Intelligent Buildings Literature Review

September 2021

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This project is supported in part by:

A grant from the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program.

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Intelligent Buildings Literature Review

Introduction

This survey of relevant intelligent buildings literature is part of a two-year project funded by the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program.[1] The project entitled, "How Smart Do Intelligent Buildings Need To Be?" is a market analysis that will study how to optimize intelligent building systems to balance energy savings against these systems' increased costs, baseloads, and operations and maintenance.[2] The literature review will highlight the areas that particularly impact Intelligent Building energy use and ensure that potential strategies are aligned with current design trends, market structure, building O&M, and work practices. The review will identify and define:

1. The pertinent published information on Intelligent Buildings.
2. The current practices and trends in office work practices and space design that will govern the implementation of smart technologies in commercial buildings.
3. The market factors and trends that could impact Intelligent Building acceptance and adoption.
4. The efforts that utilities, agencies, and other organizations can take to influence and drive Intelligent Buildings.

Intelligent Buildings Literature

The recent literature on intelligent buildings primarily concerns itself with three major topics:

1. The definition of intelligent buildings and the features and systems that characterize them.
2. The energy efficiency opportunities that Intelligent Buildings can provide.
3. The market potential of intelligent buildings.

The range of research includes analysis, surveys, and market research.

What is an Intelligent Building?

The development of the Internet of Things (IoT) and the implementation of connected devices into commercial building operation has allowed varying levels of automated control to building-related management systems. These systems include the following.

- Building infrastructure management (elevators and escalators management, parking management, and smart water management)
- Energy management (HVAC control and lighting system control)
- Network management (IT and communications)
- Security and emergency management (access control, safety, and video surveillance)
- Workforce management

The opportunities and benefits derived from these automated control processes on building utilization have led to growing interest in the concept of smart buildings or intelligent buildings. A

[1] https://mn.gov/commerce/industries/energy/utilities/cip/applied-research-development/

[2] https://www.mncee.org/how-smart-do-intelligent-buildings-need-be

survey of the published research shows that while the smart technologies can bring advances in building management, they should not distract from the importance of supporting occupant comfort, well-being, and productivity.

Clements-Croome and Derek (1997) provide historical context for intelligent buildings. They cover various definitions of intelligent buildings that have been proposed and describe how intelligent buildings have evolved and adapted with changes in civilization and technology (sensors, controls, and management). They note that the interaction between the building form, environmental systems, and work pattern are important since each building occupant will react individually to the indoor environment and, depending on user requirements, integration of the building systems will impact worker productivity. They discuss measures performed by facility management that are needed for effective building operations, delivering benefits to the occupants, and understanding the various patterns and trends of the building's operation. Recent advances in technology emphasize the need to integrate these technologies to achieve a responsive building.

In his doctoral dissertation, Himanen (2003) studies the feasibility of the intelligent building concept for office buildings. He creates an ontology for the forms of building intelligence: building connectivity, building self-recognition, spatiality, building kinesthetics, and building logic. The building intelligence framework describes the interplay between the building stakeholders and building intelligence. Like Clements-Croome and Derek, Himanen emphasizes the importance of connectivity and interplay between the buildings and its occupants. Workers in twelve office buildings were surveyed to evaluate the building quality and he presents the results of this qualitative research to describe end-user requirements and working environment design needs for the building occupants. He concludes that successfully fulfilling the intelligent building concept criteria is fundamental to the design of a successful intelligent workplace.

Through a survey of occupants of high-rise office buildings in Saudi Arabia, Reffat (2010) identifies the market requirements for intelligent building technologies. The paper presents key parameters for smart office buildings including the required smart building technologies, the level of importance of smart buildings, the benefits from utilizing smart-building technologies, and current smart-building practices. Reffat compares intelligent office buildings' utilization in Saudi Arabia to the current practices of developed countries to identify the similarities and differences. Survey respondents identified the major benefits of intelligent building technologies as reduced energy consumption, increased occupant safety and security, and improved building operation and maintenance.

The review article by Ghaffarianhoseini et al. (2016) compiles intelligent building research to determine commonly used performance indicators, definitions, common areas of agreement, and areas that may require further research. They also examine the long-term benefits of intelligent building technology. The study notes that social, economic, and environmental perspectives on intelligent buildings are a relatively recent addition to the research: environmental perspectives on buildings' energy use specifically are becoming very important in intelligent building considerations. Intelligent building research is also transitioning to be more practical than theoretical, meaning there is a need to research intelligent building technologies' actual efficiency and effectiveness. From this the authors develop ten characteristics to judge intelligent building technologies. The authors note that. Intelligent building technologies in North America emphasize performance, cost-effectiveness, and integration with IT systems, and intelligent building technology use is rapidly increasing in North America. Current concerns for intelligent buildings include a lack of evidence-based support for effectiveness, lack of expertise, and costs. There is also no standard consensus on what an intelligent building is, either. The study finds that intelligent buildings should be considered a significant part of future building design and that more research should be done on responsive buildings that balance technology with human factors.

Hoy (2016) gives an overview of smart buildings and building management systems by describing the general progression of building technologies. The article makes a distinction between smart and intelligent buildings, which are typically considered synonymous terms. The article explores smart building technologies such as networked lighting, occupancy sensors, building dashboards, electrochromic windows, and indoor positioning systems that would be well suited for libraries.

Lilis et al. (2017) assesses the opportunities and barriers of fully IoT enabled and controllable intelligent buildings compared to legacy automation systems. They consider issues of interoperability and propose hybrid integration platforms to serve as a transition from legacy building automation systems (BASs) to web-enabled building management. The advent of smart cities will necessitate communication between devices and management systems across different buildings and the grid via the cloud.

The research paper by To et al. (2018) highlights the importance of smart buildings and attempts to (1) evaluate different features of smart and sustainable building based on the level of importance, (2) identify the key factors of smart buildings from the user's perspective, and (3) understand building intelligence and sustainability approaches among different user groups. Based on this approach, the authors develop a two-part questionnaire. The first contains descriptions of smart buildings' key features. These features include lighting, fresh air supply, thermal control, security systems, and responsive designs such as daylight, rain, and smart grid. The second part of the questionnaire gathers respondents' demographic information like gender, age, education, industry, job, etc. The survey results based on 494 building users in Hong Kong maintains that intelligent security systems, intelligent and responsive fresh air supply, and elevators/escalators management are considered the most important features of intelligent buildings. The authors use statistical analysis to identify smart buildings' key factors and report that various user groups focused on different factors of smart and sustainable buildings. Again, the authors identify the human element as key to drive intelligent buildings' development and implementation.

A 2018 whitepaper from 75F concerning the benefits of intelligent building solutions focuses on heating and cooling systems, specifically the long-term financial benefits of energy efficiency. It reports that a predictive and proactive HVAC system can provide a building with 30% to 70% energy savings (in Btu) during the winter months from November to March.

Axonize (2019a) performed a smart building, smart office, and facility management online survey, receiving more than 150 responses; 47% of the respondents work for companies in North America and 35% work in Europe. They surveyed senior level executives across an array of industries and report the findings on smart building technologies. According to the survey results, the primary capabilities monitored by smart technologies are HVAC (68% of responses), lighting (56%), security (49%), energy efficiency (48%), and Wi-Fi (48%). Most participants highlight savings on cost and resources as key factors in implementation of smart technology, and 90% of the participants were tracking and monitoring HVAC, lighting, and other smart building capabilities. The survey findings show that only 39% of respondents were aware of some benefits associated with smart buildings. The largest barriers to intelligent buildings were (upfront) costs, while complexity, awareness of options, and potential inefficiencies were also main concerns.

Axonize (2019b) breaks down basic information about smart buildings, including benefits, why they are important, and examples of sensors used in smart buildings. The whitepaper also describes potential uses for smart building technology in office buildings, such as window monitoring and predictive maintenance.

Siemens (2019a, 2019b, 2019c, 2019d, 2019e, and 2019f) is a series of six whitepapers that provide an overview of IoT, smart technologies, and occupant experience in commercial buildings. The whitepapers cover topics dealing with operations and occupancy experience, sensors, quantifying the value of occupant experience, digital lighting, space utilization and workforce productivity, and safety and security.

Froufe et al. (2020) identify the disagreement on the definition of an intelligent building and set out to (1) investigate the main drivers that enhance the building intelligence, (2) explore the main systems in buildings, and (3) correlate the systems and drivers by associating them with the building users, owners, and the environment. The authors review selected articles to identify eleven drivers (technology, integration, flexibility, longevity, health, comfort, satisfaction, security, ecology, energy, and efficiency) and eight systems (HVAC, lighting, energy, security, telecommunications, fire prevention and firefighting, vertical transportation, and hydraulic). They observe that the drivers must evolve as the social demands change and that the key players involved in smart building evolution are the owners and the users. The authors note that future work objectives require opinions from experts to rank the drivers.

Targeted to facilities management, Moten (2020) discusses organizations' need to adopt and integrate smart building technologies as occupants return to facilities after the COVID-19 pandemic. With buildings re-opening, it is crucial for organizational-based reports to support the facilities manager in identifying occupant issues or trends that will necessitate changes to building systems. The article describes how the right technology and systems approach will predict outcomes that ensure safety, cost-effectiveness, and low environmental impacts thereby leading to an interconnected building ecosystem. Machine learning and artificial intelligence (AI) are identified as important features that will help optimize building systems.

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The Energy Efficiency Opportunities of Intelligent Buildings

Intelligent buildings can operate and maintain the indoor building environment through building automation systems (BAS) and energy management information systems (EMIS) to monitor and control the building's HVAC and networked lighting systems. A number of papers and reports describe intelligent buildings' abilities and opportunities to reduce energy costs while maintaining occupant comfort, satisfaction, and effectiveness.

King and Perry (2017) describe energy savings benefits that intelligent buildings bring with their automated building operations and control. Through report analysis, case studies, and expert interviews, the authors examine a range of smart technology opportunities, including HVAC systems, plug loads, lighting, window shading, automated system optimization, human operation, and connected distributed generation and power. They report that the intelligent buildings' integrated systems can achieve 30% to 50% savings when installed in existing and otherwise inefficient buildings, with savings that can reach as much as 2.37 kWh/sq. ft. The energy savings and cost-effectiveness of these technologies will vary across technology and building types.

Nguyen and Aiello (2013) focus on exploring 1) how building energy and comfort management (BECM) systems takes user activity and behavior into account, 2) impacts on energy intelligent buildings, and 3) the most common user activities and behavior impacts on energy saving potential. The report establishes the ten key modules' features and system criteria included in the survey on user activity comparative studies and the essential elements of the BECM system for various sectors such as residential, office and retail. The survey consisted of peer reviewed articles mostly focused on residential and office sector user activity functions such as HVAC, plug loads and lights. Each survey study is simulated with different building parameters (physical description, ventilation rates, mechanical equipment, occupancy schedules, etc.). The report summarizes the major findings obtained from the survey.

1. Additional research should focus on proposing smart thermostats. Predictive occupancy and sleep patterns play a significant role in understanding user activity.
2. Occupancy sensors are vital in control strategies and the survey shows 50% energy saving potential for lighting alone. Occupancy presence and behavior in a building have a large impact on space heating, cooling, demand ventilation, and energy consumption of lighting and space appliances.
3. The simulation results show 10%–40% energy saving potential for occupancy control by adapting control strategies such as occupancy sensing, daylight harvesting, and load shedding. The feasibility needs to be tested in real-life installations. A fair evaluation of energy saving potential requires better evaluation metrics.

Wireless networks are ideal for user comfort and energy management in intelligent buildings because of their low-cost hardware and easy-to-deploy network.

De Paola et al. (2014) provide a survey of existing literature on intelligent EMIS energy management systems in buildings. They cover these systems' main architectural components and explore various assessment characteristics (system accuracy, user comfort, and energy savings) to support comparative evaluations between the simulation and experimental approaches for better building management system (BMS) designs. The paper details the benchmarks needed for assessing BMS performance and discusses the research challenges of designing BMS, energy consumption, and intelligent support techniques. The authors highlight the need for additional research on design phase energy monitoring systems to configure procedures to minimize human interaction and learn user preferences and habits for better system behavior.

The paper by Pan et al. (2014) discusses current research's progress on intelligent buildings and microgrid technologies. The authors identify two trends that have accelerated research and application: (1) skyrocketing energy prices and the need to reduce fossil fuel consumption for environmental sustainability and (2) the increased adoption of mobile smart phone and Internet technologies that have raised consumer awareness of energy consumption and their ability to control use. The paper discusses the overall framework of intelligent buildings and its relationship to other building concepts. They investigate the three key modules (the building automation system, the building energy management and grid interaction system, and the building management information technology system) with a focus on networking and energy efficiency for commercial buildings. The paper provides examples and test cases of network technologies and their impact on energy efficient buildings and explains various ratings systems that can promote the adoption of intelligent buildings. The paper then describes the microgrid formed by distributed intelligent buildings and cloud computing interactions between the utility and customers.

Mofidi and Akbari (2020) survey the existing literature and define six key topics that are related to the optimal performance of intelligent buildings with respect to occupancy comfort and energy consumption: (1) occupant comfort conditions, (2) occupant productivity, (3) building control, (4) computational optimization, (5) occupant behavior modeling, and (6) environmental monitoring and analysis. They note that reducing energy consumption by controlling indoor parameters and improving occupancy conditions can often be in conflict. Therefore, intelligent buildings' energy management systems should optimize operation to achieve these objectives simultaneously. This requires monitoring and modeling occupant adaptive behavior toward the surrounding indoor environment.

Merabet et al. (2021) describe the role of artificial intelligence (AI) tools and technologies to achieve thermal comfort and energy efficiency in buildings by exploring and investigating various challenges of integrating AI components. The report identifies the difficulty of delivering thermal comfort to users within the buildings and its impacts on energy efficiency. The authors review and compile various AI technologies that were implemented in previous research papers and observe that multiple AI technologies were used in different parts of the building system. Research is still needed to improve the performance of AI-based building control, particularly with regard to the paucity of high-quality real-world data for buildings and the energy sector. They report that the application of AI techniques and personalized comfort models has achieved an average energy savings between 21.81% and 44.36% and has improved comfort on average between 21.67% and 85.77%.

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The Market Potential of Intelligent Buildings

The market penetration of intelligent buildings remains in its early stages despite the benefits and opportunities of intelligent buildings cited in the literature surveyed above. Ultimately, intelligent buildings' market potential depends on how the technologies and systems can be monetized by stakeholders and then evaluated.

CABA (2018) describes the results of a study performed by Harbor Research "to understand how use cases, customer environments and buying behaviors, and evolving business models all impact the way products and solutions are monetized in intelligent buildings." They performed primary and secondary research, in-depth executive interviews, and an online survey with stakeholders. Figure 1 shows the top use case opportunity framework developed from the responses of the stakeholder survey.

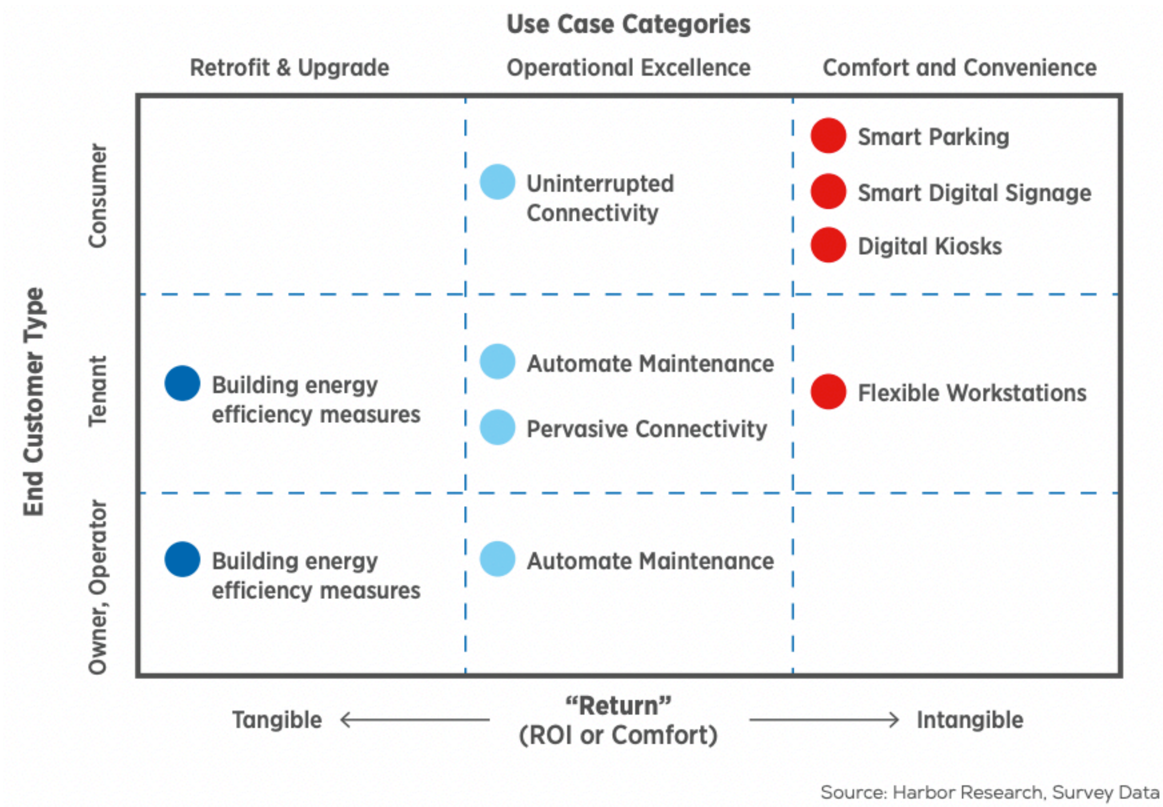

Figure 1. Survey Respondent and Stakeholder Top Use Case Opportunity Framework

After defining horizontal pain points and basic requirements, the report evaluates product-based, services-based, and solutions-based monetization models and pricing models. The report defines important monetization factors that include considerations such as the purposes and outcomes of smart technology, operator attitudes toward costs, and tangible and intangible returns on investment. As a result, the opportunity for monetizing intelligent buildings will depend on the solution, the supplier, and the operator.

Three marketing research firms, MarketsandMarkets, Mordor Intelligence, and Fortune Business Insights, recently published market analyses of the global smart building market, accounting for the impact of the COVID-19 pandemic. All three firms project robust growth of the global smart building market size over the next four to eight years, with the expectation of double-digit compound annual growth rates (CAGR). Table 1 shows these studies' projections.

Table 1. Market Research Studies of Global Smart Building Market Potential

Market Research Group	Global Smart Building Market Size				Compound Annual Growth Rate (CAGR)	Forecast Period
	Baseline	Year	Projected	Year		
MarketsandMarkets	$66.3 billion	2020	$108.9 billion	2025	10.5%	2020–2025
Mordor Intelligence	$82.55 billion	2020	$229.10 billion	2026	18.5%	2021–2026
Fortune Business Insights	$57.30 billion	2020	$265.37 billion	2028	21.6%	2021–2028

The main takeaways of their published findings are:

- Energy costs and environmental issues drive demand for intelligent buildings, with the energy management segment to grow at the highest CAGR.
- The building owners and managers' primary concern is to reduce energy use and therefore lower operating costs.
- Government initiatives to reduce energy consumption drive adoption.
- The global market share will be dominated by the United States and Canada with the commercial segment leading the smart buildings market.
- A major challenge the intelligent buildings market faces is concerns over privacy and cybersecurity regarding connected devices and IoT reliance.
- Integration of intelligent building technologies and systems requires greater cooperation among technology and system providers, standards bodies, utilities, public entities, and other stakeholders to tap intelligent buildings' full potential.
- COVID-19's impact has emphasized the need to provide a safe and healthy workplace. The space utilization changes that new office work environments are implementing could drive demand for intelligent building technologies and systems.
- Key players in the market profiled in these studies were 75F, ABB, Aquicore, Bosch, BuildingIQ, Cisco, CopperTree Analytics, Endeavor Business Media, ENTOUCH, Hitachi, Honeywell, Huawei, IBM, Igor, Intel, Johnson Controls, KMC Controls, Legrand, Mode:Green, PTC, Schneider Electric, Siemens, Softdel, Spaceti, Telit, and Verdigris Technologies.

Sharpington and Ray (2020), in an analysis for Gartner Research, forecast that IoT spending on building automation will grow by $6 billion from 2019 through 2029. They determine that energy savings from connected lighting and HVAC systems are the main driving force for revenue growth, with building structure monitoring having the highest CAGR of 27%.

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Office Work Practices and Space Design

The COVID-19 pandemic led to the emptying of offices as workers sought refuge and safety by working from home. As workers begin to consider their post-pandemic work practices, businesses have had to rethink offices spaces in order to accommodate workers returning to the office, workers who continue to work remotely, and workers who will practice a hybrid approach. In response to the expected changes, many businesses have cut back the amount of office space needed to support their workers. Building owners, property managers, and commercial real estate (CRE) will need to adapt to attract tenants. Intelligent buildings could provide an effective response to the changes in work practices and occupant concerns while reducing costs, promoting occupant welfare, and fostering productivity. The following annotated bibliography provides a survey of some of the latest thinking on the post-pandemic in-office workplace and the needs that might help drive the intelligent building market.

Annotated Bibliography

Articles

Bernstein, E. 2020. "Getting Smarter About Smart Buildings." *MIT Sloan Management Review.* August 26, 2020. https://sloanreview.mit.edu/article/getting-smarter-about-smart-buildings/.

The article discusses new attention toward smart buildings in the context of post-pandemic workspaces. Specifically, the article reviews whether smart technology is developing in the way we need and how to support this development. To do so, the article focuses on automation as an assistive tool for human collaboration and decision making. Suggestions primarily focus on improving collaboration and productivity, such as programs that encourage people to interact with those who could assist them via scheduling and email data. The article also suggests increased collaboration between facilities managers and HR departments to "[incorporate] what we're learning about effective work."

The article also mentions making data more accessible across a company. The idea is this would reduce feelings of being observed and ensure the data collected is put to better use.

Gratton, L. 2021. "How to Do Hybrid Right." *Harvard Business Review.* May 2021. https://hbr.org/2021/05/how-to-do-hybrid-right.

This article covers what should be considered and planned for to create a hybrid business model. Areas of consideration are divided into four categories: Jobs & Tasks; Employee Preferences; Projects & Workflows; and Inclusion & Fairness.

"Jobs & Tasks" focuses mostly on identifying a few solutions for offices, such as a stopover office that can be used as a midpoint when traveling to meet clients. "Employee Preferences" focuses on methods to help managers coordinate various preferences. The article highlights a method that sorts employees into personas and provides work guidelines for each persona type.

"Projects and Workflows" details what technologies may be available as well as time management. Specifically, it discusses streamlining tasks and removing redundancies. "Inclusion and Fairness" covers how to ensure that people aren't left behind in the adaptation process and how to avoid receiving responses from only certain positions or work styles, etc.

Gutman, R. 2021. "6 Questions for the Boss Who Wants You Back in Our Cubicle." *The Atlantic*. May 3, 2021. https://www.theatlantic.com/health/archive/2021/05/back-to-office-pandemic-safety/618783/.

This article covers common post-pandemic concerns and questions, specifically questions for employers concerning safety and adaptations. The six questions cover air flow and cleanliness, masking, vaccinations, and emergency management.

The article's main points conclude that significant effort will be required, as many minimum requirements for adequate safety can include updating (e.g., air filtration systems). Masking culture is also touched on, as is removing limits on sick days. It also notes that employers should strive to have a robust emergency management plan for potential COVID infections, including notification systems and office closure procedures.

Lacy, J. 2021. "Slack and Zoom were Distracting our Teams. Here's How We Regained Focus." *Fast Company.* January 5, 2021. https://www.fastcompany.com/90588307/slack-and-zoom-were-distracting-our-teams-heres-how-we-regained-focus.

The article covers remote work challenges in environments that require both frequent communication and deep focus. New rules were established for Zoom and Slack, which were previously being used in ways that were counterproductive for many.

The solutions established set times for meeting scheduling based on a person's job. For example, design teams would reserve mornings for focused work and hold meetings in the afternoon. This was designed to improve efficiency, increase productivity, and create an established routine.

Phillips, Z. 2020. "How Office Construction Will Change Post-Pandemic." *Construction Dive.* November 16, 2020. https://www.constructiondive.com/news/how-office-construction-will-change-post-pandemic/589033/.

A short article that covers the main points of a published report on how COVID has impacted the demand for flexible workspaces and what those workspaces would look like. Most of the report's main points cover flexible workspaces as well as ways to distribute density across a workplace (e.g., outdoor areas and flexible zoning). A newly designed office building is also mentioned, which was engineered to accommodate social distancing and other health and safety guidelines as needed.

Propmodo Studio. 2021. "The No-Code Revolution Is Changing the Way We Manage Buildings." *Propmodo,* April 26, 2021. https://www.propmodo.com/the-no-code-revolution-is-changing-the-way-we-manage-buildings/.

Profiles a growing trend of technology development called no-code development platforms (NCDPs). Theses programs' goal is to create a central, integrated hub for systems, allowing "non-technical individuals and teams [to] create complicated processes […] without editing even a single line of code."

While this shows significant potential for building management, there are concerns due to current widespread lack of integration for systems. That said, the NCDP method also presents a strong potential for cost savings. Moreover, they are designed with a very low entry knowledge point, making them fairly accessible.

The rest of the article discusses NCDPs and their use for building occupants, such as an app that offers centralized access to building information and temperature controls, location-based wayfinding, etc. The developer's website has a page that goes into more detail on the app (https://juberi.com/solutions/doti/) and provides examples of its appearance and use for tenants and property managers.

Roberts, R. 2021. "We Hate the Office. We Love the Office. Do We Want to Go Back?" *Star Tribune.* July 7, 2021. https://www.startribune.com/we-hate-the-office-we-love-the-office-do-we-want-to-go-back/600075744/.

This article documents ambivalence currently among office workers in the transition from fully remote work to some level of commuting to the office. Mainly, the article covers how our perceptions of the office and work expectations have changed, and how that's affecting late stage and post-pandemic transitions. The article covers the office's history in Western society, including media depictions, and notes that many issues among office workers is feeling as if they have little to no control and are being micromanaged. The article concludes that results will mostly depend on how much power a worker has in their company. These findings are likely related to the large number of people resigning from office positions.

Sisson, P. 2021. "How Data Is Changing the Way Offices Are Run." *New York Times,* April 27, 2021. https://www.nytimes.com/2021/04/27/business/smart-offices-data-collection.html.

This article covers the growth of property technology (proptech), i.e., technology used to manage property. Focusing specifically on the CRE market, the article details using proptech to manage environmental conditions and security concerns and hopes for the technology.

Popular choices include occupancy or activity sensors as well as building environmental performance. One of proptech's main long-term goals is to increase productivity and provide a competitive edge in an oversupplied office market. The article notes that much of this surge is due to this technology recently becoming more affordable as well as COVID-related changes. For property managers however, the appeal is its potential to decrease operating expenses and energy savings.

Slumbers, A. 2021. "De-Densification and the New Metrics of the Office." *Propmodo.* March 30, 2021. https://www.propmodo.com/de-densification-and-the-new-metrics-of-the-office/.

The article talks about "rethink[ing] the purpose of the office" for companies and covers potential trends in real estate that may result from these changes post pandemic. Much of this concerns balancing party interests (i.e., those of landlords and occupants) with business results. The article argues that post-pandemic offices will be less about a concrete place to do work and more about establishing an avenue for productivity. This will require a change in perspective; pre-pandemic, office space and real estate focused less on affecting productivity and more on operational costs.

The article also considers healthier buildings, or buildings that conform to occupant use patterns and accommodate occupants' health and well-being. The article suggests creating healthier buildings by gathering quantitative and qualitative data on occupant use patterns as well as on the occupants themselves (e.g., average number of sick days annually). The goal is to optimize environmental conditions for productivity with the idea that real estate value can be created through a more human-focused perspective.

Wakabayashi, D. 2021. "Google's Plan for the Future of Work: Privacy Robots and Balloon Walls." *New York Times.* April 30, 2021. https://www.nytimes.com/2021/04/30/technology/google-back-to-office-workers.html.

This article covers changes that Google is using (or is considering) to redesign their offices to "deal with an expected blend of remote and office workers" or a hybrid work model. This includes a team-pod structure, experimenting with rotation schedules, and personalization features.

The article states, "Google focused on three trends: Work happens anywhere and not just in the office; what employees need from a workplace is changing constantly; and workplaces need to be more than desks, meeting rooms and amenities."

The experimentation includes shifting from communal spaces to more personal spaces (e.g., converting conference rooms to personal, focused work rooms). There's also discussion about flexible spaces, and personalized technology is mentioned throughout. The article mentions that Google employees prefer remote work to some extent, and the experimentation on office space is being done to entice workers back, which calls into question their actual utility.

Weil, D. 2020. "How Covid-19 Could Change Workplace Technology." *Wall Street Journal*. November 18, 2020. https://www.wsj.com/articles/how-covid-19-could-change-workplace-technology-11605708627.

This article summarizes eight predictions on how workplace technology will change due to COVID. The predictions cover technology proper, but also changes in office equipment and the potential social and organizational effects of technology.

The technology-focused predictions mostly cover remote work and video conferencing. Many discuss an increase in collaborative technology as well as changes that better facilitate side conversations. There is also a focus on sensors and wearable technology to monitor various health and safety factors. Energy management and sustainability are also frequently mentioned.

Regarding offices, there's mention of greater reliance on satellite offices and office equipment that has a larger focus on comfort. Some mention technology's potential to flatten organization structures by automating some processes, allowing people to work more closely with each other and be less siloed.

Webpages

ChurnZero. "The Guide to Creating a Unique, Hybrid Remote Work Schedule." Accessed May 12, 2021. https://churnzero.net/r3/.

This page describes ChurnZero's approach to creating a hybrid work model and schedule for its employees. Their method, coined as R3 (rotational, regional, and remote), creates four groups of people and three departments (sales, sustomer, and other). Each group contains 25% of the company's workforce and creates as much of an even spread between departments as much as possible. A fifth category also exists for new employees and junior employees. This scheduling program is optional.

With these divisions in place, ChurnZero creates a rotational schedule that can be modified based on a team or department's needs. Provided there are no modifications needed, employees who opt-in to this system spend about 50% of their time in the office.

The R3 scheduling is well-regarded by employees. It's also noted that once offices open, this schedule will be modified for COVID restrictions until the end of the pandemic.

Culturally Enriched Communities. "COVID-19 and Environmental Interventions." Accessed May 13, 2021. https://www.cec-design.com/covid-19/.

This webpage is a collection of best practices and design resources for COVID interventions on a variety of topics: vulnerable populations, ongoing studies, hotels, workplaces, etc. The page is regularly updated.

The workplaces section consists of links to study and survey data as well as brief writeups on some (e.g., Gallup polling). The content mainly covers preferred workplace conditions and recommendations for indoor environmental quality, such as air circulation. Links to ongoing research on design practices are also included, such as optimizing safety in small workstations and case studies of outbreaks that took place in office buildings.

Cushman and Wakefield. "6 Feet Office." Accessed May 13, 2021. https://www.cushmanwakefield.com/en/netherlands/six-feet-office.

Details a potential strategy for "return to office" planning. The planning strategy consists of six elements that are designed to facilitate adherence to COVID guidelines and prioritize safety. Methods include establishing a strict six-foot radius between employees, entering and leaving meeting rooms as indicated, and moving around the office in a clockwise direction. These adaptations also include creating adapted workstations, and training one or a few employees on the operational guidelines to promote enforcement and adjustments as needed.

This system is less a series of design principles and more to establish an environment that allows these rules to be culturally enforced.

Steelcase. "Kickstart Your Return to the Office." Accessed May 12, 2021. https://www.steelcase.com/research/articles/kickstart-return-office/.

This page examines methods for an office plan that help mitigate negative social effects from social distancing or similar policies. This includes flexible working areas, adjustability, and mixed-use spaces. There's a greater emphasis on socialization, as well as technology integration. Examples of workspaces are included, as well as details about their intent and why they may work.

Reports

Arbnco. 2020. *Change Is in the Air: A Data-driven Indoor Air Quality Framework for Post-COVID-19 Workplace Re-entry: Summary for Policymakers*. https://arbnwell.com/a-data-driven-indoor-air-quality-framework-for-post-covid-19-workplace-re-entry/.

A report that summarizes health protocol recommendations and provides guidance for return-to-work plans. The report provides a roadmap that begins with implementing administrative and engineering controls and ends with a review and improvement process. Most engineering recommendations involve indoor air quality, and administrative recommendations involve occupancy controls and promoting proper hygiene. The report also includes a reference table for air quality measurements (e.g., CO_2, $PM^{2.5}$). The report recommends occupants as the primary input for gauging an intervention's success.

Axonize. 2019. *Designing Smart Spaces.* https://axonize.com/resources/exploring-smart-buildings-and-offices-in-the-era-of-digital-transformation/.

A whitepaper that discusses the role of technology (i.e., proptech or property technology), specifically in terms of energy consumption and office space efficiency. The whitepaper also contains a guide on how to approach smart buildings and offices, including stakeholder and relevant department (such as IT) engagement. There is a glossary on how sensors can be used, as well as information on common types of sensors that are used for office space efficiency. There is also a guide on what to consider when selecting a technology provider.

Steelcase. 2021. *Changing Expectations and the Future of Work: Insights from the pandemic to create a better work experience*. https://www.steelcase.com/research/articles/topics/work-better/changing-expectations-future-work/.

The full PDF is available on the Microsoft Teams "Future of the Workplace" channel and available to download at the link in the citation. This report analyzes how working from home has impacted the workforce, specifically the benefits and drawbacks that people have experienced. The report also creates five general “types” of people, based on their experiences with working from home. These “types” are divided based on productivity, social engagement, and sources of stress (e.g., familial responsibilities, pandemic safety, etc.).

As a general rule, people reported they enjoyed the lack of a commute. Experiences with focus and productivity are mixed; by and large, it appears to be dependent on a person’s living situation and responsibilities. Isolation was also reported as a common issue among the report’s sample population. This pattern is reflected very strongly in the data collected from workers in the United States.

The rest of the report covers considerations for hybrid office models with the assumption that people will likely spend most of their time in the office. Social connection is one of the main reasons people have for returning to offices; safety and environmental control are two major concerns people have. The report recommends that offices design with flexibility and safety in mind, and consider movement and activity, comfort, and thoughtful incorporation of technology when adapting to a hybrid model.

Miscellaneous Resources

Allsteel. "Spaces: Using Architectural Walls to Create Dynamic Environments." Accessed May 13, 2021. https://res.cloudinary.com/hni-corporation/image/upload/v1589462670/Allsteel/Resources/Public/Literature_Spaces_DynamicEnvironments.pdf.

This brochure from the company Allsteel focuses on workspaces that are multi-use and easily rearranged. The idea behind the spaces is that the components can be easily rearranged to accommodate new needs, and that different types of spaces are created that "flow" into each other. There is an emphasis on collaborative spaces as well as multiuse. There's less an emphasis on sections and more on creating variations.

Dice, J. *Nexus.* Podcast audio. December 17, 2020. https://www.nexuslabs.online/-031-why-buildings-are-behind/.

This episode examines some of the reasons why many buildings rely on old technology to operate buildings. One of the main reasons is a sense of preservation; many companies rely on the revenue from providing assistance over the initial purchase. There are also concerns about technology irrelevance, specifically if it becomes irrelevant and services are therefore no longer available. Many dominant technology companies are also older and risk averse. The podcast notes that this is changing due to COVID. The pandemic exposed the disconnect between builders and their occupants and operators. Combined with the much lower cost of current technology, a greater demand is emerging for newer technology. Adoption may be slower, possibly due to the aforementioned attitudes and changing hiring needs.

Market Factors

Research on market factors for intelligent buildings (or related areas) is slim and primarily concerns the construction industry. Available research can be sorted into three general umbrellas.

1. Case studies of geographic areas (i.e., cities, regional areas, countries, etc.)
2. Systematic reviews and/or overviews of sustainable construction and CRE markets
3. Individual smart technology incentives

Despite the relatively small amount of research on market factors and intelligent buildings, enough is available to understand trends, constraints, and benefits from a large-scale perspective. However, much of this comes from related fields and/or construction of sustainable building methods *overall* rather than intelligent buildings specifically.

Umbrella 1: Case Studies of Geographic Areas

Most publications of this type concern areas outside of the United States and tend to be older. Deng et al. (2018) reports on a case study that concerns barriers to green building development and policy solutions from a local government perspective in Ningbo, China. Current barriers include a lack of effective incentives for green building development, issues with coordinating the project team and partners, and a need for qualified professionals, among others. Surveyed property developers, consultants, and designers ranked lack of incentive high, while building designers and manufacturers ranked coordination issues as a major concern.

For solutions, the study suggests local governments provide appealing incentives for green building development, as well as mandate certain requirements for green building development, such as enforcing a certain level of green building technology in new constructions. The study also suggests providing a comprehensive online platform to share up-to-date information “for policy updating, information exchange and new technology promotion” for green buildings.

The whitepaper by Northstream (2019) uses mini case studies to present a consumer-focused action plan for landlords to develop smart buildings in Sweden. Strategies are presented for both large and small landlords.

These findings align with research conclusions in other umbrellas: incentives for sustainable buildings can stand to be better, coordination problems are a strong hindrance to market development, and knowledgeable professionals are needed.

Umbrella 2: Systematic Reviews and/or Overviews of Sustainable Construction and CRE Markets

Earlier work in this umbrella focuses primarily on singular countries; later work sometimes takes an international focus. Wilson and Tagaza (2006), from Australia, focus heavily on mitigating perceived financial and/or regulatory risks by providing “a considerable investment in an integrated design team[s] at [the] conceptual development stage” to assist with regulatory barriers and to prevent silo-based knowledge barriers. This interest in integrated design teams is also present in subsequent research; here, the authors highlight their potential to demystify negative cost perceptions of sustainable buildings. Said cost concerns are perceived as a primary barrier to sustainable buildings. This barrier is partly based in common misconception. Specifically, perceptions of high(er) initial costs and longer payback periods, both real and imagined, are consistently mentioned as barriers.

A more common theme in recent research is construction stakeholders’ preference to maintain current practices rather than adopt new ones. This is due to a variety of reasons, most notably the steady revenue stream gained from well-established technologies. Another cause is risk aversion of dominant industry companies concerning newer methods. Likely, resistance toward newer practices and cost perceptions are the primary fuel behind commonly referenced social barriers, for example, “lack of market demand and lack of demand from companies and society for sustainable buildings.”

Regarding project management for smart building technologies specifically, many barriers can be inferred as symptoms of slower adaptation incentives in construction. For example, “technical difficulties during construction processes/ lack of the technical skills regarding smart technologies and techniques” is a frequently cited barrier to smart building adoption. Siloed knowledge is also referenced, specifically a lack of communication among project team members due to organizational structure.

Clearly, a market opportunity for smart buildings exists. Collaboration appears to be the main benefit, specifically information sharing. The oft-cited integrative design team approach is one example. Among intelligent buildings’ early and current adopters, the large need for information sharing can be capitalized on. As the study from Ma et al. (2016) notes, “All participants in the study are aware of the need for networking and collaborating with other partners, but there is no current service or solution that allows them to do so, which leaves room for a potential business.” The same study also notes the potential for construction stakeholders to provide incentives to include follow-up work as part of a project, such as follow-up maintenance and “extra smart solutions for energy saving[s] and safety.”

Along the lines of collaboration, Budiardjo et al. (2018) suggest that a new deal is required between buildings owners and building vendors to repair their broken relationship that prevents their facilities from reaping the benefits of smart technologies. The broken relationship is plagued by an often adversarial nature between and within the two stakeholder groups and split incentives between capital expenses (CapEx) and operational expenses (OpEx), especially with energy management. The purpose of the new deal is to focus on the building occupants above and beyond the needs of the building owners/managers and BAS/smart technology vendors. The three basic tenets of this collaboration are open standards, model-based analytics, and service transparency.

Fletcher et al. (2018), in an article for McKinsey & Company, define six tenets that will help mainstream intelligent buildings.

1. A step change in user experience that will emphasize occupant productivity, comfort, health, safety, and mobility.
2. Security and privacy challenges must be solved.
3. Adoption will hinge on an effective combination of use cases tailored to specific environments and space uses, rather than the one-size-fits-all approach.
4. A market shift is needed from the traditional value chain approaches to a connectivity-enabled solution sales method.
5. Successful players will pursue end-to-end solutions with connectivity that requires a facilitation approach based on hardware infrastructure and software platform.
6. New building infrastructure business models will need to capture value based on connectivity hardware and software products, subscription digital services, and connectivity as a service (O&M).

Verdantix (2019) reports the results of phone interviews they performed with real estate and facilities executives from 50 large organizations located in North America and Europe and an additional 15 interviews with a panel of experts and industry veterans. The main takeaways are:

- Lower costs and multiple proof points drive increased interest and investment.
- Mobile-based solutions increase applications of digital technologies in maintenance and workplace services.
- IoT improvements overcome early adoption issues.
- Reducing building operating costs motivates real estate and facilities executives.
- Space efficiency and employee well-being are becoming priorities.

Building Engines (2021) published a buyer's guide for building operations technology for the CRE market. They provide advice on must-have capabilities and support features for choosing a building operations platform, including topics such as connectivity, interoperability, and deployment.

Renewed interest in building technology following the COVID-19 pandemic will also likely spur interest for and implementation of intelligent building technologies. BOMA (2021) presents the results of a survey of over 3,000 commercial office space stakeholders. They project that less than half their employees will work full time in the office over the next 12–18 months and about a quarter of the workforce will work remotely full time or most of the time. Honeywell (2021) with KRC Research performed a survey over 1,500 facility managers in the United States, China, Germany, and Saudi Arabia to discern the impact of COVID-19 on building trends and facility managers' priorities. 67% of those surveyed in the U.S. responded that they are now more willing to invest in smart buildings that drive efficiency and sustainability and 62% in healthy building solutions. 93% of the U.S facility managers surveyed responded that remote facility management was important.

Umbrella 3: Individual Smart Technology Incentives

As previously mentioned, one perceived barrier for intelligent building technology is the lack of sufficient incentives. Intelligent building developers frequently cite the lack of financial incentive programs as a barrier, and this lack likely contributes to concerns about higher building costs and returns on investments. Offering incentives for an individual intelligent building technology such as a networked lighting system could lead developers to integrate the lighting with other building systems like the BAS and other intelligent building incentives.

In the supply distribution chain, incentives can be paid out to increase market uptake of a product or services. An incentive is considered downstream when it is paid directly to the consumer — for example, as a rebate — or provided to the contractor or installer. A midstream incentive is when the distributor, retailer, or vendor receives the incentive, which is passed along to the contractor, installer, or consumer. In this case, the market actor is positioned between the manufacturer and the user. Finally, there are upstream incentives directed at the manufacturer or supplier. These incentives are passed down to the distributor in the form of a reduced price, enhanced support, or premium product availability.

According to Bakken et al. (2016), midstream or upstream channels typically deliver lighting and HVAC measures. They state that commercial and industrial (C&I) midstream incentives can be an effective strategy to achieve "broad-based and rapid market transformation goals." Quaid and Geller (2014) describe the benefits of upstream programs for C&I markets and provide examples of successful programs. Merson et al. (2016) describe the business concepts of an upstream program and the impact on market transformation.

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Utility and Public Sector Efforts to Promote Adoption

Utilities and public sector entities (federal, state, and local) are important stakeholders that can facilitate intelligent buildings' adoption. There are well defined and tested measures that they can take to incentivize the broader implementation of intelligent building technologies. The intelligent buildings' potential to provide demand response (DR) and demand flexibility (DF) services to utilities can trigger additional opportunities to motivate adoption. Intelligent buildings' ability to serve as grid-interactive efficient buildings (GEBs) will enhance market demand for intelligent buildings with public and utility efforts to support the State of Minnesota's commitment to energy efficiency, carbon-free electrical generation, and renewable energy.

King and Perry (2017) suggest that utilities can help proliferate the uptake of intelligent building technologies through their energy efficiency programs. Many utilities currently employ prescriptive incentive approaches for measures such as occupancy control, daylighting controls, smart power strips, smart plugs, and building management systems. Smart technologies could be introduced into these prescriptive rebate packages. With intelligent buildings' monitoring and control features, utility pay-for-performance and demand response programs could be used to provide implementation and operational incentives that help cover needed services' costs. The report provides a number of examples of existing utility programs that can serve as models.

State and Local Energy Efficiency Action Network (2020a) describes the methods and best practices that help utilities evaluate the economic benefits of demand flexibility that GEBs bring to electric utility systems. This information is needed by utilities to design programs, market rules, and rates. The report offers guidance to stakeholders such as state and local policymakers, public utility commissions, state energy offices, utilities, state utility consumer representatives regarding DF, GEBs, and grid services.

Satchwell et al. (2021) is a DOE-funded report that describes a national roadmap to address the top barriers to GEB adoption and deployment. Table 2 shows the four roadmap pillars and the recommendations for each pillar.

Table 2. DOE GEB Roadmap Pillars and Recommendations

Roadmap Pillar	Recommendation
1. Advancing GEBs through Research, Development, and Data	Develop/accelerate deployment of GEB technologies
	Accelerate technology interoperability
	Improve access and use of DF data
2. Enhancing the Value of GEBs to Consumers and Utilities	Develop innovative incentive-based programs
	Expand price-based program adoption
	Introduce incentives for utilities to deploy demand-side resources
	Incorporate DF into resource planning
3. Empowering GEB Users, Installer, and Operators	Understand user interaction with GEBs and role of technology
	Develop GEB design and operation decision-making tools
	Integrate smart technology training into existing programs
4. Supporting GEB Deployment through Federal, State, and Local Programs and Policies	Lead by example
	Expand funding and financing options
	Consider use of codes and standards
	Consider implementing state targets or mandates

The roadmap lists key actions that can be taken for each of the pillar recommendations. The second and fourth pillars are most important when considering actions that can be taken by utilities and public entities to create programs, plans, and policies to encourage greater GEB market adoption.

Dean et al. (2021) demonstrate leading by example with the first recommended pillar of the DOE national roadmap for GEBs. The General Services Administration (GSA) and Rocky Mountain Institute (RMI) conducted a feasibility study of GEB implementations to identify and describe the potential value streams in market analysis. The report defines a screen process of

GSA to its portfolio of federal buildings to identify sites with the greatest potential for cost-effective GEB implementation. The blueprint covers the issues surrounding contracting for DF cost savings, impacts on building tenants, and training on GEB measures. The report proposes best practices and recommendations for the performance contract development and implementation of GSA GEBs.

State and Local Energy Efficiency Action Network (2020b) describes GEBs in terms of state and local governments' goals. The report discusses how state and local governments can work with utilities, regional grid operators, and building owners to advance DF.

NASEO-NARUC Grid-interactive Efficient Buildings Working Group (2019) describes how states can create a GEB roadmap, adopt and implement it, monitor its progress, and update as needed.

NASEO (2021) describes how states and localities can expand building energy efficiency policies and programs to include DF. This includes promoting measures such as intelligent building energy management, grid-interactive equipment, and other distributed energy resources (DERs) (DR, onsite power generation, thermal and electrical energy storage, and electric vehicles and their charging equipment). They list building owner values streams in which DF can provide monetizable benefits, for example, energy costs, demand charges, time-of-use and time-differentiated rates, DR programs, and grid service markets. The report describes how states and localities can modify existing building energy policies and program types to include DF and grid impacts, such as energy benchmarking, ratings and labels, building performance standards, building energy codes, appliance standards, and zoning and land-use regulation.

Guernsey et al. (2021) analyze stakeholder and incentive mechanisms and create a guide for specific opportunities that federal, state, and local regulators can employ to promote DF as a grid resource. Table 3 summarizes these 11 opportunities.

Table 3. Opportunities to Improve Access and Value of Demand Flexibility

Financial Incentive Mechanism	Opportunity
Cross Cutting	1. All Financial Incentive Mechanisms: Improved consistency and standardization (see opportunities 5–10 in this table)
	2. Rates/Markets: Progressive state regulations and utility business models focusing on resiliency, reliability, and decarbonization
	3. Program/Markets: Modernization of IT and processes including enrollment, data sharing, and measurement and verification (M&V) to reduce the administrative burden
Rate Structures	4. Alternative/modern rate design
	5. Increased consistency in rate design approaches and structures between utilities (despite necessarily differing prices)
Utility Program Structures	6. Increased consistency in DR program design and implementation between utilities
	7. Integrate smart technology training into existing programs
Market Structures	8. Expanded reach of wholesale markets across the entire U.S.
	9. Unified markets and treatment of distributed energy resources (DER) (e.g., FERC orders 2222/2222-A); market/service standardization

10. Elimination of state opt outs and consistent participation enabled across jurisdiction
11. Regulatory alignment of incentives with utilities to streamline participation

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Concluding Remarks

The literature surveyed in this report shows that intelligent buildings can be an important energy resource by bringing energy efficiency and demand flexibility to the commercial building sector. Projections show that the market size of intelligent buildings can be expected to grow in the near term. The impact of COVID-19 is changing work practices and space utilization such that the need for smart, connected, and integrated building systems are needed to support building occupants' health, well-being, and productivity. As the electric grid shifts to non-carbon energy sources, intelligent buildings will serve as the grid-interactive efficient buildings required to adapt to the changing energy services, programs, and policies.