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ROLE OF CENTRALIZED BMS IN ENHANCING OPERATIONAL EFFICIENCY IN SMART MALLS AND HOTELS

O PAPEL DO BMS CENTRALIZADO NO AUMENTO DA EFICIÊNCIA OPERACIONAL EM SHOPPINGS E HOTÉIS INTELIGENTES

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Abstract
As cyber-physical service systems, comfort, safety, customer experience, cost, and the requirement that all are provided simultaneously-thus requiring a smart solution-are thus the fundamental properties of smart malls and hotels. BAS, or Building Automation System, with Building Energy Management Systems being a special case with emphasis on energy, have thus evolved from mere supervisory control to data acquisition, supervisory control, analytics, and, most importantly, a governing model. This systematic study will aggregate all available evidence from 2020 to 2025 on the benefits of Centralized Building Management System as a model for improving operation efficiency in Smart malls and hotels. Our study synthesized all relevant evidence in five key areas described by the individual authors, including energy and carbon, fault detection/diagnostics - maintenance productivity, indoor environmental quality, enterprise integration, cybersecurity, and assurance, by adopting PRISMA 2020 guidelines. Coherently in all ascertained evidence, there seems to be a coherent trend that the key to improved operational efficiency is totally encapsulated in the phrase "analytics to action" since even as there is "interoperable connectivity of all devices allowing high-fidelity visibility," there is room for a "continuous commissioning based on FDD/AFDD, occupancy-based control, and optimization, which must translate into 'governed actions' through CMMS/PMS with measurement & verification." Lately, studies have found Building Energy Management Systems with the aid of digital twin technology to be efficient, as well as Analytic Function Detection Diagnosis with the aid of agent/ontology technology to improve interpretable diagnosis reports, although there are gaps in evidence, with some authors citing the benefits seen by others by virtual

Resumo
Como sistemas de serviços ciberfísicos, conforto, segurança, experiência do cliente, custo e a exigência de que todos sejam fornecidos simultaneamente — exigindo, portanto, uma solução inteligente — são, portanto, as propriedades fundamentais de shoppings e hotéis inteligentes. O BAS, ou Sistema de Automação Predial, com os Sistemas de Gerenciamento de Energia Predial sendo um caso especial com ênfase em energia, evoluiu, portanto, do mero controle de supervisão para aquisição de dados, controle de supervisão, análise e, mais importante, um modelo de governança. Este estudo sistemático agregará todas as evidências disponíveis de 2020 a 2025 sobre os benefícios do Sistema Centralizado de Gerenciamento de Edifícios como um modelo para melhorar a eficiência operacional em shoppings e hotéis inteligentes. Nosso estudo sintetizou todas as evidências relevantes em cinco áreas-chave descritas pelos autores individuais, incluindo energia e carbono, detecção/diagnóstico de falhas - produtividade de manutenção, qualidade ambiental interna, integração empresarial, segurança cibernética e garantia, adotando as diretrizes PRISMA 2020. De forma coerente em todas as evidências apuradas, parece haver uma tendência coerente de que a chave para melhorar a eficiência operacional está totalmente encapsulada na frase "análise para ação", pois mesmo que haja "conectividade interoperável de todos os dispositivos, permitindo visibilidade de alta fidelidade", há espaço para um "comissionamento contínuo baseado em FDD/AFDD, controle baseado na ocupação e otimização, que deve se traduzir em 'ações governadas' por meio de CMMS/PMS com medição e verificação". Recentemente, estudos descobriram que os Sistemas de Gerenciamento de Energia Predial com o auxílio da tecnologia

modeling or simulation. We present our reference architecture as well as our KPIs, with a matching research requirement that will focus on credible study designs, as well as the use of semantic modeling as well as security by design, by utilizing protocol extension technologies like BACnet SC.

Keywords: Building Management System (BMS). Building Automation System (BAS). Smart Hotel. Smart Mall. Operational Efficiency. Fault Detection and Diagnostics. Continuous Commissioning. Digital Twin. Occupancy Detection. BACnet/SC. Cybersecurity. ISO 50001. Measurement & Verification.

digital twin são eficientes, assim como o Diagnóstico de Detecção de Função Analítica com o auxílio da tecnologia de agente/ontologia para melhorar os relatórios de diagnóstico interpretáveis, embora haja lacunas nas evidências, com alguns autores citando os benefícios observados por outros por meio de modelagem ou simulação virtual. Apresentamos nossa arquitetura de referência, bem como nossos KPIs, com um requisito de pesquisa correspondente que se concentrará em projetos de estudo confiáveis, bem como no uso de modelagem semântica e segurança por design, utilizando tecnologias de extensão de protocolo como BACnet SC.

Palavras-chave: *Sistema de Gerenciamento Predial (BMS). Sistema de Automação Predial (BAS). Hotel Inteligente. Shopping Inteligente. Eficiência Operacional. Detecção e Diagnóstico de Falhas. Comissionamento Contínuo. Gêmeo Digital. Detecção de Ocupação. BACnet/SC. Cibersegurança. ISO 50001. Medição e Verificação.*

1 INTRODUCTION

Such as is exemplified with regards to the mall and hotel, which is just as much high-tech as it is high-touchwith regard to servicing. Hence, it is just not only that it is a matter that is an issue that is an engineering issue, it is a logistics issue as well because all of this infrastructure is certainly important with regard to servicing. For instance, failure with regard to servicing impacts customer satisfaction time. Rules and regulations are impacted with regard to ventilation. However, over the recent past, issues regarding energy factors have been a problem. Issues that factor with regard to energy include: the cost of the utility bill, over the recent past, has certainly become unstable. Sustainability reports have certainly become a necessity as opposed to being a choice. Lastly, there is a competitive struggle with regard to energy.Regarding aspects related to BMS centralization, there is an elaboration regarding how such facilities may be controlled through the nervous system. However, there is a need to establish an understanding that BMS was only implemented in aspects related to alarm handling and schedule monitoring until the year 2020. On the other hand, BMS has been elaborated to include aspects related

to dense sensing, continuous commissioning with FDD/AFDD, data platforms, optimization, as well as cyber governance, aspects which were completed by the year 2025. According to most surveys carried out with regard to BACS, a trend has been established to include BEMS, IoT/WSN sensing, and related decision infrastructure, as identified in the research carried out by Akbulut et al. (2025) and Shahid et al. (2025). Regarding aspects related to DT development, there is a trend established wherein a shift from construction to operation has been identified, as established in most reviews related to BACS, thus establishing DT development, as identified in most surveys carried out related to BACS development. The second trend as identified related to BACS development is related to DT development as identified in most surveys carried out related to BACS development with aspects identified related to issues of security as identified in surveys carried out related to BACS development so as to establish security through mechanisms related to secure extension such as BACnet Secure Connect (BACnet/SC), among others, as identified in most surveys carried out related to BACS development so as to establish security through BACnet/SC, among other security aspects.

This review is also relevant to Saudi Arabia's Vision 2030, where large-scale smart developments and hospitality-led giga-projects require measurable improvements in energy efficiency, operational reliability, occupant experience, and ESG reporting. Centralized BMS/BEMS capabilities—particularly ISO 50001-aligned energy management, continuous commissioning, and cybersecurity-by-design (e.g., BACnet/SC governance)—support the operational goals of smart malls and hotels in the Kingdom by enabling sustained savings, audit-ready reporting, and safer convergence of IT/OT. In this context, centralized BMS functions act as a digital backbone for scalable operations across multi-property portfolios and mixed-use assets.

2 AIM, OBJECTIVES, AND RESEARCH QUESTIONS

Aim: To critically discuss the availability of the research evidence base for the potential value of a BMS system on the efficiency of smart malls and hotels based on the availability of research, expected to be released between 2020 and 2025, with specific

reference to the quality of research work based on the expectation of Q1 documents as per Scopus.

2.1 Objectives

O1: Determine which of the central capabilities identified by BMS are most associated with efficiency, i.e., energy consumption, cost of maintenance, comfort stability, response time, etc.

O2: How does this compare with the routes taken in shopping centers and hotels in relation to limitations and infrastructures made possible on the boundaries?

O3: Create novel architectures with respect to models for data flow in analytics/optimization and twin-based operation.

O4: Identify the related security controls in the cybersecurity domain as well as the other domains. The other domains are: privacy & governance, BACnet SC, Segmentation, IAM, and Auditable Workflows.

O5: A list of KPIs and reporting to be used in the production of a reproducible evidence repository in various forms, such as Ops & Log Journals.

2.2 Research questions

Regarding RQ1: What types of most impactful centralised functions of BMS, based on efficiency benefits, context-dependent and context-independent, are we dealing with? RQ2: How do different FDD/AFDD techniques, occupancy intelligence, predictive control, and digital twinning methodologies applied on BMS data translate into quantified improvements in organisational processes? Are they verified? RQ3: What types of most interesting patterns of integration, for malls/hotels, would you mention, e.g., CMMS, Hotel PMS, POS, Tenant Systems, ESG&MV, etc.? RQ4: How do security and governance issues affect architectural decisions, together with an operation?

3 METHODOLOGY

3.1 Review design and protocol

Accordingly, what we are looking at here is a systematic review with thematic synthesis. In any case, we are looking at a situation where a protocol will be in place such that this systematic review will be conducted in accordance with what the standard guidelines are with regard to what PRISMA 2020 reporting guidance statement outlines. Hence, there are substantial differences with regard to design, context, and measurement such that it is not possible to combine these in any way with a view to performing a meta-analysis.

3.2 Search strategy and sources

For this purpose, the search has been performed through choosing publications between the years 2020 and 2025 and also through choosing appropriate sources in which the information has been presented that directly affects building operational management. Also, the keywords are the combination of terms used within the sphere ('building management system,' ‘building automation system,' ‘BEMS,' ‘smart hotel,' ‘shopping mall'); the combination of terms used within the method ('fault detection and diagnosis,' ‘continuous commissioning,' ‘digital twin,' ‘occupancy detection,' ‘predictive control'); and the combination of terms used within the governance/standard section ('BACnet Secure Connect,' ‘BAS security,' ‘cybersecurity'). Literature has been chosen to be comprised of peer reviews and systematic reviews as well as standard publications when necessary and particularly prominent for implementation purposes, like BACnet cybersecurity standard/guidance, especially because it is a crucial factor for BMS in connection with its implementation into a particular environment (ASHRAE 2025).

3.3 Inclusion and exclusion criteria

All the resources used have been pertinent in the sense that they satisfied the following conditions: (i) The year of publication: 2020-2025; (ii) The relevance of

BMS/BAS/BEMS in building as well as in malls/(class) hotels; (iii) Availability of information regarding the outcomes of operation/architectures/practices, which have appeared relevant in terms of building efficiencies; (iv) Relatively satisfying levels of transparency in terms of methodologies of research used. The resources have apparently not been relevant as smart city resources in the sense that they are either conceptual without an operational link or even without an intimeframe.

3.4 Screening and quality appraisal

Title/abstract screening and full-text screening defined this stage of the systematic review process. The parameters for the quality appraisal process included a number of factors such as operational credibility through the facilitation of clear interventions or the measurement and usage of baselines in determining outcome measures or "energy normalizations," among others. For the process of cybersecurity, the major points of interest are defined as the completeness of the threat model or the extent to which it follows the protocol ecosystems (Morales-Gonzalez et al., 2024).

3.5 Data extraction and synthesis

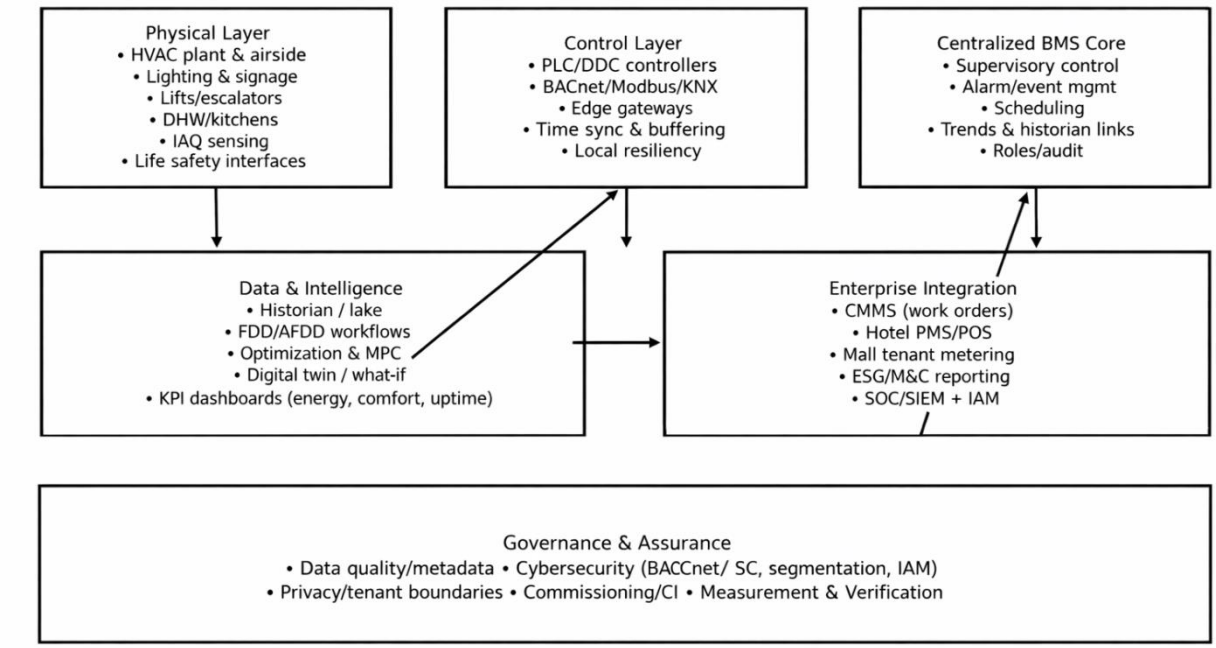
Relevant factors extracted include: type of building, scope of systems i.e., HVAC, and multiple domain applications; connectedness/integration of building solutions such as BacNet, gateway, CMMS/PMS; connectedness/integration of building solutions such as gateway, analytics i.e., FDD/Afdd, DT, building outcomes. This extracted information is then thematized and classified under five various categories, namely: T1: Energy & Carbon; T2: Maintenance & reliability; T3: IEQ & Experience; T4: Integration & Workflows; T5: Cybersecurity & Governance

Furthermore, the extracted results have a relationship with the operation of the building; the factors related with the operation of the malls/hotels are identified below:

4 GRAPHICAL REPRESENTATION: REFERENCE ARCHITECTURE

Figure 1

Reference architecture for centralized BMS in smart malls and hotels (2020–2025 synthesis).



From observation of Figure 1 below, it is evident that the proposed reference architecture of a centralized BMS, as proposed in smart malls and hotels, was developed on the foundation of pre-existing concepts and ideas, depicted and highlighted within literature over a given period - between 2020 and 2025. Observing the above illustration featured in Figure 1 above, it is elementary to note that the value proposition of a given BMS, especially when it comes to a centralized BMS, is depicted by its ability to carry out interoperable data capture at physical and control levels, its supervisory capacity in conjunction with the BMS core, intelligence with regard to FDD/AFDD, intelligence with regard to optimization, intelligence with regard to digital twins, intelligence with regard to integration at Enterprise level, intelligence with regard to governance and assurance, security by design and protocol guidelines, such as BACnet/SC, among others, and finally

integration, especially within the zones that may be categorized as variable, such as IT and OT.

5 THEMATIC SYNTHESIS

In this section, a brief description of the research findings is given together with a reference to the five themes. In relation to presenting these concepts to the readership that is more interested in logistics and operations, the characteristics of the themes in relation to the underlying mechanisms for BMS competency are identified.

5.1 Energy and carbon performance

The most common measurements for the efficiency outcome of modernization of the BMS for BMS modernization come under the theme of 'Energy Efficiency Savings.' Two items are highlighted as indicated by the prevailing trends from 2020 to 2025: "The first relates to the fact that the most savings potential appears to exist for optimization and/or scheduling of the whole plant rather than zone tuning," and "the second relates to the fact that 'ongoing savings' requires good governance and not 'set point adjustment.'" Systemic reviews on the energy management systems of buildings have revealed that the existing energy management systems reflect the attributes of the IoT technology, intelligent or artificial decisions, as well as optimization attributes. Systemic reviews of the energy management of buildings have revealed the significance of data accessibility as well as interpretability of models for building energy management systems (Akbulut et al., 2025; Shahid et al., 2025). For considering the space equipment that is installed in the mall as well as the hotels for the building management system in the building energy management system, one can deduce that the measures for the supervision of control can be regarded as critical for considering the efficiencies of the buildings in the building energy management system. The next major control strategy is the awareness of occupancy. From various studies done on awareness through occupancy detection surveys, it has been understood that "PIR, CO2, Wi-Fi, video, and booking information" could indeed prove to be beneficial in developing demand-controlled ventilation and schedules that may end up reducing energy consumption and maintaining IEQ at or above

comfort levels (Chaudhari et al., 2024). Similarly, for hotels, there exists potential for developing a system for Occupancy Intelligence by integrating it with PMS systems that sense "checked-in," "checked-out," and "do-not-disturb," without affecting any comfort parameter for occupants. Also, for shopping malls, there may exist much scope in terms of saving energy with regard to air conditioning systems because of varying levels of occupancy. Moreover, the aspects of ventilation and temperature are of major concern because of event-related variables for shopping malls and hotels. Furthermore, a large amount of work has been done on the aspects of privacy for Occupancy Estimation, as well as the avoidance of invasive approaches with cost-effective sensors, as long as data can be collected using bookings/schedules (Shokrollahi et al., 2025). Moreover, the aspects of the propositions, as discussed with reference to a DT-based EMS, highlighted DTs as enabling possibilities and opportunities not only for optimizations and possibilities, but also for optimizations and possibilities at a higher level, which can be cited as a fact with reference to proposals focusing on a DT-based EMS, its operational phase, which highlighted DTs as enabling possibilities and opportunities not only for building energy efficiency optimization, although associated with aspects and factors such as the problems and issues faced with reference to DTs, such as DTs, as well as their maintenance, as discussed with reference to dt-bems, associated with aspects such as "costs" and "twin drifts" between actual and simulated reality (Bortolini et al., 2022; Cespedes-Cubides et al., 2024). Perhaps one of the strongest aspects and lessons a professional can derive and consider with reference to the above propositions, their implications, and their aspects can be the fact that DTs will work and will make a difference if they are fed and constrained by a query associated with building opportunity, rather than DTs being capable despite the fact that they are not constrained and queried as such. Moreover, DTs are capable and powerful with stability associated with comfort, whereas intense cuts can result in potential problem aspects associated with comfort, resulting in a workforce's workload, which is perhaps one of the best and most credible sources, as discussed in the literature associated with the subject matter and field, focusing on the concept of "energy as constrained objectives with comfort and reliability, auditability, and stakeholder integration and alignment" (Rajić et al., 2022; ISO, 2020).

5.2 Productivity of maintenance, reliability, continuous commission

Scenarios like this, regarding downtime and recurring problems, make for a very expensive item in terms of mall and hotel operations. When problems occur, there is a cost for things such as services regarding issues with room comfort, issues regarding interrupting tenancy, issues regarding offending corporate reputation, and issues regarding mandatory overtime. Implementation from a central point facilitates the achievement of a level of improved reliability by three unique mechanisms: first, with respect to FDD/AFDD and Predictive Maintenance; second, with respect to the function of continuous telemetry and alarm/event history records.Hence, the research-based literature from 2020 to 2025 shows that the prime focus lies in allowing the right quantity of operational activity with the help of data transformed through the use of BMS with FDD/AFDD. Also, previous reviews associated with DT show that a majority amount of emphasis has always been provided to "FDD," which was a type of DT application for "O&M" development, as suggested by Hosamo et al. (2022). However, a few studies have shown that the focus can be changed from "possible alarms according to existing rules" to "explanatory diagnosis reports" along with "knowledge representation" in the context of AFDD/FTTs. Moreover, as a result, "very recent" research was conducted by Li in "Building and Environment" in 2025, where "agentic AFDD" was introduced that included "an AI agent, an ontology, together with general rules" which helped in generating "interpretable diagnosis reports" that helped to overcome the "adoption barrier" because "black box alarms tend to be difficult to trust by technicians, especially in locations such as malls or hotels where staffing issues due to shift workers or hired staff are possible."The process of attaining operational efficiency follows a framework called “closed-loop maintenance,” wherein BMS identifies problems, CMMS manages work requests, technicians record actions taken and BMS tracks resolution with post-repair trends. In fact, the described process is considered a good example of the concept of closing the learning loop. In relation to the US DOE building program, there was clear guidance that building FDD tools are considered highly necessary for facilitating retro-commissioning and continuous commissioning, provided these FDD tools must be used for achieving savings (U.S. DOE, 2024). In malls, closed-loop maintenance of escalators, lifts, AHUs, and chilled water systems are highly essential because these systems have

problems associated with recurring faults. Similarly, in hotels, closed-loop maintenance has been found highly essential for service recovery.

A pragmatic reality of this benefit is that, with the BMS being centralized, operating logs are created automatically. As explained earlier, the "analytics to action" concept would be made operationally possible by means of automatically generating the logs in regular intervals rather than writing shift logs by hand. This is the way of ensuring that alarms, trends, and actions are appropriately timestamped, attributable, auditable, and potentially passed on to the CMMS as actionable work orders.

5.3 Saudi vision 2030 alignment

Energy Efficiency & Demand Reduction: BMS Optimization and M&V best practices are stably applicable at the energy consumption intensity target level for mall/hotel scales.

ESG transparency: Information on automated energy, comfort, and maintenance can be useful for ESG reports and scores.

Operational Excellence: The closed-loop maintenance ensures minimal downtime of the assets. This will result in a better customer experience within the asset.

Cyber Resilience: BACnet/SC, when combined with both RBAC and audit logs, has considerable potential to minimize disruptions to interconnected smart assets.

Table 1

Saudi Vision 2030 alignment

Domain / System	**What BMS can Control**	**What BMS can Monitor**	**What BMS can Supervise / Automate**	**Operational benefit (why it matters)**
Chillers & chilled water plant	Chiller staging, setpoints, VFD speeds, CHW supply temp reset	kW/RT, ΔT, flow, pressures, alarms, runtime	Optimal sequencing, peak shaving, anomaly detection (ΔT drift), auto lockout rules	Reduced utility cost, stable comfort, fewer plant trips
AHUs / FAHUs	Supply air temp, fan speed, damper positions, economizer	Filter DP, coil ΔP, fan status, airflow, alarms	Demand-controlled ventilation (DCV), schedule-based mode switching, fault rules (stuck damper)	Energy + IAQ compliance + fewer complaints
VAV/FCU/Room units	Zone setpoints, valves, fan speeds	Zone temp/RH/CO_2,	Occupancy-based modes (hotel PMS	Comfort stability + reduced waste

Domain / System	**What BMS can Control**	**What BMS can Monitor**	**What BMS can Supervise / Automate**	**Operational benefit (why it matters)**
		valve position feedback, alarms	link), night setback, auto balancing alerts	in unoccupied areas
Ventilation & exhaust	Fan speeds, exhaust schedules	CO/CO_2, airflow, status, fire interface	Kitchen ventilation demand control, parking CO-based control	Energy savings + safety compliance
Electrical distribution (LV/MV)	Load shedding schemes, ATS/STS logic, breaker interlocks (interface)	Power quality, demand, PF, feeder loads, harmonics	Demand response, critical load prioritization, alarm escalation	Reduced downtime risk + optimized peak demand
Backup power (genset/UPS)	Start/stop sequences (via interface), test schedules	Fuel level, UPS load, battery health, alarms	Auto test logs, runtime-based maintenance alerts	Reliable contingency + audit readiness
Lighting (common areas)	Schedules, dimming, scene control	Circuit status, occupancy sensors (if integrated)	Daylight harvesting, event-based scenes (mall events)	Lower energy + improved experience
Escalators & elevators (via vendor interface)	Mode scheduling (where supported)	Fault codes, usage, availability	Early warning on repetitive faults; CMMS ticket auto-creation	Reduced downtime + faster recovery
Fire & life safety (integrated monitoring)	*Control limited* (life safety is primary system)	Status, trouble alarms, supervisory signals	Unified incident dashboard, evacuation coordination views	Faster incident response + compliance reporting
Water systems (domestic/irrigation)	Pump staging, pressure setpoints	Flow, leaks (if sensors), tank levels	Leak alarms, abnormal consumption detection	Reduced loss + OPEX control
Heat recovery / energy recovery	Wheel speed, bypass dampers	Effectiveness, temps, alarms	Auto optimization based on OA conditions	Lower HVAC energy + stable IAQ
Indoor Environmental Quality (IEQ)	Setpoint bands (via HVAC)	CO_2, PM2.5 (if deployed), VOC, RH, temp	Compliance dashboards, chronic hotspot detection	Comfort + health + ESG reporting
Refrigeration (hotel kitchens/retail)	Setpoints (where supported)	Temps, alarms, door status	HACCP-aligned alarms, after-hours alerts	Food safety + reduced waste
Tenant utilities / sub-metering (malls)	*Limited direct control*	Tenant kWh, peak, water use	Billing-ready reports, anomaly alerts, dispute evidence	Fair allocation + governance + reduced conflict
Security/Access integration (optional)	*Indirect via rules*	Door events, access schedules	"Do-not-disturb" logic integration, area occupancy inference	Better operational coordination + privacy-aware rules

Domain / System	What BMS can Control	What BMS can Monitor	What BMS can Supervise / Automate	Operational benefit (why it matters)
Cybersecurity governance (BMS side)	Account policies, RBAC enforcement	Auth logs, configuration changes, network health	Change control workflow + audit export	Reduced cyber risk + auditability

5.4 Indoor environmental quality and experience

With regard to the malls and hotels, the customer experience cannot be separated from the efficiency of the operation. This is indicated as complaints in the hotels in cases where the comfort level is non-efficient, together with a reduction in the time for the customer experience in the mall, which is then indicated as a non-efficient operation of the building. Thus, it is not appropriate to measure the efficiency of the operation of the management of a building as service and comfort concerning energy.In regard to research on occupancy detection, IEQ sensing mechanisms, and analytics conducted in the period between 2020 and 2025, there appears to be an indication of an improvement and enhancing of the underpinning for demand response mechanisms for comfort management techniques. From some of the reviews on occupancy detection mechanisms and techniques, there appears to be an emphasis and focus on potential cost savings on energy costs by means of automating lighting and HVAC systems as well as enhancing interior air quality through demand-only approaches for ventilation (Chaudhari et al., 2024). Perhaps one of the most vital opportunities for responsiveness as a means of operation appears to go beyond “turning off” and further into bands that include high percentages and potential problem areas for high occupancy.These also provided IEQ monitoring and were cheaper sensors. It monitors indoor CO2, particles such as PM2.5, humidity, and temperature. Comparatively, operationally with thermostat measurements, there is a much more complete monitoring configuration for IEQ sensors. There are three processes from the standpoint of operations which can be implemented using IEQ sensors: (i) monitoring for compliance/sufficiency of ventilation, (ii) incident investigation/hot spots, and (iii) continuous improvement/chronic underventilation and or overcooling. For hotels, IEQ sensors translate into requests for service, while for the mall it also involves stratification and volume of air.It has been suggested that digital twins of

comfort be used for management, which can be utilized for exploring trade-offs and simulations for strategy development. The reviews that have been suggested by several have segmented the digital twins of comfort management into three categories and subgroups such as optimization of comfort, building BOM, and decision support. While considering the comfort of the service environment, there should be a relation of comfort with operational workload-for instance, taking into account an increase in range and, as a result of that, an increase in cycling of valves and fans, influencing maintenance. The best approach, along with consideration of the objectives and constraint optimization, is to take BMS logs into account. The comfort and experience are complimentary to the above and yet another area which most literature doesn't cover. Most of the literature talks of the results obtained from energy saving outcomes without effectively analyzing comfort. In ensuring stability, the measures of comfort augmentation considered are Scopus/ Q1 venues: temperature deviation distribution, complaints, etc.

5.5 Workflow integration: CMMS, PMS/POS, Tenant Systems, and ESG

Centralization is efficient under the conditions that either coordination cost is zero or centralization is a translation from signals to decisions. In a mall or hotel environment, there will be many operating roles including engineering, security, cleaning, customer relations and leasing, besides vendors. Hence, "integration" must be considered as an issue or problem in the workflow, not as a computer program API. The PMS in the hotel industry would have included a facility to integrate the logic corresponding to the states of a room. This reduces waste in case a room is kept unoccupied for a long period and discomfort in case a person occupies a room. With respect to prioritization of tasks, the grievance of high-value customers gets quick service depending on the PMS signal by linking with the BMS signal of the task where adjustment can be made to kitchen ventilation, etc. In regard to a shopping mall, for example, the extent of the boundaries of its tenants adds yet another layer of complexity. Generally speaking, the party owning a mall operates the HVAC and central plant. Regarding the purpose of the project with sub-metering, there might be utilities a centralized BMS may be. For security and life safety incidents, many processes have to be handled from a BMS, security systems, and a fire alarm. Regarding the aspect of building operations, there is a benefit. The benefit is the

increased operational efficiency in which all issues can be addressed quickly. A bigger role in "Operational Efficiency" is that of ESG and M&V, and can be done by imposing disciplines in reporting, hence making individuals responsible and not letting drifts of any kind occur. ISO 50001 provides a management system in developing strategies for improvement in building performances because developing these kinds of strategies needs to be a "management system" toward improving energy performance, as stated in Energy Management - A Management System For Energy Performance Improvement According to ISO 50001 (ISO, 2020). ISO 50001 frameworks also have been proposed concerning the hotel industry, supported by an empirical research study with a greater sample size, with a focus on the role that organizational methods will result in these forms of savings: “Organizational routines play a crucial role in maintaining energy savings.” Rahić et al., BMS plays a prime role in measurement backbone, Yet another generalization that is general in all these texts penned within 2020-2025 is that of defining governance - roles and responsibilities, triage systems, and audit trails-as pa…

5.6 Cybersecurity, privacy, and governance

It is one of the critical factors for the efficient operation due to security threats, which potentially compromise efficiency based on reduced costs of operation. The second class under this category is hotels and shopping centers, which, although vulnerable, may have complex security threats, especially concerning complexities involving cyber technology, which are comprised of guest network, tenant network, and vendor remote access network.In terms of a survey paper that focuses on the domain of the Internet of Things, there have been discussions on various protocols that are associated with BAS. In addition to that, there have been discussions on various protocols that are associated with BAS and security attacks that are associated with BACnet, KNX, LonWorks, Zigbee, etc., and development of security protocols that include BACnet Secure Connect (BACnet/SC) developed by Morales-Gonzalez et al. (2024). By implication, it appears that these connectivity options that have been used by the legacy BAS would not be adequate for managing the dynamics of the threat scene that is being presented here. There are interesting security issues that are being presented with regard to the approach that would have to be taken for providing security for the BAS, and this has been highlighted

through a document presented by the IoT Security Foundation for facilities practitioners."This same process has also had an impact within the world of BACnet, as the following examples will delineate this process in greater context. For example, within the publication written by the ASHRAE pertaining to 'Managed BACnet,' the following has been written: 'BACnet/SC plays a key role in facilitating cybersecurity improvements and offers implementation considerations consistent with IT best practices.' In the second publication pertaining to BACnet International, the following passages were also written: 'BACnet/SC facilitates secure connections between BAS equipment using IP connectivity.'"From this, it can be quickly determined that what is needed in this particular case are the following security architecture patterns: segregation of OT networks/IT networks, identity and access management, RBAC implementation within the BMS system, audit trails, monitored remote services, and SOC/SIEM sensitivities.Finally, there is also the issue of privacy as well as that of the boundaries of the tenants themselves, which can also be seen as a governance issue in relation to the above analytics projects. Finally, in relation to the issue of detecting occupants by use of cameras and/or WiFi signals that can be seen as sensitive signals in relation to the above issue of privacy preservation in relation to the above mechanisms associated with the issue of detecting occupants, it should be clearly noted that in relation to the above issue of privacy preservation in relation to mechanisms associated with the issue of detecting occupants, this can be seen as a critical issue in relation to the general usage of the above issue as far as the above mechanisms associated with the issue of detecting occupants are concerned. As a matter of fact, as it is noted in Chaudhari et al. (2024) and Shokrollahi et al. (2025), the issue of privacy in relation to its governance is seen as operationally relevant in relation to reputational risk and legal analytics usage.Another key factor in governance is data quality assurance. Apparently, out of all the issues identified in the course of all reviews of requirement specifications of digital twin, the most vital one has been identified with regard to data quality issues affecting the accuracy of digital twin itself, hence affecting trust in that manner. Of course, one has to take care of issues regarding how this newly emerged level of this system under the caption of 'Governance & Assurance' can be made to be acceptable other than being merely in the nature of a policy document.

6 EVIDENCE MAP TABLE

Table 2 suggests one that describes the description of the mapping with regard to the centralization capabilities of BMS, the result, data, and context concerning the domain 'malls' and 'hotels.' It is meant to offer a structure that is relevant to a researcher, together with a structure that is relevant to a practitioner and a map of evidence. It is meant to offer a description of "what matters operationally" together with a proposed structure shown in Figure 1, without taking into account the technology component.

Table 2

Evidence map linking centralized BMS capabilities to operational efficiency outcomes (2020–2025).

Centralized BMS capability	Operational outcome pathway	Key data inputs	Malls vs hotels (context)	Representative 2020–2025 sources
Supervisory HVAC & plant control	Energy intensity, peak demand, comfort stability	Plant telemetry, zone temps, valve/VFD states	Malls: atrium/footfall variability; Hotels: room states & events	Akbulut et al. (2025); Shahid et al. (2025)
Occupancy-aware schedules & ventilation	Energy + IAQ via demand-controlled ventilation	CO_2, PIR/video, Wi-Fi counts, bookings/PMS	Hotels: PMS-linked room modes; Malls: footfall/event spikes	Chaudhari et al. (2024); Shokrollahi et al. (2025)
FDD/AFDD + continuous commissioning	Reduced faults, lower energy drift, improved uptime	Trend logs, alarms, equipment KPIs	High value in aging assets and 24/7 operations	Li (2025); U.S. DOE (2024)
Digital twin-assisted operations	What-if evaluation, predictive control, O&M planning	BIM/physics models + real-time streams	Hotels: room-level strategies; Malls: plant optimization	Bortolini et al. (2022); Cespedes-Cubides et al. (2024); Hwang et al. (2025)
Cybersecurity governance (BACnet/SC, IAM, segmentation)	Lower disruption risk; safer remote access; compliance readiness	Asset inventory, network flows, identity logs	Hotels: guest network coexistence; Malls: tenant/vendor access	ASHRAE (2025); Morales-Gonzalez et al. (2024); IoTSF (2023)
ISO 50001-aligned EnMS and M&V practices	Sustained savings and accountability	Baselines, metering, EnPIs, corrective actions	Hotels: multi-property benchmarking; Malls: common vs tenant allocation	ISO (2020); Rajić et al. (2022)

7 MANAGERIAL IMPLICATIONS AND IMPLEMENTATION ROADMAP

A reasonable roadmap for the operator to follow could be a pattern which has four distinct phases.

Phase 1: Visibility and point governance, which entails the creation of a single asset hierarchy and a tagging policy, as well as trending. In addition to that, it is also important to affirm time synchronization, sensor calibration, and alarm rationalization. Thus, it can be assumed that UNDERSTANDING, as a component of the proposed ACCEPTANCE criterion, will be demonstrated when operators are able to trust the information enough to understand that it shows reality.

Phase 2: Workflow: At this phase, we see a combination of information from alarms in the building management system as well as information from tickets in the CMMS system, which represents a sense of priority as well as a sense of play as well. This information would include, for example, in an environment like a hotel, information from property management in general, or for room modes in terms of occupancy, and sub-metering boundaries for an environment like a mall.

Phase 3: Continuous commissioning & analytics, FDD/AFDD, Rationalization of Alarms, Integration of diagnostics with CMMS, and Incorporation of occupancy schedule and baseline M&V approach to strengthen the value case for energy savings and comfort, respectively (Li, 2025; U.S. DOE, 2024).

Phase 4: Digital twin and optimization. Create a decision-centric operation twin, e.g., an efficient plant model, or a stability comfort model, along with its associated governance, considering some factors, i.e., but not limited to, a drift check and change control, as proposed by Bortolini et al. (2022); Cespedes-Cubides et al. (2024).In all forms, it is a necessity for cybersecurity, especially for deep integration technology that needs secure connections with BACnet/SC, as clearly emphasized in the recommendations and surveys conducted (ASHRA, 2025; Morales-Gonzalez et al., 2024).

8 RESEARCH GAPS AND AGENDA FOR SCOPUS/Q1 LOGISTICS-ORIENTED PUBLICATIONS

Nevertheless, despite the fact that this particular piece of technology is well-developed and well-founded, there are certain gaps in knowledge that bear relevantly on Q1 outlets.

G1: Operationally Credible Evaluation Design: Signs of an improving trend without any adjustments for seasonality, occupancy, or concomitant indicators. Possibility, in the future, of using techniques like those employed with the 'Sister Science of Quasi-Experimentation,' such as before-after normalization, control groups, and even the 'Tiered Rollout Approach,' especially with regard to G2: Standardization for reporting key performance indicators: With the standardization of energy efficiency as a routine process, security will become measurable as part of security policies. Then reports will be generated for MTTR, MTBF, time taken by technicians, percentage distribution for stability, and complaints raised for comfort. G3: Transferability, Semantics Interoperability - Vendor-related point models are limitations that need to be addressed in achieving transferability of learning results across multiple sites. The scope of studies may include work on semantics for transferring/interoperating, deploying with speedup, and enhancing transferability. G4: Socio-Technical Adoption AFDD using the agential approach in explainability in technology has immense potential as proposed in Li (2025). However, most studies based on technology adoption need to ensure trust elements are incorporated. G5. Privacy and Tenant Governance. To exemplify this based on the case presented on the malls scenario, there is a need to conduct empirical studies on fair agreements for sub-metering, data sharing agreements, and privacy-preserving analytics. G6: Security by Design economics. There is also a cost factor where studies require defining the cost of ownership risk and disruption potential with possible benefits in creating a "Business Case" of a secured "solution". 9. Limit With all of the backgrounds and definitions that have been stated regarding the study and the literature review that has already been done within this piece of work, there exist some kinds of limitations with regard to the following: first and foremost, there is a need to consider the fact that the literature varied; apart from merely studying and implementing this, there is a need to include the implementation of this literature as part of it, in spite of the fact that this

particular literature was very influential; apart from merely the office setting and the implementation that already exists today with regard to the office setting, this might not have been as crucial as the other literature that is also supposed to have been included and noted; however, in spite of the fact that this has not generally been considered when undertaking a study with regard to this particular piece of work, there exists a probability that there might have been an inference to the setting of a mall/hotel setting; apart from all of these disadvantages and limitations that have already been noted in this piece of work with regard to this very notion of implementing the literature in the office setting, this in spite of the fact that this has not delved too Much

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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