypothesis. BMS performance depends on interface clarity, safety logic segregation, and validated cause-and-effect behavior more than on the number of connected devices. HVAC and energy functions benefit from supervisory control and trend-based optimization. Electrical and ELV systems benefit from monitored visibility and alarm escalation. Fire alarm and emergency control functions require dedicated authority, documented interfaces, and periodic retesting. Reliable BMS integration results from architectural discipline, controlled interfaces, and operational feedback.

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