Intelligent Building Technologies: A Technical Overview

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Lester S. Shen, PhD and Di Sui, PE
CENTER FOR ENERGY AND ENVIRONMENT

Maureen Colburn, AIA; Stacee Demmer, AIA; Claire Winters;
David Williams, PE; and Nathan Wriedt, PE
LHB

Brad Kult, PE
BUILDING INTELLIGENCE GROUP

Luis Suau
LUIS SUAU CONSULTING LLC

Matthew Schwartz
PARALLEL TECHNOLOGIES

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Introduction

This white paper is intended as an overview of the current state of intelligent building technologies and the potential for intelligent buildings to increase the efficiency of building operations, promote greater occupant comfort and productivity, and serve as an energy resource to the electrical utility grid. This overview will describe what it means for a commercial building to be "intelligent," how this "intelligence" can be imbued, and opportunities that this "intelligence" can bring to the building's owners, operators, and occupants, as well as the grid.

The Energy Conservation and Optimization Act of 2021

On July 27, 2021, Governor Tim Walz signed into law the Energy Conservation and Optimization Act of 2021 (ECO Act),[1] which increases the statewide annual energy savings goal from 1.5% to 2.5%. The ECO Act updates the Conservation Improvement Program (CIP) which oversaw the utility energy efficiency program goals in Minnesota. Electric investor-owned utilities (IOUs) will now be required to save 1.75% of gross annual retail energy sales. To achieve this goal, the ECO Act will allow IOUs to pursue fuel-switching improvements and load management, along with their traditional energy efficiency programs. The ECO Act also requires consumer-owned utilities such as municipal electric utilities (munis) and electric cooperatives (co-ops) to achieve an average 1.5% savings goal over the length of their approved plans. Up to 0.55% of their average savings goals can be attained through efficient fuel-switching measures. Load management will also be allowed to be counted toward their savings goals.[2]

In 2017, Minnesota's commercial building sector consumed 19.5% of the total energy consumed in the state.[3] To assist utilities in achieving the savings goals set forth by the ECO Act, commercial building energy use must be improved through more efficient building operation. According to the U.S. Energy Information Agency, electricity in commercial buildings accounted for 61% of that sector's total energy end-use consumption in 2012 with heating, ventilating, and air-conditioning (HVAC) accounting for 33%, lighting for 17%, and computers and office equipment for 14% of the electricity use. Miscellaneous appliances, plug loads, pumps, and

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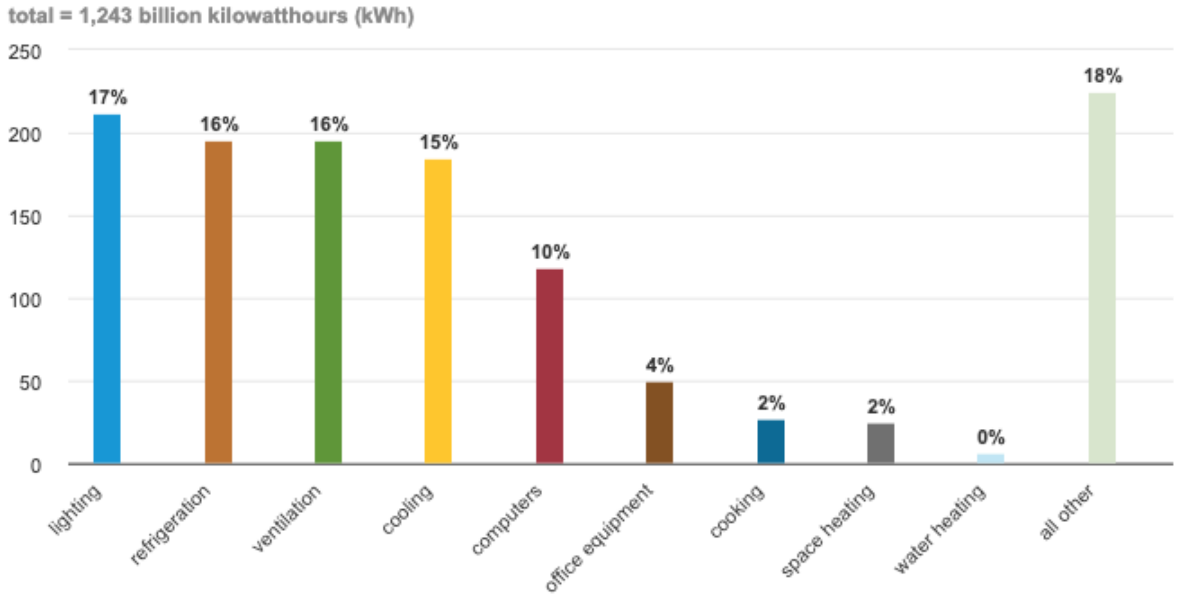
[1] http://wdoc.house.leg.state.mn.us/leg/LS92/HF0164.2.pdf

[2] M. Wazowicz, "Minnesota Passes the ECO Act, a Modern and Expansive Update to its EE Framework", Midwest Energy Efficiency Alliance blog, May 26, 2021, https://www.mwalliance.org/blog/minnesota-passes-eco-act-modern-and-expansive-update-its-ee-framework

[3] Minnesota Department of Labor and Industry and the Minnesota Department of Commerce. 2020. Improving building energy efficiency in commercial and multi-family construction. https://www.dli.mn.gov/sites/default/files/pdf/BuildingsEnergyEfficiency2020.pdf

motors comprise part of the 18% that is listed as “all other.”[4] Figure 1 shows the major commercial building electrical end uses in 2012.[5]



Note: *All other* includes motors, pumps, air compressors, process equipment, backup electricity generation, and miscellaneous appliances and plug-loads.

Source: U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey*, Consumption and Expenditures, Table E5, May 2016

Figure 1. Electricity Use in U.S. Commercial Buildings by Major End Uses, 2012

Each of these end uses have energy savings opportunities that can be realized by equipment upgrade, system maintenance, and efficient operations. Typically, the responsibility for operations and maintenance (O&M) of HVAC falls to the property management maintenance team and their mechanical/controls contractor, computers and office equipment to a tenant’s IT manager, and the other systems to the facilities department (if one exists), with each often treated as a disparate component rather an integrated system. The additional energy savings benefits of building system integration provided by intelligent buildings can help Minnesota achieve the updated energy savings goals of the ECO Act.

The Internet of Things

The Internet of Things (IoT) and connected devices have brought communication ability between devices and systems not only within the local area network, but also in connection across the internet (i.e., the cloud). With the addition of sensors, automated controls, and information system dashboards, the ability to monitor and manage building systems has been greatly enhanced by IoT. Building automation systems are being further upgraded with fault detection and diagnostics (FDD), using artificial intelligence and machine learning to assist in

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[4] https://www.eia.gov/energyexplained/use-of-energy/commercial-buildings-in-depth.php

[5] 2012 is the most recent year for which detailed data were available at the time of the most recent EIA update.

building O&M. Previously disparate systems can share information and be operated by an integrated management system. This integration can have synergistic effects to provide a greater opportunity for building energy efficiency.

A 2017 American Council for an Energy-Efficient Economy report[6] found that "[w]hereas an upgrade to a single component or isolated system can result in energy savings of 5–15%, [an intelligent][7] building with integrated systems can realize 30–50% savings in existing buildings that are otherwise inefficient. Savings can reach 2.37 kWh/sq. ft." The report examined a range of smart technology opportunities that included the following:

- HVAC systems
- Plug loads
- Lighting
- Window shading
- Automated system optimization
- Human operation
- Connected distributed generation and power

Figure 2 shows how these technologies interact within the intelligent building system. The figure divides the elements of intelligent buildings into two groups: the connected building systems governed by the building automation system (shown by the elements denoted with green backgrounds in the figure) and the building performance monitoring provided by the energy information system (shown by the elements denoted with blue backgrounds in the figure).

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[6] J. King and C. Perry. Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings. American Council for an Energy-Efficient Economy. Report A1701, February 2017. https://www.aceee.org/sites/default/files/publications/researchreports/a1701.pdf

[7] The King and Perry report uses the term "smart buildings." Currently, it has become accepted practice to refer to commercial buildings that incorporate IoT or smart technologies as "intelligent buildings," while residential buildings are usually referred to as "smart homes." For this report, to avoid confusion, we will use the term "intelligent buildings" for smart commercial buildings.

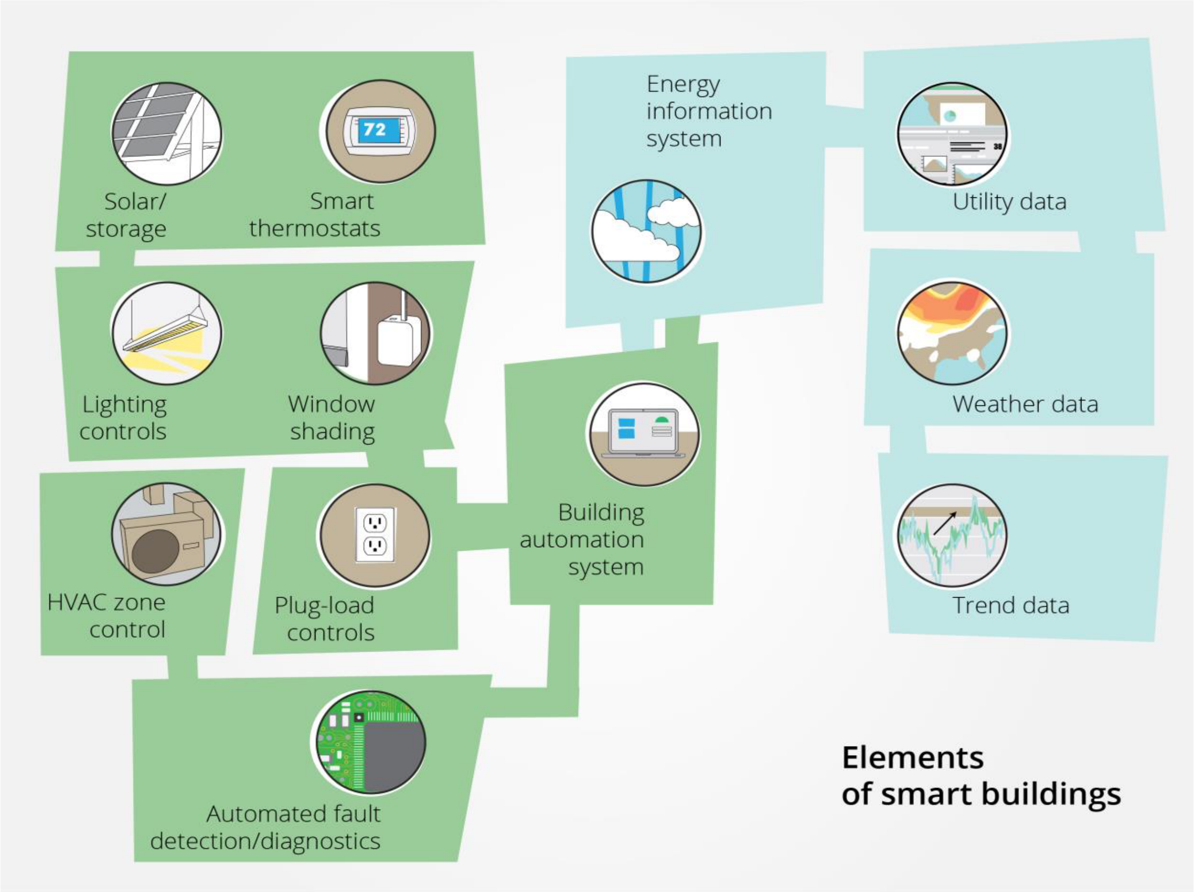

Figure 2. Overview of Intelligent Building Technologies [from King and Perry (2017)]

Table 1 provides their list of the various smart technology options with the associated estimated energy savings.

Table 1. Savings Estimates for Intelligent Building Technologies [from King and Perry (2017)]

Category	Technology	Components	Energy Savings
HVAC	Wired sensor	Energy, temperature, flow, pressure, humidity sensors	Not applicable
	Wireless sensor	Energy, temperature, flow, pressure, humidity sensors	Not applicable
	Variable frequency drive (VFD)	Variable frequency drive (pumps and motors)	15–50% pump or motor
	Smart thermostat	Smart thermostat	5–10% HVAC
HVAC & lighting	Hotel guest room occupancy controls	Door switches, occupancy sensors	12–24% HVAC, 16–22% lighting
Lighting	Advanced lighting controls	Occupancy/vacancy, daylighting, task tuning, lumen maintenance, dimming, daylighting	45%
	Web-based lighting management system	Software and hardware	20–30% above controls savings
Plug load	Smart plug	120v 220v	50–60%
	Advanced power strip	Tier One types	25–50%
Window shading	Automated shade system	Shades w/ automatic controls	21–38%
	Switchable film	Self-adhered	32–43%
	Smart glass	Thermochromic Electrochromic	20–30%
Building automation	Traditional BAS	Sensors, controllers, automation software	10–25% whole building
Analytics	Cloud-based EMIS	Sensors, communication systems, web-based software	5–10% whole building
DER	Smart inverter	Smart inverter	12%

Table 2 replicates the data King and Perry reported for the energy savings these smart technologies could provide to various commercial building subsectors.

Table 2. Commercial Building Subsector Energy Savings from Intelligent Building Technologies [from King and Perry (2017)]

Building Type	Floor Area (sq. ft.)	Smart building technology	Average energy consumption (kWh/year)	Percent savings	Average savings (kWh/year)
Education	100,000	Occupancy sensors; Web-based lighting control management system	190,000	11%	20,900
Office	50,000	Lighting controls; Remote HVAC control system	850,000	23%	200,000
Hotel	200,000	Guest room occupancy controls	4,200,000	6%	260,000
Laboratory	70,000	Air quality sensors; Occupancy sensors; Real-time ventilation controllers	980,000	40%	390,000
Hospital	120,000	Lighting controls + LED upgrade; Data analytics software package	7,900,000	18%	1,400,000

Through IoT, existing and new buildings have the ability to become “intelligent” — to not only operate more efficiently but also be able to provide for the productivity and comfort needs of the building’s occupants. IoT adoption in commercial buildings is already significant. In their 2020 IoT Signals report,[8] Microsoft surveyed a global set of IoT decision makers and found that, for their U.S. respondents:

- 92% had adopted IoT in 2020 with the primary benefits being efficiency; productivity, and cost savings;
- 86% believe that IoT was critical to the success of their company; and
- 69% planned to increase the use of IoT in their business over the next two years.

Intelligent Buildings

“Intelligent buildings” has become a catchphrase for smart, connected commercial buildings with integrated building systems such as IT, lighting, HVAC, and hard-wired loads including security, fire/safety, and elevators. Intelligent building technologies (IBTs) are defined by the presence of

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[8] Microsoft | Hypothesis. 2020. IoT Signals. Edition 2. https://azure.microsoft.com/mediahandler/files/resourcefiles/iot-signals/IoT%20Signals_Edition%202_English.pdf

networked hardware and software that provide real-time sensing and analytics, control, and management that can enhance the O&M of commercial buildings. Adoption of both individual technologies (i.e., point solutions) and IBT is expected to grow in response to increasing energy costs, environmental issues such as carbon emissions and pollution, and operational practices to increase staff productivity, promote worker health and safety, and optimize space use.

MarketsandMarkets™ projects that the commercial segment will lead the growth of the intelligent building market, with commercial segment will grow from $66.3 billion in 2020 to $108.9 billion by 2025, at a compound annual growth rate (CAGR) of 10.5% during the forecast period.[9] This forecast was performed during the COVID-19 pandemic, accounting for its impact on commercial building occupancy and the transition to remote work. They define the range of IBTs as:

- Safety and security management systems
    - Access control
    - Video surveillance
    - Fire and life safety
- Energy management systems
    - HVAC control
    - Lighting management
- Building infrastructure management systems
    - Parking
    - Water (such as irrigation and domestic hot water systems)
    - Elevator and escalators
- Network management
- Integrated workplace management systems

Gardner, Inc. (2020) forecast that, from 2019 through 2029, IoT spending on building automation will grow by $6 billion. Energy savings from connected lighting and HVAC systems was determined to be the main driving force for revenue growth, with structure monitoring having the highest CAGR (27%).[10]

In 2019, Axonize performed a smart building, smart office, and facility management online survey, receiving more than 150 responses, with 47% of the respondents working for companies in North America and 35% working in Europe. According to the survey results, primary capabilities that are monitored by the smart technologies were HVAC (68% of responses); lighting (56%); security (49%); energy efficiency (48%); and Wi-Fi (48%).[11]

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[9] https://www.marketsandmarkets.com/Market-Reports/smart-building-market-1169.html

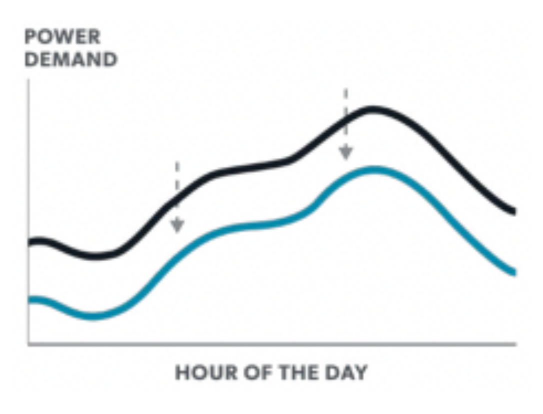
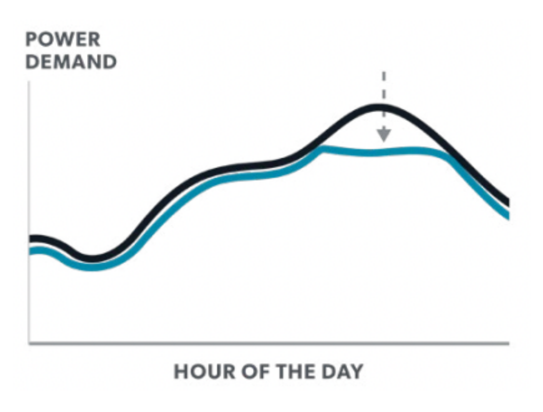
[10] https://www.gartner.com/en/documents/3991166/forecast-analysis-building-automation-iot-endpoint-elect

[11] Axonize. 2019 Axonize Smart Building, Smart Office, and Facility Management Survey, Survey Results and Executive Summary. https://www.axonize.com/wp-content/uploads/2019/09/Whitepaper_SmartBuildingManagementSurvey_v1.pdf

Grid-Interactive Buildings

While intelligent buildings have been promoted to developers, building owners, and tenants as operationally superior, these same connected systems can be enhanced to provide communication with the grid to create grid-interactive efficient buildings (GEBs). The U.S. Department of Energy (DOE) defines GEBs as “energy-efficient buildings with smart technologies characterized by the active use of distributed energy resources (DERs) to optimize energy use for grid services, occupant needs and preferences, and cost reductions in a continuous and integrated way.”[12] Table 3 shows how GEBs can benefit the grid.

Table 3. Grid Benefits of GEBs

Load Impact		Example Measure	Example Benefit
Efficiency		Building has an insulated, tight envelope and an efficiency HVAC system to reduce heating/cooling energy needs	Reduced costs of burning fuel to satisfy energy demand and reduced emissions associated with lower fuel use
Shed Load		Building dims lighting system by a preset amount in response to grid signals while maintaining occupant visual comfort levels	Reduced investment in generation and transmission capacity due to lower peak demand

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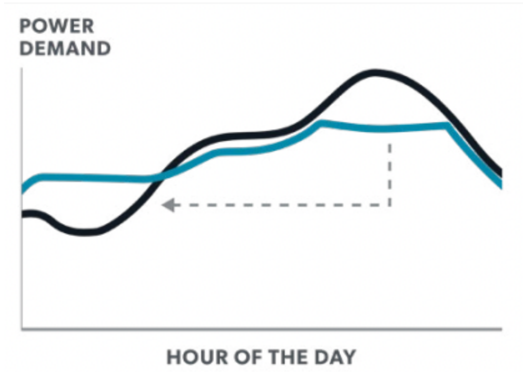
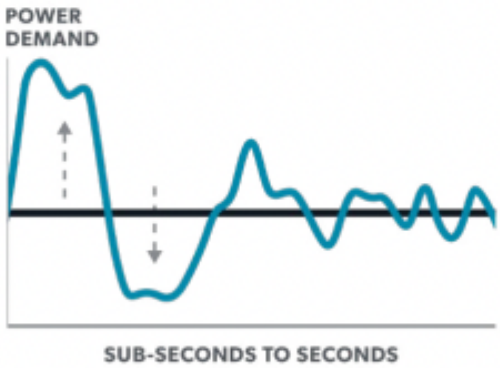
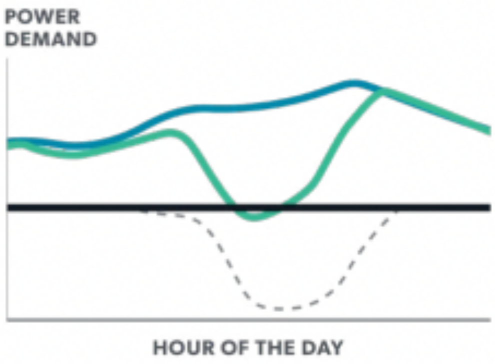
[12] A. Satchwell, M.A. Piette, A. Khandekar, J. Granderson, N. Mims Frick, R. Hledik, A. Faruqui, L. Lam, S. Ross, J. Cohen, K. Wang, D. Urigwe,D. Delurey, M. Neukomm, and D. Nemtzow. 2021. A National Roadmap for Grid-Interactive Efficient Buildings. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, Building Technologies Office. https://eta-publications.lbl.gov/sites/default/files/a_national_roadmap_for_gebs_-_final_20210517.pdf

Shift Load		Connected water heaters pre-heat water during off-peak periods in response to grid signals.	Reduced energy costs due to shifting consumption to cheaper hours of the day; avoided curtailment of renewables during off-peak periods
Modulate		Batteries and inverters autonomously modulate power draw to help maintain grid frequency or control system voltage	Reduced ancillary services costs, improved integration of variable generation resources (e.g., wind, solar)
Generate		Rooftop solar PV exports electricity to the grid	Reduced T&D losses due to on-site consumption; avoided need for grid-scale generation

DOE has announced a national goal for GEBs to “triple the energy efficiency and demand flexibility of the buildings sector by 2030 relative to 2020 levels.” Table 4 describes the main features that will enable GEB technology integration.

Table 4. Key Features for Enabling GEB Technology Integration

GEB Integration Layers	Large Commercial
Physical systems, hardware, and equipment	Insulated and tight envelope; Persistent and flexible loads; Dynamic façade, HVAC, lighting; Miscellaneous electric loads
Sensing (temperature, air flow, energy use, occupancy, light level)	Granular, distributed sensing for predictable and reliable building and grid service delivery; state of charge sensing for active or passive thermal storage
Local communication and control	End-user controls, such as thermostats or HPWH, capable of interacting with supervisory control and adjusting setpoints based on external input
Supervisory communication and control	BASs and energy management information systems providing predictive integrated control

DOE has defined the demand flexible (DF)-enabled technology pipeline for each of these GEB layers, as shown in Figure 3.[13] For commercial buildings, supervisory control technologies (shown in teal) is provided by the BAS (which on the timeline is shown as commercially available) and predictive control and multi-building control (which are both shown towards the in-development stage). Local control technologies (shown in the dark blue boxes) are commercially available for smart thermostats and water heaters with increased availability for connected lighting systems. Appliances and miscellaneous electric loads (MELs) currently have more limited availability and in many cases are still in development. Many physical systems (shown in orange) such as heat pump water heaters are commercially available. Thermal energy systems (denoted by the red boxes) tend more toward the limited availability/in development stages.

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[13] Ibid.

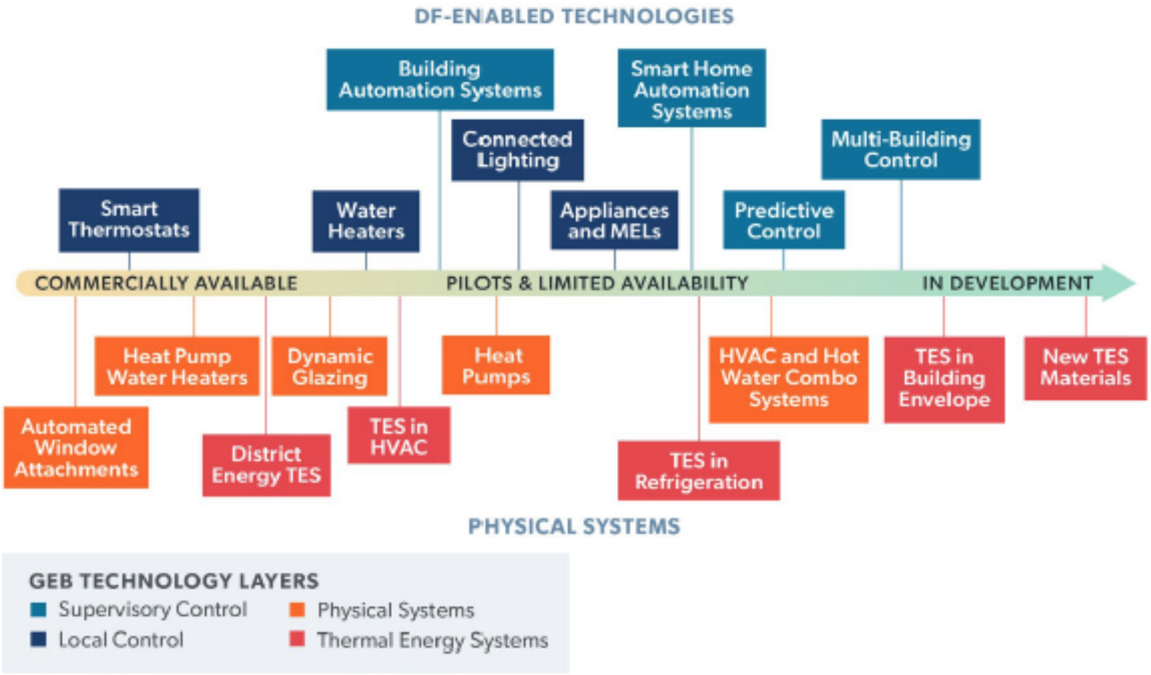

Figure 3. Technology Pipeline Examples for Each GEB Layer

Intelligent buildings provide the sensors, controls, and building system integration necessary for the building to achieve the demand flexibility required for grid interactivity. For example, two-way communication between the building and the grid will allow the grid to send signals to the BAS to modify building operation in response to grid needs. By managing the power loads of buildings through efficiency, load shedding, shifting, modulating power, and even energy generation, intelligent buildings will be an essential clean and flexible energy resource. Figure 4 shows an example of how an intelligent building can serve as a GEB.[14] Within the building, the intelligent building elements would be the HVAC system, connected lighting, plug loads, dynamic windows, occupancy sensing, and BAS. The GEB elements (which would incorporate the intelligent building elements) includes the rooftop PV + inverter, battery storage, EV charging, smart meter, additional inputs for optimization with the BAS, and the communications with the grid.

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[14] C. Harris. 2019. Grid-interactive Efficient Buildings Technical Report Series. Windows and Opaque Envelope. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy.https://www.nrel.gov/docs/fy20osti/75387.pdf

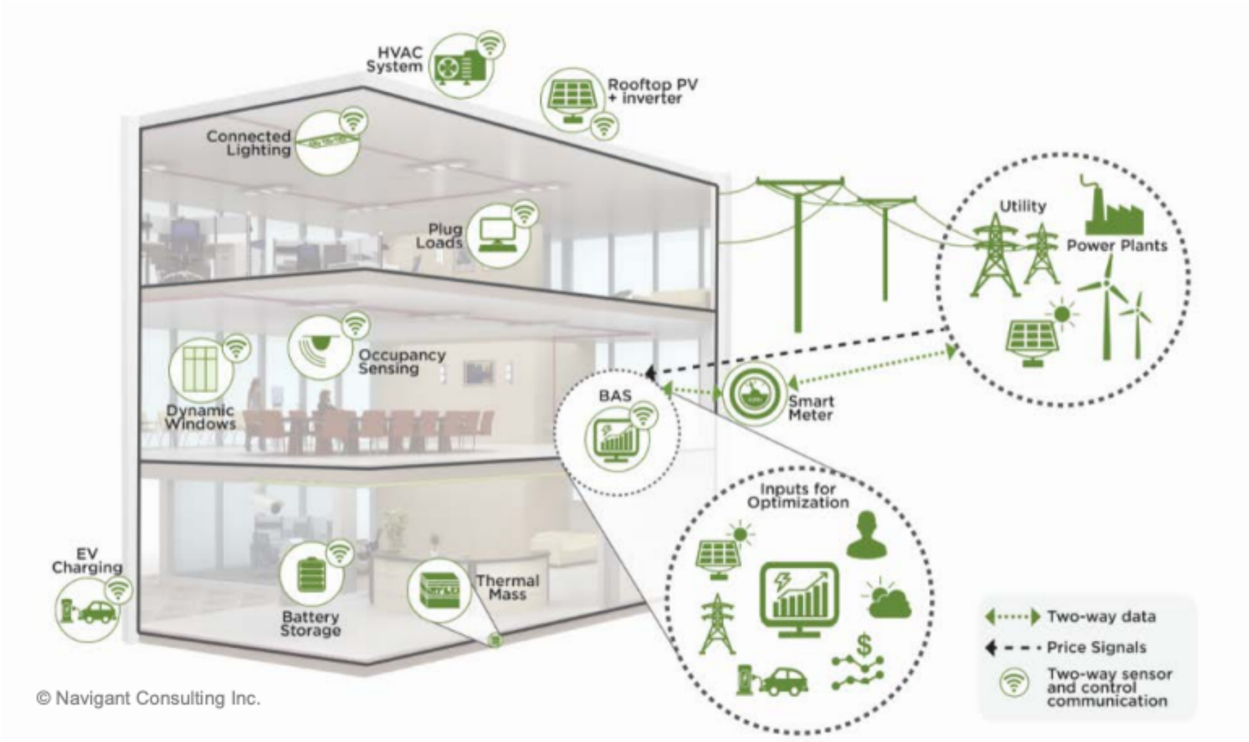

Figure 4. Example of a GEB

GEBs, Demand Flexibility, and Carbon-Free Electrical Generation

The ability of GEBs to reduce and shift the timing of electricity consumption through demand flexibility can bring a significant reduction in electric utility GHG emissions. DOE suggests that by 2030, GEBs could reduce CO_2 emissions by 80 million tons per year, or 6% of the total power sector CO_2 emissions.[15] This is another benefit that intelligent buildings can bring to Minnesota's efforts in achieving carbon-free electrical generation. Since the Next Generation Energy Act of 2007, the State of Minnesota has been one of the leading states in climate policy with a commitment to renewable energy and carbon-free electrical generation.[16] Xcel Energy and Minnesota Power, Minnesota's two largest public utilities, have committed to supply customers with 100% carbon-free electricity by 2050. Xcel Energy has pledged to reduce carbon emissions 80% by 2030 (over 2005 emissions), while Minnesota Power has pledged to achieve this target by 2035.[17] Great River Energy, a wholesale electric cooperative and the state's second largest electric utility, expect that their currently ongoing power supply changes will bring a 95% reduction in carbon emissions (relative to 2005 levels) by 2023.[18] In a report by the Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Commerce (MDoC), electricity generation was the only sector on track to meet the Next Generation Energy

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[15] A. Satchwell, et al., op. cit.

[16] https://www.pca.state.mn.us/air/state-and-regional-initiatives

[17] https://www.minnpost.com/environment/2021/01/minnesota-power-pledges-no-carbon-by-2050-zero-coal-by-2035/

[18] Great River Energy. 2021 Integrated Resource Plan Update. https://greatriverenergy.com/wp-content/uploads/2021/04/2021-Integrated-Resource-Plan-040121.pdf

Act GHG emission reduction goals.[19] Between 2005 and 2018, GHG emissions in this sector decreased by 29%.

On January 21, 2021, Governor Tim Walz proposed more accelerated clean energy measures that would call for Minnesota to be sourcing 100% carbon-free electricity by 2040.[20] The plan also calls for existing buildings to cut their greenhouse gas (GHG) emissions by 50% by 2035. The MPCA/MDoC study found that the commercial buildings sector saw an increase of 15% in GHG emissions (1.05M CO_2e tons) between 2005 and 2018.[21] GEBs and IBTs can be one approach to mitigating further commercial sector GHG emissions.

Optimizing the Design and Operation of Intelligent Buildings

Building Automation Systems

Since the term “intelligent building” connotes a centralized, automated system that monitors and operates the building, the primary IBT currently found in most commercial buildings can be identified as the building automation system (BAS). The BAS is most closely associated with the building’s HVAC systems and allows the energy use and conditions in the building to be monitored, controlled, and tracked. Schedules can be programmed for operating equipment (e.g., setpoint temperatures for the HVAC equipment, ventilation control, and occupancy schedules), and trend data can be collected to ensure the building is operating properly and efficiently. The BAS can also flag issues it detects, allowing service tickets to be created for actions that need to be taken.

Typically, a BAS has five components, described below, that provide the automated operation and management to the building: sensors, controllers, output devices, communication protocols, and the user interface.

Building system sensors can be used to monitor occupancy (presence, count, location, and identity); light levels and daylighting; indoor air quality (humidity, CO_2, VOC, and $PM_{2.5}$); security (duress, intrusion detection, door position, video, locks, ID badges); fire/smoke; network; sound; and smell. The sensors send the data they collect to controllers.

Controllers act on the data received from the sensors as well as any data collected by the equipment that they control to determine the state of the building. Based on defined rules, algorithms, or models programmed into the system, the controllers decide on any actions to take and then send out commands to the building systems (e.g., HVAC, lighting, security, fire/safety, water, and elevators).

Output devices perform the actions that take place as a result of the commands from the controllers. These include devices such as relays and actuators that signal the need or initiate

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[19] F. Char, A. Hawkins, and D. Sullivan. 2021. Greenhouse gas emissions inventory 2005-2018. https://www.pca.state.mn.us/sites/default/files/lraq-1sy21.pdf

[20] https://mn.gov/governor/news/?id=1055-463873

[21] Char et al., op. cit.

state changes in the building, such as changing the space temperature for a defined zone or controlling lights in the building.

Communications protocols allow the various building systems, devices, and equipment to interact through a common command language. BACnet is one of the most commonly used communication protocols. In addition, gateways are sometimes needed to allow the different systems and devices to communicate via these protocols.

A user interface such as a dashboard, console, or terminal provides the window into the building systems where operators, facility managers, and contractors will need to monitor conditions and manually perform changes in operations as needed. Data can be compiled and displayed showing trends and signaling issues and alerts.

Each of these five components requires additional equipment and devices to function, and that functionality adds to the infrastructure of each building system.

Table 5 provides a representative list of the commonly used BASs in the United States. While some manufacturers have their own proprietary hardware and software systems, many are also original equipment manufacturer (OEM) partners of systems such as Tridium's Niagara Framework and J2 Innovations' FIN Framework. In other words, if a third-party device is designed to work with either of these frameworks, it can communicate with the BASs of their respective OEM partners.

Table 5. A List of Building Automation Systems

Building Automation System		
Manufacturer	**System**	**OEM Partners**
Automated Logic	WebCTRL	[redacted]
Delta Controls	enteliWEB	
Honeywell	Alerton	
Honeywell	EBI-600 (Enterprise Building Integrator)	
J2 Innovations	FIN Framework	ASI Controls
		Bee
		Cube-Controls
		EntroCIM
		Optec
		Siemens Desigo Optic

Johnson Controls	Metasys	
Schneider Electric	EcoStruxure	
Siemens	Desigo CC	
Trane	Tracer Synchrony	
Tridium	Niagara Framework	Alerton
		Delta Controls
		Distech Controls
		EasyIO
		Johnson Controls Facility Explorer
		Honeywell
		KMC Controls
		Lynxspring
		Schneider Electric
		Siemens Talon
		Vykon
		WattStopper

Because of the ubiquity of BASs in commercial buildings, the BAS can be considered the backbone of an intelligent building — the system to which the other building systems integrate.

Automated Fault Detection and Diagnostics

To ensure that the building systems are functioning properly, automated fault detection and diagnostics (AFDD) tools have been and are being developed and implemented with BASs to:

- Detect when the building system deviates from expected or normal operation based on monitored system data;
- Diagnose the issue and determine where the fault is occurring; and
- Prompt the required remedial action to be taken by creating recommendations or follow-up actions by building staff, automated work orders, and automated fault-correction, if feasible.

Figure 5 shows the types of methods used to create AFDD systems [22] which can be based on quantitative physical models, qualitative models (rule- or physics-based), or the process history.

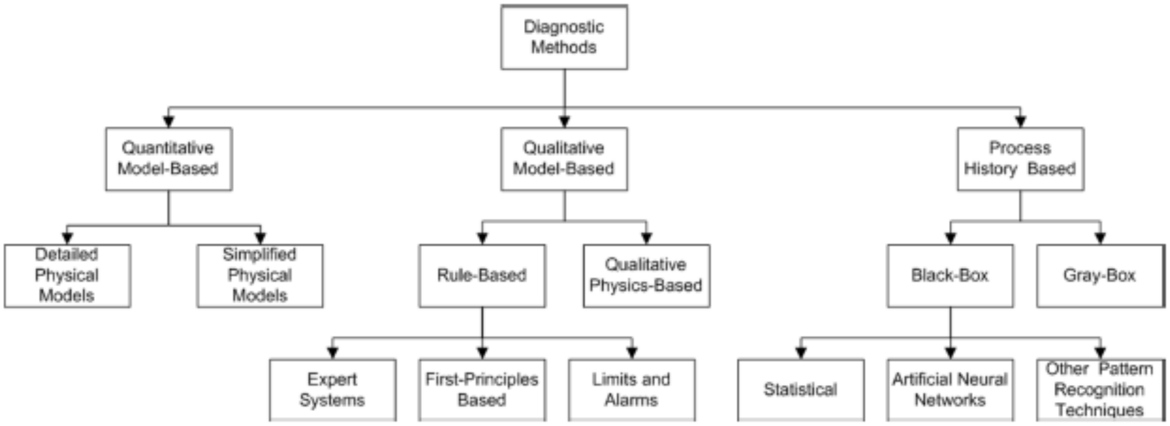

Figure 5. Classification Scheme for AFDD Methods

AFDD can be an important IBT tool by providing continuous commissioning of the building. Integrated with the BAS, AFDD tools collect data from the BAS database or directly from controllers, gateways, sensors, and meters. They can detect faults regarding real-time or trend data collected such as energy use, heating/cooling systems, ventilation and economizers, sensors, scheduling, equipment cycling, pump and fan systems, and lighting. An AFDD tool can reside on the local network or workstation, in the cloud, or embedded in the controller. Machine learning and artificial intelligence are being employed to develop and enhance the benefits of AFDD. Granderson et al. (2017) provides an overview of AFDD tools and a comprehensive list of the capabilities and features of the tools they surveyed.[23]

Energy Management Information Systems

The BAS and AFDD are part of a family of tools that comprise the energy management information system (EMIS). These tools can be classified as either building system–level EMIS technologies, such as the BAS or AFDD, or whole building–level technologies, which include monthly utility bill analysis and benchmarking. Table 6 describes these categories of EMIS technologies. [24]

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[22] S. Katipamula and Brambley, M. Methods for Fault Detection, Diagnostics and Prognostics for Building Systems - A Review Part I. United States: N. p., 2005. Web. doi:10.1080/10789669.2005.10391123.

[23] Granderson, J., Singla, R., Mayhorn, E., Erlich, P., Vrabie, D., Frank, S., Characterization and Survey of Automated Fault Detection and Diagnostic Tools. Lawrence Berkeley National Laboratory, November 2017, LBNL Report Number LBNL-2001075.

[24] Better Buildings. 2015. A Primer on Organizational Use of Energy Management and Information Systems (EMIS). U.S. Department of Energy's (DOE's) Better Buildings Alliance (BBA). https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/A_Primer_on_Organizational_Use_of_EMIS_V1.1.pdf

Table 6. EMIS Technologies

EMIS	Technology	Description
Building System–Level	Building Automation System (BAS)	As described above, the BAS provides the automated operation and management of the HVAC system as well as other possible systems such as lighting and security.
	Automated Fault Detection Diagnostics (AFDD)	As described above, AFDD tools can detect building system–level or equipment-level performance issues and propose possible causes and remedies for those faults.
	Automated System Optimization (ASO)	An ASO uses two-way communication with the BAS to signal changes in building system operation that optimize energy use while maintaining occupant comfort and productivity.
Whole Building–Level	Monthly Utility Bill Analysis and Benchmarking	Utility bill analysis allows for whole building energy performance tracking while benchmarking (using a tool like EPA's Portfolio Manager) allows peer-to-peer building energy performance tracking within a building portfolio or in comparison with regional and national building stock.
	Energy Information System (EIS)	The EIS is composed of the tools that collate building data to allow the analysis and display of building energy performance. The EIS can also relate this building information to external data such as real-time weather data, energy prices, and grid signals such as demand response events.
	Advanced EIS	An advanced EIS builds on the basic EIS functionalities with more advanced automated analytics that can employ models to baseline or predict performance and detect anomalous behavior.

These EMIS tools provide valuable insights that can greatly improve building operation and result in appreciable savings. The following findings illustrate the range of energy and cost savings that could be attained with the aid of an effective EMIS:

- Identifying and eliminating simultaneous heating and cooling in a building can reduce HVAC heating and cooling energy by 5%–20%.[25]

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[25] S.P. Doty. 2009. "Simultaneous Heating and Cooling—The HVAC Blight." Energy Engineering 106(2): 42–74.Available at: http://www.tandfonline.com/doi/abs/10.1080/01998590909509174.

- Depending on climate and cooling loads, the introduction of outside air through proper economizer use energy costs can be reduced by 10%.[26]
- Faulty or degraded equipment or system operations can account for 5%–30% of the whole-building energy use.[27,28]
- Regularly benchmarked buildings have been found to consume less energy on average, by approximately 2% per year.[29]
- The users of EIS technologies have achieved an average portfolio savings of 8%.[30]

Table 7 summarizes the opportunities offered from EMISs.[31]

Table 7. Summary of EMIS Opportunities (from Better Buildings 2017)

Opportunity	Applicable EMIS Type	Analysis Approach	Common Data Requirement
Scheduling	EIS	Load profiling	Whole-building or submetered energy use
		Base-to-peak load ratios	
		Heat maps	
	FDD	Tool dependent	System and equipment status: air-handling units (AHUs); terminal units; cooling towers; chillers; boilers; fans; pumps
Simultaneous heating and cooling	EIS	Energy signature	Outdoor air temperature Whole-building or submetered energy use

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[26] US Environmental Protection Agency. ENERGY STAR Building Upgrade Manual. 2008. United States Environmental Protection Agency. Available at: https://www.energystar.gov/sites/default/files/buildings/tools/EPA_BUM_Full.pdf.

[27] K. Roth, Llana, P., Westphalen, D., and Broderick, J. “Automated whole building diagnostics.” ASHRAE Journal Vol. 47, No. 5, May 2005, 82-84.

[28] Katipamula and Brambley, op. cit.

[29] US Environmental Protection Agency. ENERGY STAR data trends: Benchmarking and energy savings. US EPA, October 2012. Available at: https://www.energystar.gov/sites/default/files/buildings/tools/DataTrends_Savings_20121002.pdf.

[30] J. Granderson and G. Lin. 2016. “Building Energy Information Systems: Synthesis of Costs, Savings, and Best-practice Uses.” Energy Efficiency 9(6), 1369–1384, DOI 10.1007/s12053-016-9428-9. Available from http://link.springer.com/article/10.1007/s12053-016-9428-9.

[31] Better Buildings. Using EMIS to Identify Top Opportunities for Commercial Building Efficiency. U.S. Department of Energy’s (DOE’s) Better Buildings Alliance (BBA). May 2017. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/EMIS_Top_Opportunities-May_2017.pdf

	FDD	Tool dependent	Outdoor air temperature AHU: heating, preheating, and cooling coil valve status; outdoor air damper position Terminal units: reheat coil valve status
Outdoor air usage	FDD	Tool dependent	Outdoor air temperature AHU: mixed-air temperature, discharge air temperature and setpoints, return air temperature, outdoor air damper position
Air-side setpoint optimization	FDD	Tool dependent	AHU: discharge air temperature and setpoint, static pressure and setpoints Zone heating and cooling temperature and setpoints
Sensor errors	FDD	Tool dependent	Outdoor air temperature AHU: discharge, return air, and mixed air temperature; wet bulb temperature or relative humidity Zone: thermostat space temperature, carbon dioxide Central plant: hot water, chilled water, and cooling tower condenser water leaving temperatures
Portfolio prioritization	EIS	Cross sectional benchmarking	Gross floor area Whole-building or submetered energy use
Automated savings estimation	EIS	Avoided energy use or energy cost	Outdoor air temperature Whole-building or submetered energy use
Continuous energy anomaly detection	EIS	Typical use vs. actual use	Outdoor air temperature Whole-building or submetered energy use
Peak load management	EIS	Load profiling and load duration curves	Whole-building electricity demand

Building System Integration

When the variety of building systems are siloed, each system has its own sensors and separate controls, which can lead to redundancies and inefficiencies. In some cases, the operation of one system might actually work in opposition to another.

For building operators, property managers, and controls contractors (i.e., integrators), the ideal scenario for building systems integration is the “single pane of glass,” which is a way of describing a dashboard display reflecting a single platform from which the building systems can be managed. Figure 6 shows the variety of building services that could be monitored by an integrated intelligent building management system (IBMS).[32]

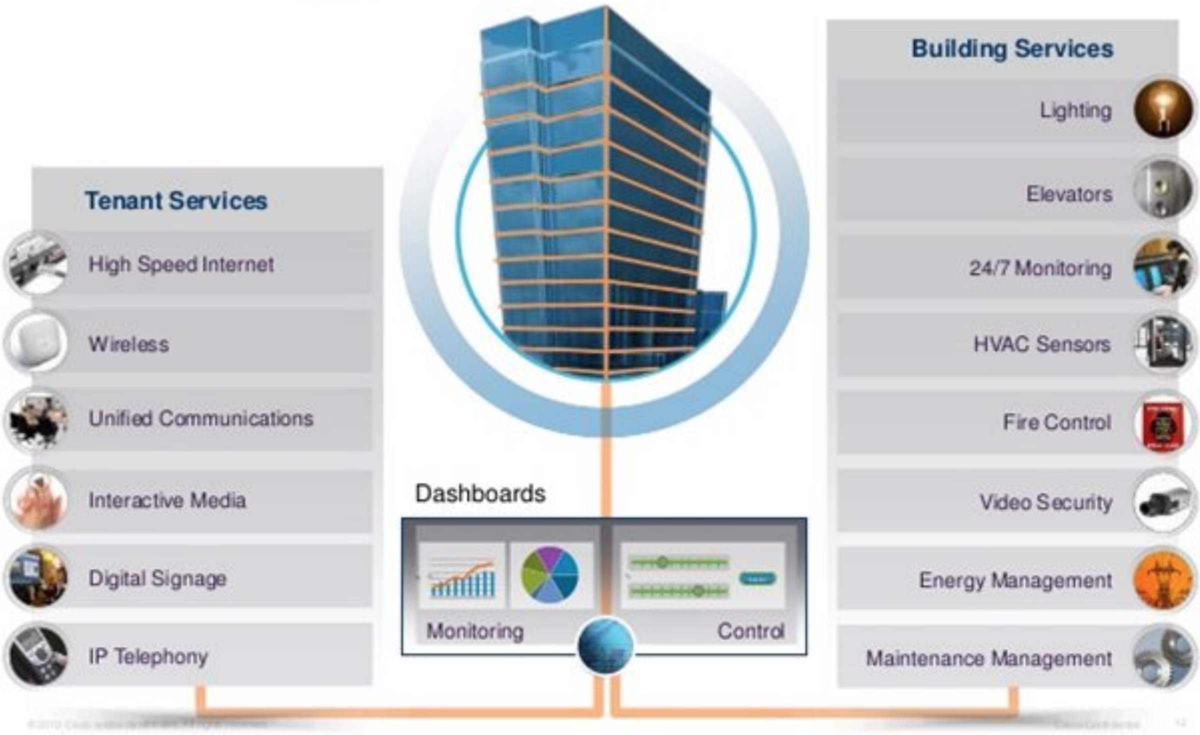

Figure 6. The Building Information Network

The IBMS provides some of these basic functionalities (including GEB functionality):

- HVAC—maintain scheduled setpoint temperatures for occupancy and inoccupancy; ventilation adjusted based on occupancy by temperature, CO_2, or occupancy count; control HVAC equipment such as fans, dampers, air handling units, fan coil units, pump, valves, and boilers; respond to communications from the grid.
- Lighting—control lights according to a specified schedule, space occupancy, and daylighting; respond to communications from the grid.
- Electric power control—monitor and manage building power usage and loads; oversee backup power systems; manage DERs; respond to communications from the grid.
- Security and observation—monitor and control building and parking access; oversee surveillance and intrusion detection.
- Fire alarm system—smoke detection; active alarm locations; fire control.
- Elevators—manage and monitor elevator operation and system status.

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[32] https://www.ifsecglobal.com/security/intelligent-building/

- Plumbing and water monitoring—monitor hydraulic flows and hot water temperatures; open/close valves automatically; manage thermal energy storage; respond to communications from the grid.
- Miscellaneous electric loads—monitor and manage smart technologies that can include plug load control, appliances, office equipment, window treatments, and ceiling fans.
- IT—monitor internet and Wi-Fi networks, servers, workstations, AV systems, and IP telephony.

To integrate these disparate elements, a common language is needed for the systems to pass information and interact. Communication protocols allow the building systems to talk to one another through either proprietary or open protocols. Systems that use proprietary protocols are closed systems that require vendor-defined network protocols and programming tools, which may result in limitations. Building operators may rely on a specific brand or dealer to ensure system compatibility and obtain reliable service, restricting future choices for system upgrades and expansions. This could also result in buildings having multiple closed systems which complicate management, limit integration of third-party systems and equipment, and create convoluted maintenance/servicing arrangements. Open communication, on the other hand, provides a shared language in which a variety of devices and systems can communicate with each other.

Open communication protocols enable interoperability by allowing the BAS to monitor and control devices (e.g., thermostats, occupancy sensors, and third-party systems such as lighting controls) and equipment (e.g., chillers, boilers, and air handlers) supplied from different manufacturers and integrated in a single system. Open protocols allow the BAS to communicate with both new and existing equipment using a common interface to oversee and control multiple building systems. No longer reliant on one brand or manufacturer, integrated solutions can be created to fit the present and future budget and performance needs of buildings. Many BASs offer the use of a variety of open communication protocols. Table 8 shows the commonly available open communication protocols, both wired and wireless.

Table 8. Common Open Communication Protocols

Open Communication Protocols								
Wired Protocol							**Wireless Protocol**	
API / Web Services	BACnet	Lonworks	Modbus RTP	Modbus TCP	MQTT	XML / SOAP	EnOcean	ZigBee

The two main communication protocols are BACnet and application programming interfaces (APIs). BACnet is an open, peer-to-peer communications protocol developed and maintained by ASHRAE and defined by ANSI/ASHRAE Standard 135-2020 and ISO 16484-5:2017.[33] An ANSI standard since 1995 and an ISO standard since 2003, it is the most common protocol used by

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[33] http://www.bacnet.org/

BASs today. BACnet is available in multiple versions with varying levels of backward compatibility and interoperability with other building systems such as commercial lighting controls, electrical gear, and card access.

APIs are a set of functions and procedures that allow applications to access data and features of other applications, services, or operating systems. When made available to third parties by the manufacturer, they offer an open platform for integration by allowing communication with third-party applications. APIs can be created to access and interpret the data from the BAS, send data to the BAS, or integrate devices with the BAS.

The Components of Intelligent Building Technologies

An IBT must be able to monitor the conditions within the building, determine if any actions need to be taken, and then perform the required building operations. To perform these functions, sensors, network devices, and controllers are an integral part of an IBT. As an example, consider a networked lighting system. Figure 7 shows a schematic for a typical Digital Addressable Lighting Interface (DALI®) lighting control system.[34]

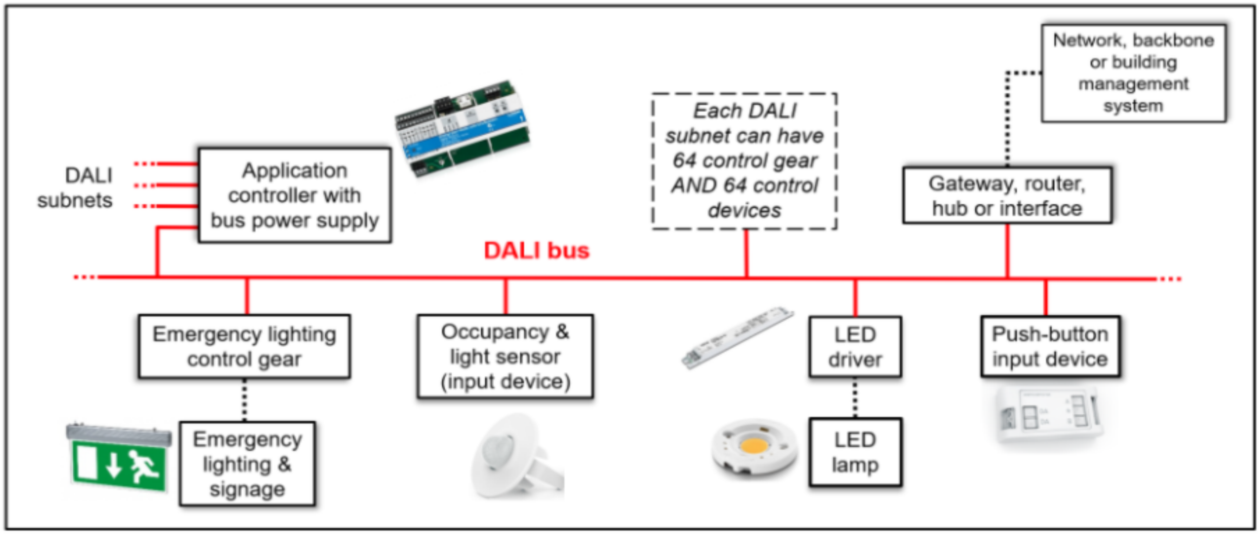

Figure 7. An Example of a DALI® Lighting-Control System

The system has five main product types:

- Control gear which powers the lamps, such as LED drivers
- Input devices, which include sensors that monitor space conditions (e.g., occupancy and daylighting) and user-input devices that allow occupants to make adjustments to the lighting (e.g., dimmers, timers, and scene controllers)
- A gateway to the building management system or network
- Application controllers which take information from the BAS, input devices, or other network sources to send commands to the control gear

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[34] https://www.dali-alliance.org/systems/

- Bus power supplies that provide DC power to connected DALI system devices

While these devices provide the added benefits of DALI systems, they add complexity, first cost, and additional power loads to building operations.

Standby/Baseload Power

A consequence of implementing these connected devices and systems results from the added cost, energy load, and operational complexity that comes with the supporting networked hardware and software. These networked building systems continue to draw power around the clock, as the sensors, controllers, and network devices remain on alert in case a change in state requires the system to alter its operation (such as when lighting and HVAC systems adjust to occupancy changes).

In a study of power over ethernet (PoE) technologies, a PoE lighting system in a school classroom was compared to an AC-powered line voltage lighting system in an identical, adjacent classroom.[35] Both classrooms had LED luminaires lit at a color temperature of 4000K. The PoE lighting system was a networked lighting system with each lamp being IP-addressable (i.e., luminaire-level lighting control); dimmable; and color tunable. The PoE classroom was equipped with two occupancy sensors, dimmer lighting switch with scene controls, and a photosensor. The line-voltage lighting system was a standard AC-powered LED lighting system that was not color-tunable, was controlled by a wall light switch with dimming capabilities, and was not connected to a lighting management system. Figure 8 shows the comparison of the lighting levels versus power draws for the two classrooms.

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[35] L.S. Shen, D. Sui, R. Lysholm, W. Bernal Heredia, A. Kirkeby, K. Trenbath, G. Barker, and D. Podorson. "The Demonstration of Power over Ethernet (PoE) Technologies in Commercial and Institutional Buildings." Proceedings of the 21st ACEEE Summer Study on Energy Efficiency in Buildings. 2020. https://aceee2020.conferencespot.org/event-data/pdf/catalyst_activity_10693/catalyst_activity_paper_20200812131042891_b97a1fba_fc55_47a1_9830_6676b6ff0649

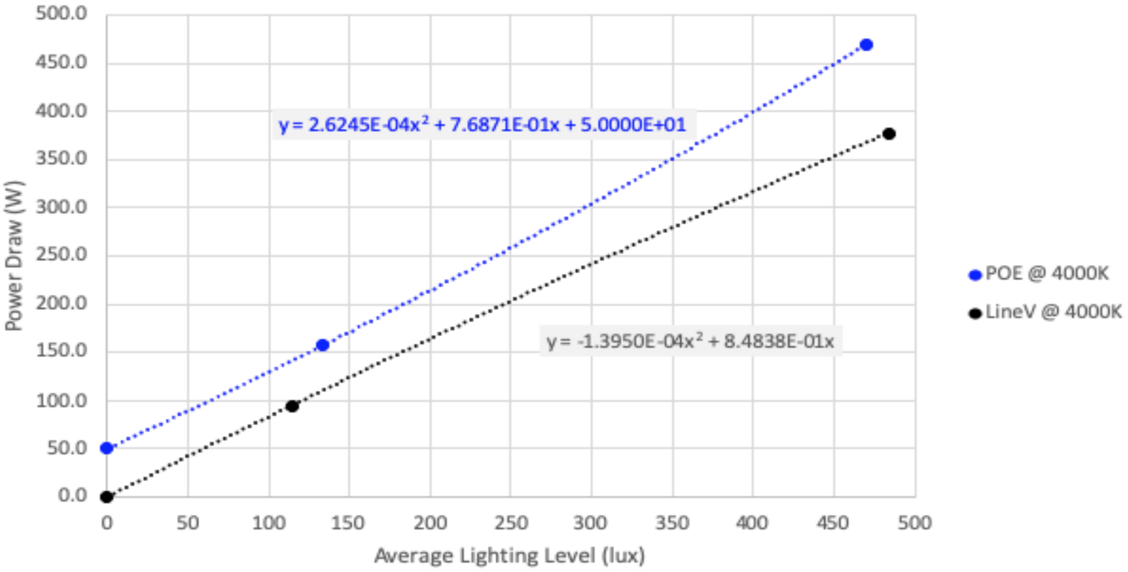

Figure 8. Light and Power Measurements Comparing Line Voltage and PoE Lighting Systems

The lighting performance of the two systems result in nearly identical slopes, but the PoE system has a non-zero y-intercept of about 50W. When the PoE devices are operating, these can be considered as baseloads, and when the PoE devices are off, they would be seen as standby loads. This is a continuous load of 50W, since the network devices, PoE nodes, sensors, and controls run 24/7, whether the classroom lights are on or off.

IBTs and Commercial Office Space

Because networked building systems continue to draw power around the clock, an "all of the above" approach may be expensive in terms of both first cost and operating cost. Over-engineered systems can be an issue with the application of smart technologies as unneeded functionalities and complexity are added. For example, for a lighting system in a classroom or conference room, does every light need to be individually controllable? Does each fixture need its own occupancy sensor or photocell? Does this space need networked luminaire-level lighting control? Not all spaces need the same level of intelligence.

For a typical commercial office building, a number of space uses can be defined. Roughly, these can be divided into office area(s), meeting and/or conference rooms, and common areas (i.e., kitchens, break rooms, lobbies). Across these space use types, it can be understood that some technologies are universally applicable — for example, plug load controls, adjustable heating and cooling, and indoor environmental quality monitoring. In other aspects, it can be understood that different controls are needed based on the space in question. Table 9 below outlines the potential needs of office space use types that can be considered unique to said type.

Furthermore, many needs of commercial offices are similar to the needs of schools: plug load control systems are one of many examples. Across all space use types in a school, it can be expected that lighting controls, occupancy management, and some form of an integrated alert system are universally applicable. As well as outlining unique potential needs of office space types, the table below also outlines the potential needs for two school space use types.

Table 9. Commercial and School Space Use Types and Needs

Space Type	Specific Space Type	System	Level of Detail and Control	Type of Control
Office	Open Office Plan	Lighting	Mix of individually adjustable and non-adjustable lighting; primarily manual control.	Seasonal adjustment of lighting; ability to control overhead lighting fixtures above workstations.
		Heating and Cooling	Floor-wide system; high integration by default. Facilities managed.	Adjustment of heating and cooling based on need.
		IEQ and IAQ; EMIS	Automated data collection; adjustments to the office environment are made as needed. High level of integration. Facilities managed.	Monitoring of air quality and other environmental conditions.
		Electronics	Some automation; mostly manual. Moderate level of individual control and integration. Aimed toward reducing unnecessary energy consumption.	Plug load controls; scheduled automatic computer shutoff.
		Occupancy Control	Higher level of detail; primarily non-automated system.	Visitor management; scheduling tools for hybrid work rotations.
		Personal Comfort Systems	Individual control ideal; manual control is likely to work for most tools.	Adjustable workstations; personal comfort systems.
	Small Collaborative and/or Small Conference Area	Occupancy Control	Higher level of control, by individuals.	Scheduling of rooms.
	Traditional Large Conference Room	Occupancy Control	No control; low level of detail.	Acoustic management.
	Lobby/Common Area	Occupancy Control	High level of manual operation of systems; high level of integration.	Visitor management; occupancy sensors and/or tracking.
	Kitchen/Break Room	Electronics	Primarily automated; low level of control and detail.	Scheduled downtime for appliances; timer-based plug load controls.
School	Classroom	Heating and Cooling	Primarily manual; high level of individual control.	Individual classroom controlled thermostats.

	Auditorium	Lighting	Primarily automated; highly integrated. Little to no level of individual control.	Scheduled downtime shutoff; occupancy sensors.

Commercial Space Use in the Age of COVID-19

The COVID-19 pandemic caused a major disruption in how work could be performed in commercial office spaces. To isolate people to reduce the spread of the virus, most U.S. offices closed, and most employees worked remotely from their homes. Even though there are plans for offices to open up again in the fall of 2021, health concerns and the desire of workers to continue to work remotely has had an immediate and perhaps lasting impact on how commercial office space is used and designed. IBTs will have a role to play in responding to these new space needs and requirements. The following discussion describes how office space use and design will respond to the new demand for hybrid workplaces.

The replacement of open-plan offices with a blend of private and collaboration spaces

One of the most notable changes in post-pandemic office concepts is a switch from open-office setups to more flexible configurations that are a mix of private and collaborative space. Through modular design, the aim is to create flexible spaces that can accommodate rotating hybrid schedules and conceptions of office spaces as a place for collaborative work. Small groups (i.e., four to six people) would be able to rotate through the office day by day, depending on their needs, and use private spaces as needed. Private spaces, which includes small meeting rooms, also includes spaces designed for individual focused work and impromptu telecommunications.

Naturally, more modular design requires different considerations for furniture. Publications concerning post-pandemic flexible office setups showcase furniture options that control acoustics — said setups also use more walls (both opaque and transparent). These options allow for easier reconfiguration, letting spaces be rearranged as needed to meet occupant needs: for example, more furniture and/or structures with wheels or lighter frames.

These changes toward environment flexibility require an analogous change to happen in smart building technology: In short, it requires an acceleration of the trend toward understanding behavioral patterns.[36] Smart building technologies will need to handle less predictability in space use patterns and environmental conditions — there will also be a larger need for moveable (and otherwise adjustable) lighting and power sources. In many flexible office setups, said requirements for power and lighting sources may also apply to HVAC systems.

Because of these expanded typologies within the office, a greater selection of technology solutions will need to be available. To manage this, less predictable space use patterns, and environmental conditions, AI-based technology has been suggested as a solution to help learn

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[36] A. Ghaffarianhoseini, A., U. Berardi, H. Al Waer, S. Chang, E. Halawa, A. Ghaffarianhoseini, and D. Clements-Croome. 2016. “What is an intelligent building? Analysis of recent interpretations from an international perspective.” Architectural Science Review. 59:5, 338-357. https://www.tandfonline.com/doi/full/10.1080/00038628.2015.1079164

the needs of each group or team within the office. Other methods to manage space use patterns may include scheduling systems. Compared to “walk-up” use areas, spaces reserved in advance may not need as many technological solutions for needs to be properly met.

There is also an expanded opportunity for energy management technology. Flexible, hybrid-oriented office setups experience energy savings from fewer desktop computers in the office. Combined with occupancy and space use pattern tracking, offices could be enabled to take greater advantage of off-peak hours to power rechargeable electronics (i.e., laptops and tablets). Similar opportunities may exist for heating and cooling or for lighting.

Transient-use spaces require ease of use interfacing with technologies

Transient use of office space is a common feature of hybrid office setups. Typically aimed at allowing an individual to come into the office two or three times a week, a transient use system furthers the need for flexibility in intelligent buildings. While this primarily includes design considerations, it also has technological aspects that focus on end users.

Under a flexible office setup geared toward transient use, workstations are designed to be quickly accessible and shared (often on a first-come, first-served basis). Another key feature is that employees bring a work laptop back and forth instead of using individual desktop computers. As such, smaller space and energy requirements are needed for workstations: Because people are working via portable laptop, the resources required to accommodate larger desktop computer setups are unnecessary. This is further emphasized by the shared nature of these workspaces: Because they are shared amongst the office, personalization is generally kept to a minimum.[37]

Successful implementation of transient use setups requires accessible and easy-to-use technology. By and large, the focus on accessible technology for transient use centers itself around quick, efficient access to workspace setup upon arrival. As with other features of intelligent building design, this includes reliable internet connectivity. It also includes a simple, easy end-user experience either in program design or in the amount of information to input.

Primarily, internet connectivity is needed to be able to reliably login to the connections at the workplace. Reliable connectivity may also be needed to employ the smart features of a workspace. For example, a system may remember employee preferences for a smart screen or smart table, automatically adjusting table height or monitor setup. These systems would also be useful for group workspaces, which would allow a team to quickly pick up where they left off. While these workspace features would certainly be capable of manual adjustment, reliable connectivity would be needed to fully access them.

More intensive space sharing requires innovative scheduling methods

Clearly, the above vision of a hybrid office space and rotating employee schedules is easier said than done. Because these workspaces are geared toward focused collaboration and not seating all employees in the same space (nor, in fact, do they intend to), proper scheduling and

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[37] For example, one person may prefer to use two monitors rather than one. Because the technology at shared workspaces would be the same across all desks, larger setups may not be present.

communication is critical. Employees should be able to view the rotational work schedule as needed to mitigate any such issues, and scheduling expectations should be clearly stated.

This need is especially apparent when you consider the case for businesses to have less real estate per person — due to purposeful downsizing of said real estate, for example. It may also be the case that rotational scheduling is used to grow a workforce without expanding office space. Whatever the reason, it is likely that many offices will have little to no space for unscheduled walk-ins or a variety of other issues that may appear with rotational scheduling. Clearly, well-communicated and understandable scheduling is important if an office decides to make a strong commitment to the hybrid model.

It is important to note that while employees may manage their own schedules individually, office-wide scheduling must consider both individuals and teams in their design. Examples may include rotating specific departments in and out of the office on set days, requiring individuals to create and stick to a self-assigned schedule, or dividing employees into groups and assigning each group given days to work at the office.[38]

Whatever the chosen method is, there will exist a need for scheduling software to manage it. Further, it cannot be expected that scheduling methods will closely correlate with business size — scheduling will conform to the needs of the business, and not the other way around. As such, there will be a need for scheduling software to be able to work for organizations at a large range of scale. Instead, differences between programs would be about what scheduling method is offered.

Conference and meeting areas will need hybrid functionality

Because conference and meeting areas are a category of space in an office, many of the ideas discussed above hold true here as well. Meeting and conference rooms in hybrid workspaces are able to take up less space due to transient use, similar to workstations. Meeting rooms will also require reliable internet connectivity to use telecommunications software — due to hybrid work, it can be expected that most meetings will have some participants attending remotely. That said, smaller size and different communication needs do not remove privacy and function-based needs. There will still be a need for traditional conference rooms that convene around a table, and both meeting and conference rooms will still require acoustic separation. In fact, the need for acoustic separation may be stronger with virtual participants due to reverberation from speakers or other such inputs from audiovisual equipment.

Another consideration when imagining meeting and conference rooms is indoor air quality (IAQ). Meeting rooms are enclosed spaces, which seat people in close proximity to one another. As such, IAQ is of primary concern for these spaces in a post-pandemic office. Some considerations for IAQ management include requiring the reservation of meeting and conference spaces ahead of time and monitoring through intelligent building systems. Monitoring could include sensors and data tracking of conference and meeting room air quality,

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[38] One example of a hybrid schedule is ChurnZero's R3 method, which utilizes all three example methods at once. See: https://churnzero.net/r3/ for an explanation of their method.

which would be combined with other building technologies for environmental management of the office.

Indoor air quality is critical for post-pandemic workplaces and the re-entry process

Unsurprisingly, surveying of employees regarding their concerns and desires for post-pandemic workplaces has revealed a concern for safety. Air quality ranks as one of the highest safety-based concerns for employees — international surveying revealed that it was the top concern for American employees.[39] These results tie into trends on environmental monitoring as a whole: namely, that indoor environmental quality (IEQ) monitoring and evaluation systems have gained new significance in post-pandemic workplaces. IAQ measurements specifically have been noted by employees and intelligent building technology manufacturers as a method capable of improving feelings of safety and important to workplaces beyond the transition period. Not only will IAQ measurement methods be needed to address office re-entry, but to make the system and design adjustments needed to facilitate the anticipated trends in workplace design and function. As mentioned previously, environmental conditions in buildings will be more flexible than before. HVAC and similar systems may be required to become more flexible as a result, capable of quick adjustment to occupancy conditions. To meet these greater flexibility needs, IAQ monitoring systems can serve as a welcome assistive measure. Such systems are also beneficial when assessing if an HVAC system needs an upgrade to meet current indoor air quality standards — and for workplaces already planning to upgrade, data provided could help identify their needs specifically.

While daunting at first, this process does not require a high level of user control or oversight — though, these systems can be highly detailed and may require special attention during setup and initial launch. Contrary to the rest of this system’s relatively low maintenance, IAQ systems have some of the same management concerns as other facility management IEQ technologies. IAQ systems can be expected to involve building operations and facilities management, and they will potentially influence future building upgrades. They are also likely to involve IT, as monitoring equipment typically transmits data through the internet. However, it is expected the average level of involvement with said systems is very little: for example, reviewing gathered information a few times a month or addressing errors in functioning.

As a smart building technology, any quality IAQ monitoring system should be capable of performing the following functions: measurement of CO2 concentrations; evaluation of TVOC levels; measurement of $PM^{1.0}$, $PM^{2.5}$, PM^{10} concentrations; and measurements of relative humidity and air temperature. To properly track these measurements, monitoring of air quality is best collected via automation. Rather than collecting periodic “snapshots” of IAQ, automating collection provides a fuller, “big picture” understanding as well as a method to assess current conditions and identify any patterns or areas of concern.

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[39] Steelcase Global Reports. 2021. Changing Expectations and the Future of Work, Insights from the pandemic to create a better work experience. pp. 20-21. https://www.steelcase.com/content/uploads/2021/02/2021_AM_SC_Global-Report_Changing-Expectations-and-the-Future-of-Work-2.pdf

Equally important as providing high air quality is providing occupant peace of mind and addressing their concerns. The tracking and displaying of IAQ data is one way to do so. While displays of indoor air quality would be highly beneficial to those in charge of maintaining or improving IAQ, making these displays visible to other occupants would provide peace of mind. To make this process more efficient, said information displays could update periodically on an automated schedule.

Other ways to provide occupant peace of mind include surveying. Designed to track satisfaction with office conditions (e.g., lighting or temperature), they also can provide measures of concern or feelings of safety. Such surveying could be important during post-pandemic transition periods and be used periodically post-pandemic to maintain occupant satisfaction.

Lastly, it’s important to note that IAQ sensors and monitoring equipment are simply one example of monitoring available to post-pandemic workspaces. These systems are useful not for their monitoring capabilities, but for their ability to highlight concerns and facilitate adjustments as needed.

IB Schemas, Ontologies, Rating Systems, and Standards

A number of approaches have been developed to define the properties of intelligent buildings (IBs), systemizing the relationships and information between the building systems, and assessing the level or potential of intelligence that a building possesses. These approaches range from schemas and ontologies to rating systems and standards. Table 10 lists some of the approaches that have been developed or proposed:

Table 10. Available IB Schemas, Ontologies, Rating Systems, and Standards

System	Type	Description	Link
Brick	Schema	Brick is an ontology-based metadata schema that captures the entities and relationships necessary for effective representations of buildings and their subsystems. Brick describes buildings in a machine-readable format to enable programmatic exploration of different operational, structural, and functional facets of a building.	https://brickschema.org/concepts/
Google Digital Buildings	Ontology	The Digital Buildings project is an open-source, Apache-licensed effort to create a uniform schema and toolset for representing structured information about buildings and building-installed equipment. A version of the Digital Buildings Ontology and toolset is currently being used by Google to manage buildings in its portfolio	https://w3c-lbd-cg.github.io/bot/index.html

Project Haystack	Ontology	Project Haystack is an open-source initiative to streamline working with data from the internet of Things. We standardize semantic data models and web services with the goal of making it easier to unlock value from the vast quantity of data being generated by the smart devices that permeate our homes, buildings, factories, and cities. Applications include automation, control, energy, HVAC, lighting, and other environmental systems.	https://project-haystack.org/
W3C Building Topology Ontology	Ontology	The Building Topology Ontology is a minimal OWL DL [owl2-primer] ontology for defining relationships between the subcomponents of a building. It was suggested as an extensible baseline for use along with more domain specific ontologies following general W3C principles of encouraging reuse and keeping the schema no more complex than necessary.	https://opensource.google/projects/digitalbuildings
RealEstateCore	Ontology	The open-source Smart Building RealEstateCore ontology for Azure Digital Twins is now available to accelerate time to market as well as to enhance interoperability and extensibility of your smart building solutions and the reusability of your code.	https://techcommunity.microsoft.com/t5/internet-of-things/realestatecore-a-smart-building-ontology-for-digital-twins-is/ba-p/1914794
WiredScore / SmartScore	Rating System	WiredScore is the global digital connectivity rating scheme, working with landlords to assess, improve, benchmark, and promote their buildings. SmartScore is the smart building certification helping landlords understand, improve, and communicate the user functionality and technological foundations of their buildings.	https://wiredscore.com/
Smart Readiness Indicator for Buildings	Rating System	The Smart Readiness Indicator will allow for rating the smart readiness of buildings (i.e., the capability of buildings [or building units] to adapt their operation to the needs of the occupant), also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid (energy flexibility).	https://smartreadinessindicator.eu/

SPIRE™ Smart Buildings	Rating System	A single-source to measure all smart building technologies. Built by TIA and UL, SPIRE is the industry's first smart building program that holistically measures building technology and performance. Available now, the SPIRE Self-Assessment online tool can evaluate building intelligence based on an expertly curated, objective framework. And coming soon, the SPIRE Verified Assessment and Rating offers a complete smart building evaluation with the opportunity to earn a Smart Building Verified Mark.	https://spiresmartbuildings.ul.com/
IB Index	Rating System	The International Intelligent Buildings Organization is leading an industry consortium to create an Intelligent Buildings Index (IB Index). This industry first technology standard uses qualitative and quantitative IB performance measures to rate a building's relative intelligence. Using a state-of-the-art literature review, international stakeholder engagement and calibration against a global spectrum of smart buildings, the IB Index offers a technical framework and classification system upon which to support strategy development and decision making.	https://ib-index.org/
ANSI/BICSI 007-2020, Information Communication Technology Design and Implementation Practices for Intelligent Buildings and Premises	Standards	The seminal standard for the design and implementation of ICT infrastructure necessary for all network enabled building systems, from traditional, smart, IoT, emerging, and everything in between.	https://www.bicsi.org/standards/available-standards-store/single-purchase/bicsi-007-iot-intelligent-building

Concluding Remarks

With the development and adoption of IoT and the new space use considerations brought about by the COVID-19 pandemic, the commercial real estate sector expects IBTs to help drive growth in the market. These market forces can provide a boost to implementing the energy efficiency benefits of IBTs and GEBs and help utilities achieve the energy savings goals of the ECO Act. Much still needs to be developed and studied in terms of the design, implementation, operation, and maintenance of IBTs with respect to energy use and occupant impact. IBTs represent an important resource for both existing and new commercial construction in saving energy, fostering productivity, reducing costs, and creating a zero-carbon electricity future.

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