The Past, Present and Future of Smart Building Management

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Abstract

This paper explores the use of smart building technology to provide lower building operating costs as well as increased revenue opportunities with improved safety, security and resilience. When the term "smart" technology for buildings is used in the context of this paper, it refers to integrated sensors and systems that enable monitoring and control across a range of functions to include comfort, safety, security, functionality, utility (especially energy and water management), transactions (such as transactions with the electric utility or other business partners), and other functions. These systems can communicate with other devices and the "cloud" to permit analysis of data and decisions based upon needs and preferences. These technologies can reduce costs for operations and for maintenance, even generating revenue or accomplishing lower-carbon or zero-carbon goals. Another significant benefit of these technologies is an improvement in self-sufficiency or resiliency, that can range from improved redundancy to full microgrid capability.

Smart building technology has evolved as information technology advances have provided more means to collect, analyze and control building systems. Buildings have long utilized control systems for HVAC or lighting, but these were not designed for optimization. The initial smart systems that were deployed were based upon proprietary (specific to one supplier) platforms that typically offered the potential to improve the efficiency of the building's functions as well as energy usage, offering substantial energy cost reductions. These systems were expensive and limited to large facilities or large collections of buildings. They were justified on the basis of energy savings alone, not the more comprehensive value potential of smart building management that will be described in this paper.

Going forward, the evolution of secure, open-source platforms (especially Volttron, which is explored here) allows a wider array of functions to be interconnected, analyzed, and even offers transactional capability with the electric grid, opening the door for Demand Response (DR) and Distributed Energy Resources (DER) as sources of revenue. Lower cost and smart sensors and communication technology offer the ability to monitor more activities than before. Also, buildings may be the power plants of the future as renewable generation and energy storage are more routinely deployed at buildings. They may even be the gas stations of the future as companies increasingly incorporate electric vehicles into their operations. State-of-the-art and future building systems offer advanced analytics to identify and even control for far more effective building operation. This is facilitated by cloud storage and the advanced analytics that are being offered by cloud storage providers.

Introduction

The Industrial Internet of Things (IIoT) has opened new opportunities in the management and operation of buildings and industrial systems. The IIoT has been made possible through advances in web-based and other computing platforms, lower cost sensors with data collection and analysis (smart sensors), ubiquitous networking with WIFI and wireless enabled devices, and other advances. Buildings and other facilities with smart capabilities allow for improved operation and comfort while also offering improved security, safety, energy and water management, transactions (such as transactions with the electric utility, natural gas utility or other business partners),and resilience to weather and other extreme events. These systems can communicate with other devices and the cloud to permit machine-based or human-driven analysis of data and decisions based upon needs and preferences. However, only a small percentage of commercial buildings are equipped with what would be regarded as a full complement of smart technologies. This is in part because their existing data is in multiple disparate data sets, making consolidation, presentation and analysis in a unified, methodical manner very difficult. As a result of this, data has become so ubiquitous, but also so poorly organized, that building owners are faced with the problem of having too much data and not enough information.

Why don't building owners make better use of the data? First, the systems to efficiently manage all of the data are relatively new, or until recently, have been very expensive, making them cost effective only in limited applications. Many building owners are not aware that today the technology exists to cost-effectively configure the data in a manner where a better understanding of building operation and utilization is possible, opening the door to greater energy efficiency, improved safety, security and comfort, and more effective utilization of the building asset. Lacking the understanding of what is now possible with modern Smart Building technology, many owners or managers of buildings believe that they are doing the very best that they can when it is in fact now possible to do much better.

The second reason that data is not more effectively used is that most buildings have several disparate systems that do not communicate well with one another, and data from different systems are not generally collected in a single place. HVAC systems have one set of data. Energy management may have a different set of data. Lighting a third, etc. These systems usually have proprietary data formats. Owners or managers of buildings may have new building systems, but cannot integrate the various data streams to inform them how they can better manage the various building systems in a more unified manner. To have a truly smart building, it is necessary for the IT backbone of the system to handle any kind of data. Therefore, an additional system that can interact with each of the building systems to integrate all of the data is necessary in these situations.

To add to the need for better building management, developments in Distributed Energy Resources (DER, especially renewable energy) as well as energy storage in combination with time-of-day metering have created opportunities for improved facility energy management. These require transaction management of energy purchases/sales, as well as tracking and conducting transactions of environmental attributes that contribute to sustainability goals. The United States Department of Energy (US DOE) identified a need for a secure, transactive system that could interface with the grid and their Pacific Northwest National Laboratory (PNNL) developed a cybersecure, open-source platform called Volttron for this purpose. It will be discussed in more detail later in this paper.

The underlying platform, whether Volttron or a proprietary system, is a necessary component for successful building energy management and improved automation. Also necessary is an effective interface between the underlying system and people using the building, maintaining the building, and managing the building. Building owners and tenants can both benefit significantly, and they become essential contributors to the solution when the proper tools are available.

Achieving Key Goals: Building Functions and Priorities

Building and plant owners are faced with a range of priorities that must be managed. How well these priorities are managed will have a direct impact on the building value.

- *Safety* includes physical or structural safety, safety from extreme events such as fire, flood or severe weather, and personnel safety. All of these can be improved with the use of monitoring sensors – whether they be sensors for fire or hazardous materials, video surveillance, or wearable or portable personal monitoring devices. These sensors provide signals that can be sent to a platform for analysis to identify safety events or to algorithmically anticipate potential upcoming safety issues. Today, safety also incorporates physical separation as needed and adequate ventilation to help prevent the spread of infectious disease. Basing ventilation on building occupancy can enhance health and safety while maintaining efficient energy use.

- *Security* includes both physical security and cyber security. Physical security is enhanced with monitoring technology. Technology to monitor personnel access has been available for decades. Now it can be integrated with other functions, such as energy and comfort systems to improve both physical security and these other functions. Advances in sensors also enable improved monitoring of physical security. Low-cost, WIFI or wireless enabled, video cameras now offer the opportunity to monitor more locations in the building. Cyber security is also crucial in today’s interconnected world. Cyber security can be enhanced with both local and cloud-based computing – one providing the backup in the event that the other is lost. Cloud computing adds great potential for data storage, flexibility and powerful data analysis tools that are becoming available on commercial cloud platforms from Microsoft, Amazon Web Services (AWS) and others. These providers also go to great lengths to secure their cloud platforms from attack and in many cases are more secure than local storage due to the advanced security features that they deploy. Nevertheless, having a local data historian with analysis and control functions can be beneficial in the unlikely case of a loss of network connection.

- *Comfort* includes those building functions and processes that make a workplace a productive environment for employees. These are functions such as lighting, HVAC, plumbing, etc. For most office buildings, these represent a substantial portion of the energy load of a building. Occupancy-based lighting controls (typically using infra-red detectors) have been in use for many years. New, smart lighting includes WIFI connected light bulbs and incorporation of more natural light during daytime hours (“daylighting”). Connection of these devices to a data analysis platform can identify patterns for improved controls and enable remote control. Comfort loads vary over time and also are highly weather dependent. Use of network connected smart thermostats and similar technology enable adjustment of building comfort conditions based upon measured occupancy (using infrared or CO_2 monitoring). Sensors on exterior temperature and humidity as well as information on weather forecasts can play an important role in reducing HVAC loads. HVAC systems are also available that are much more controllable and efficient than in the past - only cooling or heating as needed and only where and when it is needed. A smart building management system can also incorporate equipment monitoring and predictive maintenance in order to anticipate and manage maintenance and repair activities.

- *Functionality* relates to the function of the business. This includes the equipment necessary for the business to perform its principal function, such as computers, manufacturing equipment, equipment used for storage of material, etc. This equipment, along with equipment used for comfort, comprise nearly all of the energy load of a building or group of buildings. Many of these pieces of equipment have their own control systems that are supplied with the equipment and will also usually have data interfaces available for remote monitoring and perhaps even allow for control of this equipment from a smart building system.

- *Resiliency* is the responsiveness of the system as a whole to unusual conditions or outages, and its ability to both stay functional and recover. Resiliency demands have increased the need for remote management of the building and optimizing the building under a wider range of conditions. The recent COVID 19 pandemic has created a need to maintain a building secure and operating while largely empty for an extended period of time. Most buildings are not constructed to be empty for extended periods, and the various systems - especially HVAC - may not work optimally at low occupancy levels. Comfort and functionality are also impacted by the need for resiliency in some cases.

  Resiliency is becoming an increasing concern with respect to the higher frequency of severe weather events as a result of climate change. Resiliency of electric power supply can be addressed with the use of distributed generation and energy storage resources. These systems must often be integrated with the electric grid and therefore require the ability to transact with the grid and local utility. Resiliency needs will differ from one entity to another. For example, a hospital requires a high level of resiliency for both comfort and functionality equipment. Therefore, hospitals have back-up sources of electricity and other critical utilities. Another example, a biopharma company that develops biologic treatments for diseases, requires very high energy resiliency with respect to functionality because of the high economic impact of a power loss. In one situation a biopharma company built its own power plant on site to assure high reliability for power. The company normally self generates and does not rely on grid power except when the power plant is not in operation due to maintenance or repair activities. For a retailer, energy resiliency might not be as critical as for a hospital or a biopharma company, depending upon the amount of perishable items it sells. For instance, a supermarket will have a large amount of perishable items while a department store will not. So, their resiliency needs with respect to energy will differ.

- *Achieving environmental goals* - Today and in the future buildings are being built and managed to minimize the impact on the environment. Municipalities are mandating zero carbon buildings and construction of buildings to comply with Leadership in Energy and Environmental Design Standards (LEEDS) building standards. An increasing amount of building floor space is covered under state or local energy use or benchmarking policies. Smart buildings can more readily achieve these objectives and keep track of how environmental goals are being achieved.

- *Predictions and transactions* - Ideally, it would be possible to forecast building energy usage and to manage transactions for energy, environmental attributes and other accounts. This aspect of building management takes all of the above categories and inputs, and combines internally-generated data with external data such as weather data from the National Weather Service to accomplish predictive load analysis. It can be used to manage and verify greenhouse gas or carbon footprint goals and to make decisions about storing or selling power based on time of use. This in turn can enhance building resiliency while optimizing revenue.

Balancing Priorities

All of the above priorities must be achieved first with careful consideration to what the building is for and what the building is supposed to produce. The building must meet the functional and operational objectives of the enterprise that occupies the building. There is always a clear desire to reduce the cost of achieving all of the aforementioned building functions while meeting the organization's objectives. But it may also be important to achieve other priorities for the organization, especially environmental sustainability goals or goals for resiliency. Ideally, policies will align these goals to reduce cost with the goal of reducing the environmental footprint. In the case of owner/tenant situations, this could take the form of *Green Leases* – leases that are designed to align the goals of both the owner and tenant to reduce energy consumption (especially during peak demand periods), waste generation, or to achieve other sustainability goals. As an example, time-of-day metering is a policy that encourages a reduction of energy consumption during peak demand periods by charging more for electricity consumed during those peak demand periods. Investment into systems that facilitate moving some loads to off-peak periods will reduce energy charges. Similarly, green leases could encourage investment into energy saving systems or practices with benefits shared by both the tenant and the owner.

New developments that have changed the equation of building management include self-generation, such as use of solar arrays, and energy storage and increased availability of wireless technology. Even electric vehicles that may be used on site can potentially be used for storage. These technologies are becoming more cost effective and are therefore starting to be deployed more widely. The possibility of Building-to-Grid (B2G) generation and distribution requires policies and information systems to manage these resources effectively.

Wireless and WIFI technology enables sensors and devices to be added without the need for routing wires for data - greatly reducing the installation cost of these sensors. Moreover, smart sensors, sensors equipped with processors and software to better manage and share data, make the data from these sensors higher quality and also permit local control of devices. Because these sensors have dropped in cost and are easier to install, they can be added to existing buildings, providing data that was not available in the past.

In light of the various devices, systems, functions, and accounts associated with large buildings and collections of buildings, there are a wide range of disparate data sources that exist in different forms. These may also exist in different organizational "silos". The number and variety of data sources can be overwhelming, making it difficult to manage all of the organizational objectives in a holistic manner. Information needs to be transformed into a decision aid that can help people interpret actions into impacts. Even with existing motivation to improve energy use, health, safety or other aspects of a work environment, people still need tools that enable good decision-making. In a review of publicly-available tools such as EPA's Energy Star program, DoE's EERE calculators, and LBNL's Home Energy Saver tool, this was described as "...the information contained in the typical decision aid available today forces decisions to be made in an ad-hoc manner with only partial knowledge of the range of actions, the available choices, and the cost-effectiveness of each option… framing of the information provided needs further improvement."[1] The same idea applies to ongoing building operations as to initial choices made in the design and procurements phases.

Smart building systems allow the parties (owners, operators, tenants, etc.) to have a "dashboard" that shows the status of the various building functions and transactions - taking multiple disparate data sets and configuring them into one area. It is possible to see an overall compilation of how the buildings are performing as a whole, as well as to drill down to see the performance of individual buildings. These systems maintain a historian that can be accessed to permit analysis of data to identify ways to improve operations and optimize the various functions while also minimizing cost and meeting other objectives, such as environmental objectives. Smart building technology has enabled the party utilizing the smart building system to identify efficiencies, areas where there are redundancies, manage transactions more efficiently and to keep the building safer and more comfortable for its occupants while still fulfilling the organization's mission. With the ability for costs to go down and revenues to go up, the building will also become more valuable, a direct benefit to the building owner.

Saving Energy - part of the ROI equation

Energy consumption for comfort and potentially even for functional loads is an important area where significant improvement is possible while also supporting and perhaps improving building comfort and functional objectives. Historically, this has been the main focus for smart building systems. Increasingly, appliances, lighting, thermostats, door controls, and other equipment are being supplied with WIFI capability, which enables these energy consuming devices to be monitored and even controlled remotely. But, as will be discussed, energy savings are not the only source of returns.

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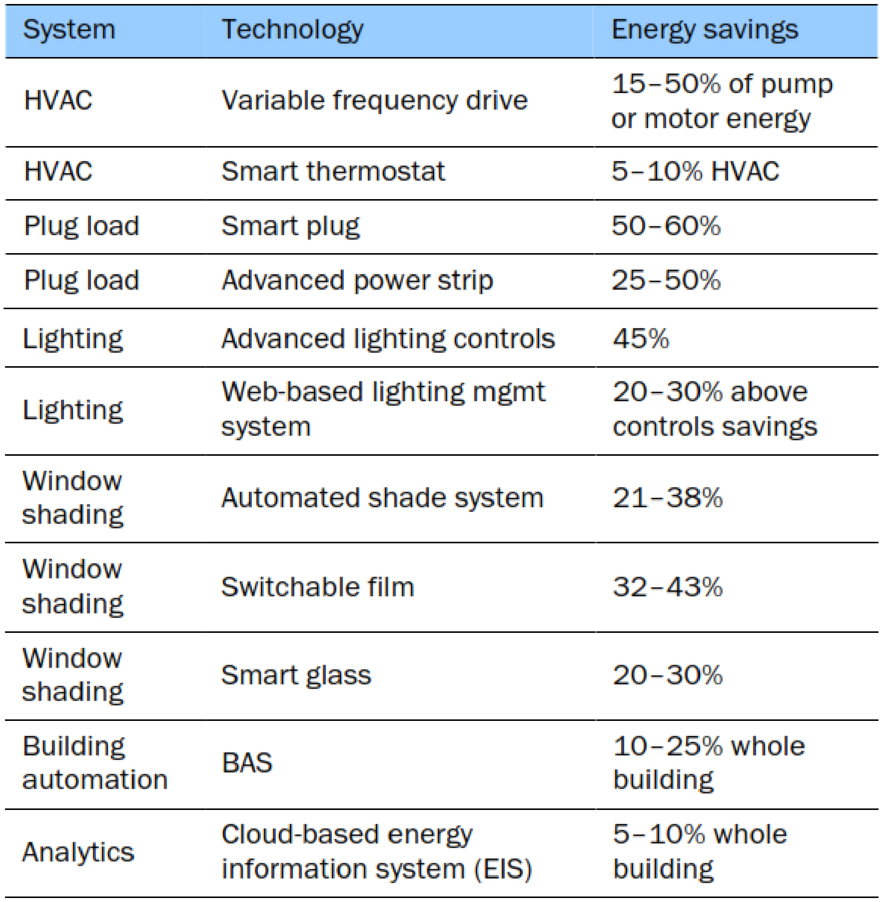
[1] Attari, S. and D. Rajagopal, "Enabling Energy Conservation Through Effective Decision Tools," Journal of Sustainability Education, Vol. 8, Jan 2015 ISSN:2151-7452.

Table 1. Energy savings that are possible from individual smart energy technologies[2]



System	Technology	Energy savings
HVAC	Variable frequency drive	15–50% of pump or motor energy
HVAC	Smart thermostat	5–10% HVAC
Plug load	Smart plug	50–60%
Plug load	Advanced power strip	25–50%
Lighting	Advanced lighting controls	45%
Lighting	Web-based lighting mgmt system	20–30% above controls savings
Window shading	Automated shade system	21–38%
Window shading	Switchable film	32–43%
Window shading	Smart glass	20–30%
Building automation	BAS	10–25% whole building
Analytics	Cloud-based energy information system (EIS)	5–10% whole building

Table 1 shows individual smart energy technologies and possible energy savings. It is important to note that these methods are not additive, because use of one method will often impact the savings of another method. While most of these loads are self-explanatory, the automated shades, window film, and smart glass offer energy savings with respect to HVAC and lighting. But these also offer other benefits. By filtering UV rays these technologies will reduce damage to light sensitive materials (for example, upholstery, wood furniture, rugs, carpets, etc.). A building automation system (BAS) with cloud-based analytics enables the total operation of the building to be analyzed to find areas for improving operation. None of the technologies shown here account for revenue opportunities that may be available. These revenue opportunities are discussed later in this paper.

Beyond Energy Savings - maximizing building value

Smart building systems offer the opportunity to increase the value of the building through revenue opportunities, such as Demand Response (DR) and DER, as well as finding new ways to extract value from the building. Investment into and operation of energy efficiency or renewable energy equipment

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[2] Jennifer King and Christopher Perry, American Council for Energy Efficient Economy, "Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings", Report A1701, February 2017; Note that these methods are not additive. Use of one method will often impact the energy savings that are possible from the other methods.

often generate environmental attributes such as tax credits or renewable energy credits (RECs) that have an economic value that can be used to generate a revenue stream. Building to Grid (B2G) generation will entail a transactional component that will include these attributes in addition to the energy supplied to the grid. Similarly, energy management practices that include DR will entail a transaction with the utility. It is also possible to actually improve the safety, health, and overall utilization of the building with smart technology. Smart buildings that incorporate these features with regard to energy can manage these transactions with the utility or between owner and lessee or even between owners of different buildings. With the opportunity for costs to go down and revenue to go up, the building will also become more valuable, a direct benefit to the building owner. There are additional benefits. These include:

- Improved inventory management - avoiding duplication of parts storage among buildings
- Improved space utilization - occupancy and use can be monitored to identify which parts of the building are underutilized and may be redeployed
- Integration of accounts and transactions with vendors and contractors
- Improved safety and security - occupancy can be monitored as well as the concentrations of oxygen, CO_2 and any pollutants that may be of concern
- Monitoring, control and optimization of fuel, water, sewer and other utilities
- Analysis of data to optimize each function of the building and to optimize all of the functions collectively to achieve the goals of the enterprise.

More data = more value (more than just energy savings!)
Smart building management systems enable monitoring and control of all aspects of building operation. Analysis of building data will create opportunities for improved asset utilization, improved safety and security, revenue opportunities and integration of transactions, all in addition to energy savings that have historically been used to justify smart building systems.

The following sections will provide case studies of applications where smart building technology has been and where it is now. These sections will also discuss where smart building technology is heading in the future, helping to define the opportunity for building owners, tenants and managers.

Smart Building Technology - The Past

“Full Building Smart Building technology” has been available for at least a decade in proprietary systems that required substantial development and therefore has carried a high cost. Until recently, it has been used in limited applications where there was a large enough asset base to justify the expense. The following case studies provide a couple of specific examples of where Smart Building technology has been applied and the types of benefits it has to offer.

Case Study - The State of Missouri

Leveraging Technology and Data to Enable Ongoing Savings of $30 Million Every Year

In the State of Missouri a project was initiated in 2005 that put thousands of state-run buildings on a unified, proprietary platform. This project effectively demonstrated the potential for dramatic improvement to facility costs, management, and planning using an information system to integrate disparate systems that displayed the information in an organized manner in a "dashboard" that also permitted drilling down to see details. A short summary of the program is described below, with more details available in the paper "The State of Missouri Enterprise Sustainability Platform" included as Appendix A.

This project work saved the state $30 million the year after deployment.[3] The experience demonstrates what was possible 15 years ago!

The Challenge

The state building portfolio in Missouri consisted of more than a thousand administrative, correctional and historical buildings spread over hundreds of miles. The state lacked the visibility for energy management and space utilization due to inadequate instrumentation, metering, and controls and no means to effectively organize the limited data that they had. Energy consumption was growing, yielding higher costs and adverse environmental effects. Despite having a centralized facilities department, they did not have the real-time data necessary to proactively manage capital requests from occupants or compare performance against benchmarks. The areas that needed to be addressed ranged from facility functionality, safety, and comfort, while reining in and managing uncontrolled costs for both operations and maintenance. Program goals were initially:

1. Improve building safety
2. Reduce maintenance costs
3. Reduce energy costs and environmental impact
4. Improve visibility for facilities managers into entire building fleet with one, unified system
5. Evaluate and consolidate data on space utilization
6. Streamline building management in a centralized way rather than by department
7. Develop a credible capital plan
8. Make O&M predictable

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[3] Peter Scanlon, Dave Mosby, "Reducing Total Cost of Ownership: How to Control Renewal, Operations, Maintenance and Energy Costs For Your Facilities: The State of Missouri Story," PowerPoint presentation, August 2009.

The Enterprise Sustainability Platform - leveraging technology to create knowledge

This was achieved by *leveraging technology to create knowledge* with an Enterprise Sustainability Platform. With data available from diverse inputs such as real-time monitoring of building information, manual condition assessment, and video, comprehensive modeling and planning tools were applied. Computerizing much of the planning and monitoring was effective in planning and managing maintenance, among other benefits. One of the features of the system was the ability to take in existing raw data from a wide range of data formats. Having all of this information organized and displayed in one place enabled the creation of useful summary interfaces that managers could use to visualize the data in concise forms. Drilling down within the interface dashboard enabled details to be quickly retrieved. The system also streamlined billing, payables, procurement and planning. The system framework included a range of software packages specializing in various functions. All were integrated with real-time building data. Today, over 4,000 buildings are on the system. This was achieved because the state's team was willing to commit from the start to a comprehensive approach, without knowing exactly where improvements would come in each building. They believed that their personnel would improve operations once they had the right information. The top-level portal of the system provided gives a window into the ease of access to information at the building, campus or agency level. There were a number of modules, each one specializing in one type of information, whether energy, space usage, or ongoing operations and maintenance plans. Key Performance Indicators could be tracked, providing the visibility needed to flag unusual conditions and anticipate problems. Figure 1 depicts the information available in the top-level facilities portal. On the left side of the facilities portal it is possible to select how information is displayed - by building, campus or agency. On the upper portion of the main part of the top-level portal it is possible to pull up information modules for utilities, operations, space, energy or capital and display by a time series. Quick-view gauges are available for key performance indicators, such as average electricity cost per square foot, occupancy in square foot per person, condition with respect to capital deferred maintenance, and average total electric cost. To provide insight into operations, this dashboard-style interface could pull up individual utility bills and metrics over a range of time periods and locations. This enabled processing of the 1,000 or so utility bills to become highly automated and independently verified.

Key to Success in the State of Missouri Program

***The IT backbone can handle any kind of data*.** This is even more critical today, when innovation is so rapid that today's sensors can be replaced by better and cheaper options as incremental improvement is performed, either to achieve the same functionality or to add functions such as CO_2 monitoring, humidity testing, or other human comfort or safety factors, as well as integration of environmental or revenue metrics such as utilizing on-site generation.

Figure 1. The State of Missouri Building Facilities Portal

Results

The eight goals that were initially proposed for the program were met. Some of the key results from implementing this program include:

- Work order tracking by schedule, scope and cost improved transparency and efficiency, resulting in less redundancy and improved supply chain management, yielding *lower maintenance costs*.
- Benchmarking by comparisons against base year and against other buildings' performance profiles enable identification of areas for improvement. Investment paybacks are visible, *improving budget accuracy and predictability*.
- The dashboard can be accessed from any location, so the data can go to the experts as needed for analysis and troubleshooting, enabling *more efficient use of time*. Root cause analysis has a very good head start. This is even more valuable in today's environment where the ability to collaborate remotely is a crucial part of the workplace. The dashboard can be accessed from any location, allowing staff to collaborate remotely to analyze data and troubleshoot problems.

- In one building where a kiosk in the lobby showed building operational data, employees became proactive in helping to reduce energy use, resulting in about 6% reduction in energy consumption.
- All of the above add up to significant cost savings. *Annual savings for the program are ongoing and estimated at $30 million per year*. The payback period for the investment in this program was within one year. Unquantifiable benefits in safety are also being realized, with improved knowledge of building conditions, from sprinklers to equipment condition.

There were benefits to the program that had not been anticipated, as well:

- The state learned that buildings designed to LEED-Platinum certification standards do not necessarily operate consistently with their potential. Once data became visible for all buildings, identification of issues such as a continuously-running chiller achieved *over 6% energy improvement even for a LEED-certified building*. Other large buildings achieved more dramatic improvements, well over 20%.
- Combining all of this data in one place gave the state facilities' managers the inputs they needed to design an estimate of carbon footprint. This automated part of the facilities management dashboard combines commuting and fleet data, building and map data to calculate carbon footprint and measure the impacts of improvements and changes.

Immediate Energy Savings from the State of Missouri Program

One example problem that the command center engineer noticed was that one building's cooling units never turned off, unlike similar buildings. After a request to the on-site building manager, they learned that several rooms were being cooled for computer servers that were never installed. Modifying the low setpoint immediately initiated **tens of thousands a year in energy savings**.

The state of Missouri case study shows us what could be accomplished using 2005 technology on a large, distributed and diverse fleet of buildings. Today the potential benefits are even greater and cost to implement is lower due to improvements in information technology and improvements in sensors.

Case Study - UC Irvine Laboratories[4]

Healthier Air with Lower Energy Usage

At UC Irvine, HVAC for laboratories is critical to assure a safe environment. Harmful chemicals can potentially enter the spaces and the HVAC system is therefore necessary to maintain the safety of the spaces as well as the comfort. HVAC is also the largest energy load. The laboratories' HVAC systems had been controlled 24/7 at a constant air exchange rate regardless of occupancy. After installing smart sensors and controllers that monitored the air for harmful contaminants, it was possible to reduce the air exchange rate by one third without sacrificing occupant safety. Additional efficiency upgrades were

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[4] Jennifer King and Christopher Perry, American Council for Energy Efficient Economy, "Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings", Report A1701, February 2017

made to the HVAC systems that resulted in 60% reductions in energy consumption across 10 UC Irvine Laboratories.

HVAC systems are generally the largest load for most buildings. There have been several advances in HVAC systems over the traditional constant air volume rooftop units, as described below. But, to take full advantage, advanced sensors and controls are needed.

Modern HVAC systems

Modern building HVAC systems offer substantial advantages over HVAC systems of the past; however, to take full advantage of these systems, it is necessary to have the appropriate sensors and controls.

Traditional rooftop units of the past utilize a single air handler to supply a large zone (perhaps a single floor of a building) through a network of ductwork and a constant air volume (CAV) air handler. Rooftop units can be improved by having variable air volume (VAV) controls with a variable speed air handler that can supply individual zones, each zone having independently controlled dampers that can vary the volume flow from the ductwork to the individual space. This enables the system to only supply the spaces that need to be supplied. Occupancy controls and individual room thermostats can be incorporated into the system as well as space air quality monitoring. The ability to monitor and control individual spaces in commercial buildings - to include air exchange rate - may be another important capability when trying to mitigate infectious disease transmission.

Variable refrigerant flow (VRF) systems are the most efficient and flexible systems. VRF systems facilitate operation of different zones with a single exterior compressor unit that uses a variable frequency drive to regulate refrigerant flow to match cooling or heating needs. VRF systems can offer substantial energy savings while also having several independent zones that heat or cool each zone at the ideal level. Individual rooms in a building can be regulated to different temperatures because with VRF it is possible to heat one zone while simultaneously cooling another. There are also numerous installation and space saving advantages over separate HVAC systems for each zone because VRF also eliminates the need for a network of ductwork served by a single air handler. Each zone is served by an individual, smaller air handler for that space. These systems require separate thermostats for each zone and also work well with occupancy controls and air quality monitoring.

Smart Building Technology - The Present

Smart building technology is being deployed, but it is not yet widely deployed. A very small percentage of commercial buildings currently use what would be regarded today as comprehensive smart building technology that integrates many functions. Because of economies of scale and because these owners tend to be the most sophisticated owners, smart building technology has been deployed primarily at larger buildings or large collections of buildings. It is also easier to deploy smart technology on a new construction building where it is possible to integrate the technology for the smart building and to design the building to utilize its functions.

Many of the large companies that sell and deploy building monitoring and control technology sell systems that use proprietary systems. These proprietary systems tend to be more costly to deploy and may require additional effort to be integrated with other systems. On the other hand, proprietary technology provides the company that sells the technology an incentive to support and enhance their system because competitors are locked out.

Open-source systems utilize coding methods that are publicly available and they often can integrate more easily with other technologies while also offering lower cost than proprietary systems because development of software and devices is spread over a broad community. Open-source systems provide greater flexibility to change or expand a system.

Potential of Smart Sensors

The increasing number of inexpensive smart devices that can be monitored and controlled by WIFI or wireless technology make open-source attractive because the open-source platforms are well suited for such devices and can be expanded inexpensively, using common software languages. Sensors with embedded microprocessors have become less expensive, more reliable and easier to integrate into a smart building system. In addition to proliferation of smart thermostats, sensors for air quality, water quality, energy use and other devices have become more widely available at lower cost. These modern smart sensors do much more than provide a simple, continuous signal. Smart sensors have many of these qualities:

- small, requiring little space for installation
- wireless or WIFI - to avoid a wired connection
- very low power demand (long battery life) to permit fully unwired installation
- provide self diagnostics and self calibration, or can be diagnosed or recalibrated remotely with a wireless link
- data processing, to provide the data to the system in a more efficient and usable manner
- can offer control capabilities for local control if desired

These are now less expensive and easier to integrate into a building management system. Any open-source approach to building management must also take measures to assure security. With security addressed, open-source systems offer large advantages over proprietary systems from the perspective of cost, flexibility, expandability, and data analysis.

Volttron

Volttron is an open-source software *platform* in the sense of Android or iOS that was developed by the United States Department of Energy's Pacific Northwest National Laboratory (PNNL) to provide a *secure*, flexible, and integrated management, control and communication platform for the IIoT. It is an open-source, open-architecture transactional network platform that enables interactions among networked systems such as building loads and the electric grid.[5] Transaction-based controls that are part of the Volttron platform permit a framework "wherein mutually-beneficial and cost-effective market-based transactions can be enabled between multiple players across different domains. Transaction-based building controls are one part of the transactional energy framework. While these controls realize benefits by enabling automatic, market-based intra-building efficiency optimizations, the transactional

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[5] https://www.energy.gov/eere/buildings/downloads/transactional-network

energy framework provides similar benefits using the same market-based structure, yet on a larger scale and beyond just buildings, to the electricity market and the society at large."[6]

Volttron - An Open-Source Platform

Newer, open systems offer security with the benefits of open-source architecture - lower cost, greater flexibility, protection against obsolescence. Volltron, a platform that was developed by the United States Department of Energy's Pacific Northwest National Laboratory, offers a secure means to monitor and control building functions. The Volttron platform also enables transactions to be performed securely with the electric utility, enabling DR and DER.

With Volttron, transaction-enabling building systems are achieved through applications or "agents" that reside either in the local equipment or in the cloud. Volttron can interact with proprietary systems from the major vendors. It has been described as "an important and versatile resource for improving building system performance and creating a more flexible and reliable power grid. But the technology's adaptability has significantly expanded its potential beyond buildings and the grid; users are applying the platform in ways not originally envisioned."[7] Volttron was specifically designed to be able to transact with the electric utility for DR and distributed generation while also managing other building functions.

As described above, Volttron is a platform - not an integrated solution - that enables distributed sensing and controls. It is a flexible and extensible platform for allowing application developers to work with devices, external resources, and each other over a common interface without worrying about underlying details. It has available drivers for Modbus and BACnet, services for storing data, logging, accessing historical data, and scheduling resources. It permits secure application packaging and communication.[8] Applications are agnostic to the programming language - Python, Perl, C, C++, Java, Matlab, Energy+ and others. Integration of Volttron into a commercial smart building management solution is offered by companies that have developed applications for building management that operate on the Volttron platform.

Volttron Security Features

Volttron was developed as a distributed control and sensing software platform for efficient buildings and distributed energy resources. It was developed with security being of paramount importance. During development of Volttron cyber security experts used "a threat-model approach for determining software threats and vulnerabilities and how to reasonably reduce the attack surface and/or harm from a compromise. Through established mitigation strategies, VOLTTRON™ addresses a range of possible attack avenues and risks."[9]

The Volttron platform uses special applications called V-agents that adhere to Volttron Internet Protocol (VIP) to collect, analyze and convert growing data streams into actionable information for the purpose

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[6] Pacific Northwest National Laboratory, Transaction-Based Building Controls Framework, Volume 1: Reference Guide, PNNL 23302, December 2014, pp 1.2-1.3

[7] https://volttron.org/about-volttron

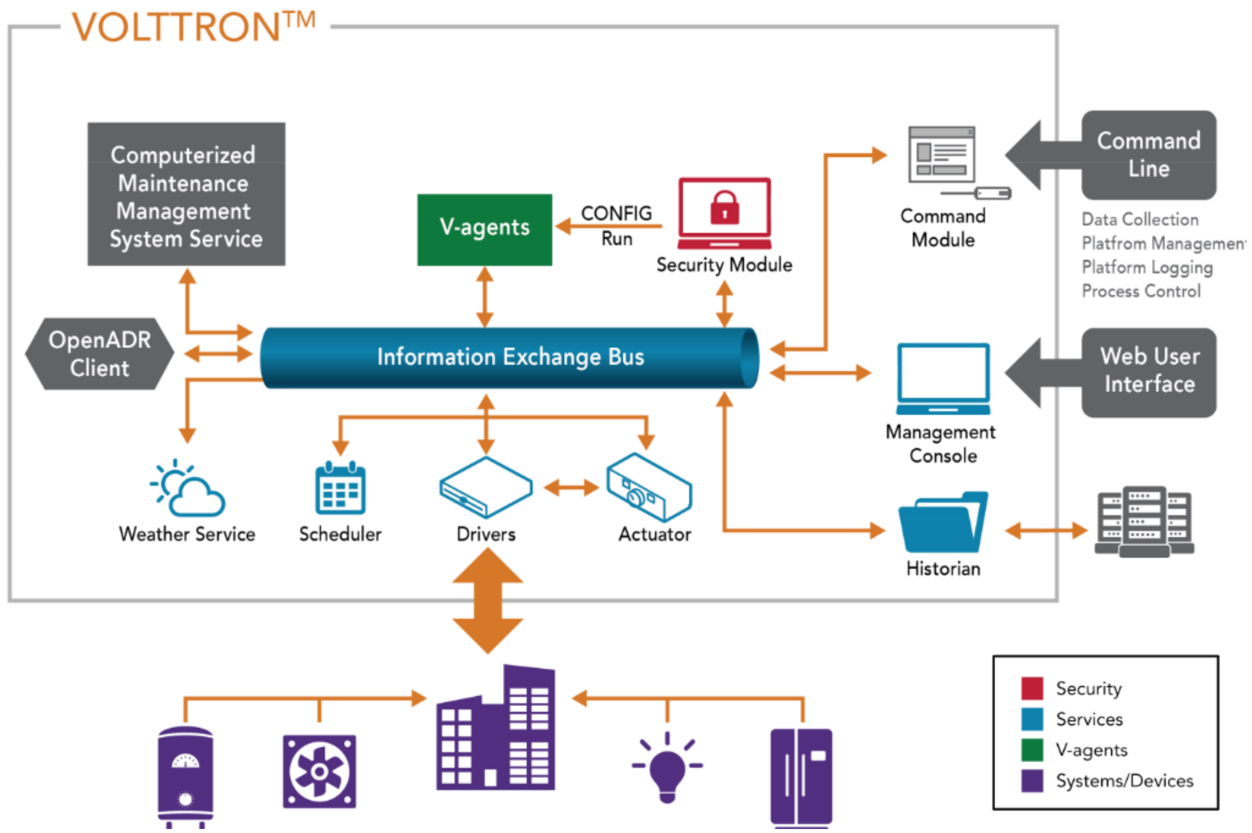
[8] https://www.energy.gov/sites/prod/files/2014/07/f18/Volttron%20-%20Intro%20%26%20History%20%28Haack%29.pdf

[9] https://volttron.org/benefits/secure

of improving building operations, energy management and integration with the electric grid. VIP utilizes encryption so that data can be exchanged securely. The use of registered V-agents is designed to permit data to be securely exchanged with the cloud and with other registered devices and systems.

The Volttron platform is depicted in Figure 5. Central to the Volttron platform is the Information Exchange Bus (IEB), that provides a means to exchange and transfer data securely between devices. Only registered V-agents can access Volttron's IEB. Data that is not from sources registered as V-agents (encrypted using VIP) will not be introduced to the IEB. The IEB interacts with devices on the system – for example, HVAC, lighting, smart equipment and other devices, each having associated V-agent applications. The IEB also exchanges data with a historian, equipment actuators, the weather service, a scheduler, clients, user interfaces, an Automated Demand Response (ADR) client, and maintenance management software.

Figure 5. Volttron building management platform[10]



Volttron for Building Management and for Control

Because Volttron was specifically developed for the purpose of managing building interactions and transactions with the electric grid, it can address the emerging demand for B2G generation, Demand Response (DR), as well as building internal loads (lighting, HVAC, and other loads). Self-generation using photovoltaics is currently being used in combination with the Volttron platform on zero-carbon buildings. Volttron can help manage other functions and utilities, natural gas and water usage, security,

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[10] https://volttron.org/sites/default/files/publications/VOLTTRON_Brochure_V11_WEB.pdf

maintenance and other factors, providing the opportunity to develop an application "dashboard" that allows the user to see the big picture while also being able to "drill down" to see the detail.

Volttron can be used as a control system as well as a system that interacts with and collects data from other systems in the building. For example, it can be used to directly control the HVAC system while being an operator interface, or it can alternatively be used to interact with the HVAC vendor's controls while also providing an interface for the building operator to manage all building activities. For existing buildings that retrofit Volttron, Volttron would most likely be deployed in the latter fashion. But, in a new construction building Volttron could be used directly as the controller for the HVAC.

Volttron devices

Volttron operates on the Linux operating system and can be deployed on any number of commercially available, inexpensive, Linux computing platforms, including low-cost platforms like Raspberry Pi, Onion or others. This makes it possible to inexpensively deploy intelligent sensors and controls using Volttron.

The open-source nature of Volttron makes it cost-effective, because it is free of charge and can be installed on inexpensive computing systems, including smart sensors or even larger control systems. It is highly scalable and can be used on any number of facilities. It is interoperable, and is designed to function in collaboration with other devices and systems. It is secure, with a robust security foundation that was specifically designed to offer the security for interfacing with the electric grid. Finally, because it is open-source, it is updated by the Volttron development community and is resistant to becoming obsolete. Updates and other advances are carried out by a PNNL research team working in concert with an active nationwide community of users.

Voltron is *not* a stand alone commercial solution in and of itself. It is a technology *platform* that makes it possible to develop applications for smart building management. For this reason commercial development of Volttron applications have been a necessary part of bringing Volttron to commercial buildings. Commercial Volttron implementations for buildings are being performed by companies such as Verdicity (Newton, MA) Ace IoT Solutions (Chattanooga, TN), and Intellimation (Norristown, PA). These companies have developed and deployed special applications to be used with Volttron for building management. The Volttron platform is developed and encoded using Python - a widely used programming language. Applications and V-agents may be developed in Python, but other coding languages can be used (C++, Perl, Java, etc.). Using a completely open-source platform enables users to develop applications that meet their individual needs at a low cost.

Volttron incorporates the ability to utilize transactional determination[11] to manage the energy and HVAC needs of a facility, thereby reducing energy usage. For example, if a building has one chiller running to support an air handler, and an additional air handler indicates that it may need chilled water, one of two things could occur. In one case a second chiller would immediately start to serve the needs of the second air handler. In the other case, with a transactional model that is possible with Volttron, a decision could be made based upon the incremental cost of power and the incremental value of the

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[11] Transactional determination can be important when time-of-day metering is used. It allows a decision to be made with consideration of the cost of energy at that time and the value of the benefit of the energy-using load.

need for cooling from the second air handler. The additional chiller would start only after the incremental value of cooling exceeded the incremental value of the power required to run the chiller.[12]

The following is a case study where the Volttron platform was deployed in 2019 by Verdicity.

Case Study - Kansas City Fire Station 15

New Construction with Integrated Smart Controls for Health and Improved Water and Energy Use

Kansas City built a new fire station that was completed in September of 2019 and the Volttron-based smart building system was supplied by Verdicity. The size and capacity of the firehouse is shown below:

- 12,127 total square feet
    - 6,143 square feet of apparatus bay and mezzanine
    - 5,984 square feet living quarters
- Full capacity is 12 fire fighters – 24 for brief moments at shift change
- Two pumper trucks and one ambulance
- Air quality sensors monitor the following:
    - CO
    - CO_2
    - Benzene
    - PM2.5
    - Temperature
    - Humidity
    - Pressure

The home screen of the smart building system is shown in Figure 6. The main display shows the floor plan and overall metrics for the building, to include air quality, energy star compliance, and water consumption per day. The display shows whether or not the room is occupied, the color shows the temperature of the room relative to the room temperature setpoint, and it also indicates relative humidity. Other screens show more detailed information on utilities, air quality, and on each HVAC zone. The goals of the smart building system were threefold:

- Maintain a Healthy Work Environment
- Water Conservation
- Energy Efficiency

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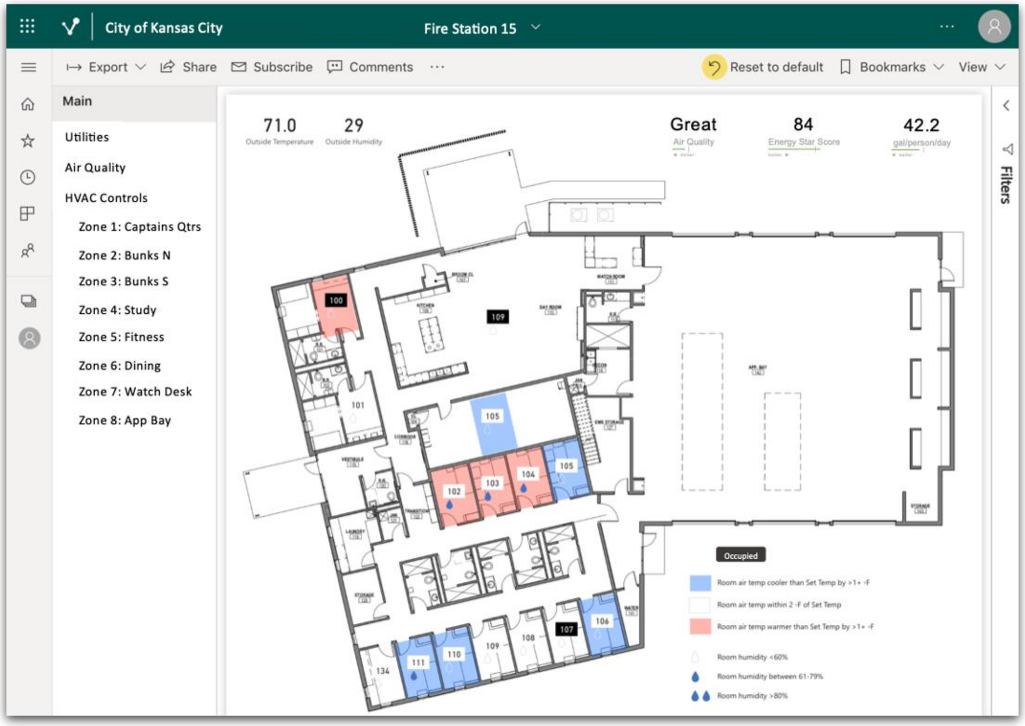
[12] Pacific Northwest National Laboratory, Transaction-Based Building Controls Framework, Volume 1: Reference Guide, PNNL 23302, December 2014, pp 1.2-1.3

Figure 6. The home screen of the smart building system for KC Fire Station 15.



Maintain a Healthy Work Environment

Firemen, of course, have very dangerous work. They enter buildings that are being consumed by fire. But, in addition to the risks associated with entering the burning buildings, firemen tend to have much higher rates of cancer than the general population. This is believed to be in part to dangerous substances that deposit on their clothing and equipment and can become airborne at the fire station, where they normally do not wear protective breathing equipment. For this reason, equipment and clothing are cleaned after a fire to remove the dangerous substances that might be on their clothing and equipment so that the contaminants do not reach the living quarters. An additional precaution that was taken with the new fire station was an air quality monitoring system that monitored the concentration of assorted substances.

CO and NO_2 are monitored in the apparatus bay to ensure that vehicle emissions are exhausted properly. They are monitored by the Verdicity system. Should concentrations reach a setpoint, it will trigger an alarm and exhaust fans will start.

Of particular concern with regard to carcinogens are benzene and PM 2.5. Benzene is a known carcinogen. PM 2.5 may include condensed toxic materials that can deposit deep in the lungs. Continuous monitoring of these species in the decontamination area permits evaluation of the effectiveness of decontamination washing of equipment and clothing.

CO_2 is monitored as an alternative to IR motion detectors for occupancy in spaces, such as berthing spaces, where IR sensors will not always be effective. Occupancy sensors are used to vary the space temperature setting to reduce overall HVAC loads.

Water Conservation

The firehouse has a rainwater collection facility that is used to collect water for washing equipment. This eliminates the need for city drinking water to be used for vehicle and equipment washing and decontamination. The water is treated before being sent to the sewer. Water usage and the water treatment is monitored in the Verdicity system and this has enabled more efficient use of the limited rainwater.

Energy Efficiency

All of this information can be used to help control the HVAC, which is a Variable Refrigerant Flow (VRF) system. This allows control of specific spaces according to need. With the use of the Verdicity building management system (based on Volttron), for both monitoring of the building and control of HVAC, a VRF system became the ideal HVAC solution.

Future Expansion

The expandable nature of the Kansas City Fire Station platform makes it ideally suited to integrate other existing or future fire stations or additional functions and features into one interface. The goals could include improved health, environmental footprint and costs. This can be achieved through incrementally improving their systems through retro-commissioning, identification of areas of vulnerability, and addition of smart sensors.

Opportunities for Improvement to Existing Office Buildings

The Kansas City Fire Station case study above is a great example of new construction use of the Volttron smart sensor platform. However, there are many existing buildings, of a range of types and uses, that could benefit today.

A recent study authored by the Rocky Mountain Institute and the Urban Land Institute for the Building Owners and Managers Association (BOMA) International evaluated the potential for energy efficiency improvement in Class B/C office buildings.[13] The study concludes that this class of building tends to be constrained on three fronts: information, resources, and funding (lack of capital access). However, the value of the business case is on the order of 15 to 35% reduction in energy costs. This translates to increased net operating income, property value, IRR, and rentability. In conjunction with green leases, the maximum energy efficiency value for a given property can be realized. Steps identified include an energy audit and retro-commissioning, which can help quantify the benefits of capital improvements including smart sensors and controls. Developing a benchmark is key, and activities like retro-commissioning can pay for themselves within one to two years. Energy efficiency projects can be financed. A few measures include cost recovery in leases, local utility rebates, performance contracting, and vendor-provided financing. Suggested language for green leasing establishes energy efficiency as a priority, shares the value of investments, and has requirements for tenant fit-outs. Based on this report, the tools available today using open-source controls such as Volttron are ideally suited for low-cost retrofits to Class B/C office buildings.

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[13] Cathcart, Joey, Monika Henn, Greg Hopkins, Marta Schantz, "Unlocking Hidden Value in Class B/C Office Buildings: Best Practices for Pursuing Low-Cost, High-Impact Energy Efficiency and Green Leasing Strategies," Rocky Mountain Institute, Urban Land Institute, and BOMA International, 2020, www.rmi.org/insight/unlocking-hidden-value-class-bc-office-buildings,

Smart Buildings - The Future

In the future, smart building technology will enable improved management of the various functions and priorities of the buildings. Traditionally, smart building technology has been utilized to lower the cost of various functions, such as using occupancy to minimize functional and comfort loads. The use of a smart building technology system permits these functions to be performed more efficiently. Data can be mined to identify opportunities for reducing these loads or optimizing these loads with time-of-day metering. However, when additional capabilities are added to the building it is possible to create revenue opportunities and also enhance resilience.

Local governments are increasingly requiring zero carbon buildings and are increasingly concerned about resiliency to major weather events. Both of these goals can be achieved more easily with a smart building platform. In fact, the smart building platform can be used to achieve those goals and to provide data that verifies that the goals of zero carbon are indeed achieved. Because these goals often entail more efficient use of resources or greater use of renewable energy, achieving these goals can often result in lower costs as well as other opportunities.

Figure 6. Functions for a Smart Building system and opportunities for value creation

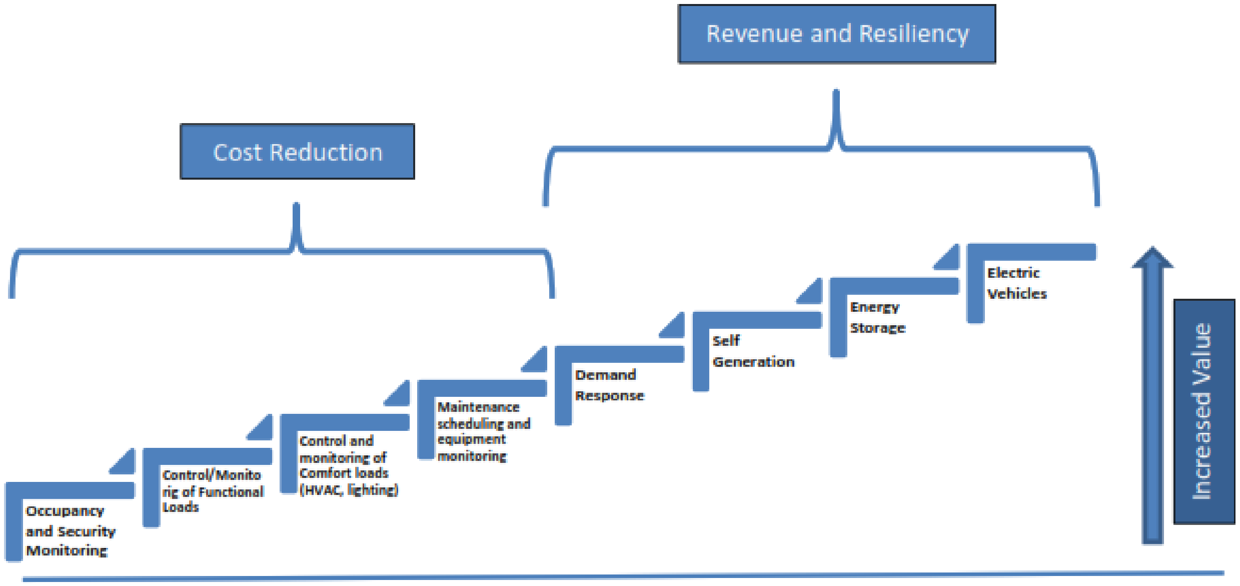

Figure 6 shows functions that can be incorporated into a smart building technology system to increase value to the building. Improved management of various building functions can provide opportunities for substantial cost savings in the form of reduced energy (electric and/or natural gas) use, reduced water use, and improved asset utilization. Energy use benchmarking is increasingly required. Bloomberg New Energy Finance reported that from 2008 to 2019 the amount of floor space that was covered under state or local energy benchmarking or disclosure rose from under one billion square feet to about 11 billion square feet.[14] Revenue opportunities can be created and resiliency can be enhanced by addition of DR, Self-Generation or DER, Energy Storage and even incorporation of Electric Vehicle capabilities:

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[14] Bloomberg New Energy Finance, 2020 Sustainable Energy in America Factbook

- DR, or shedding of loads in response to a utility signal in return for payments, is made more verifiable and more quantifiable when used with a smart building system. For this application, cyber security is crucial. In fact, *Volttron was specifically developed by the US Department of Energy to transact with utilities for DR and for self-generation.*

- Self-generation or DER, especially with renewable generating technology, offers significant *opportunity for revenue both for B2G energy sales as well as selling environmental attributes* such as renewable energy credits. DER also provides key benefits for resiliency. The Energy Information Agency (EIA) projects that end-user generation with photovoltaic technology will increase its share of generation from 0.5% in 2015 to over 2.0% of total power generation in 2030 and over 3.5% by 2050, as shown in Figure 7. This assumes EIA's reference case, which does not include future policy changes to increase zero carbon buildings, which will accelerate this trend further.

- Energy storage, by batteries or other means, can enable storage of renewable power to balance demand with renewable energy supply or to arbitrage power cost for time-of-day metering. It can also provide resiliency in the event of lost grid power or even supply of power to the grid when the grid is in need of power. *Energy storage could create revenue opportunities* for ancillary services under some circumstances. With new manufacturing capacity under construction and announced, energy storage system capital costs are projected to drop by over 50% in 2030 from 2018 levels.[15]

- *Electric Vehicles (EVs) add other opportunities and challenges.* EVs must be charged prior to use, which can cause a large demand for power when charging. EVs may provide an opportunity for supply of stored energy to the grid especially when grid demand is high or resiliency is needed. Having a system that interfaces with the grid while monitoring and controlling EV charging and storage can add value in these respects.

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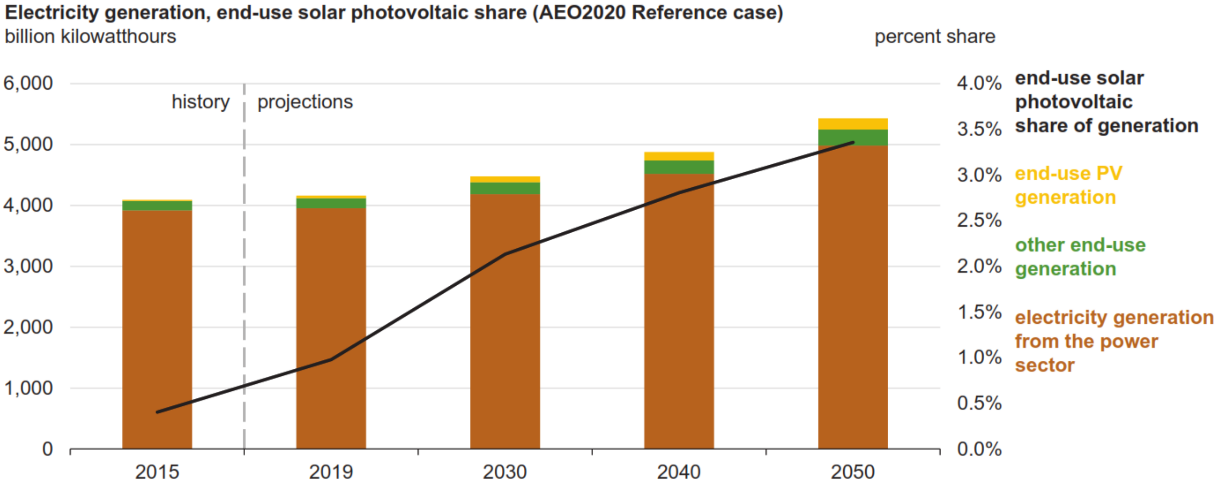
[15] Ibid

Figure 7. An increasing share of total electricity demand will be met with customer-owned generation, including rooftop solar photovoltaic.[16]



The power plant of the future may look like your building!

DER and energy storage can enable buildings to generate enough electricity to cover their load, and in many cases enough to supply energy to the grid when it is needed, or B2G. Renewable generation, especially photovoltaics, are extremely well suited for buildings. And the cost of photovoltaics has dropped to a point where they can produce power less expensively than most thermal energy power plants. Combined with storage, renewables can supply power when it's needed, not just when it's being produced. Electric vehicles that are located on site can provide additional opportunities for storage.

A smart building can help manage and control all of these functions for one building or for a portfolio of buildings. Figure 8 shows how each building function can be monitored, controlled and optimized to achieve enterprise goals. For each building it is possible to have a digital system that interfaces with the grid to address transactions such as DR or building to grid generation as well as transactions of environmental attributes such as renewable energy credits (RECs) or carbon trading. The smart building digital system will also collect data from other sources for weather, the electric grid, and to also interface with various accounts.

The system dashboard needs to be designed in a manner that facilitates improved behavior by employees - presenting data in a digestible and understandable way that they can relate to. Metrics should be developed that employees can use to gauge performance, these could be carbon footprint per employee, water consumption per employee. Or, depending upon the function of the building, such as output of a product for a manufacturing plant, these metrics could be per unit of output or simply per square foot of building space. These could be displayed in time series to show trends.

Figure 8. Building portfolio smart building system structure

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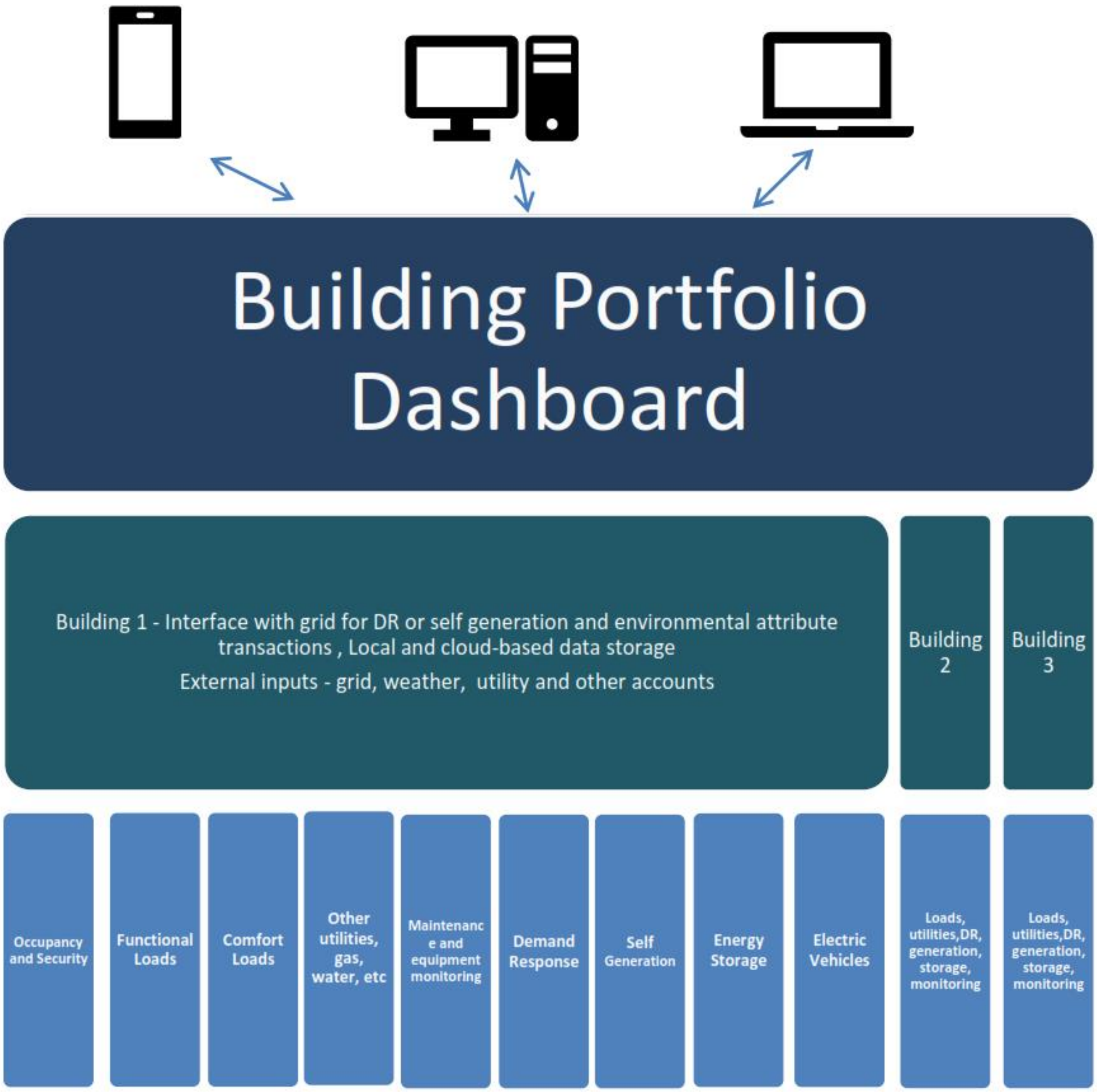
[16] Energy Information Administration, Annual Energy Outlook 2020 - with projections to 2050



When a company has a portfolio of buildings, it would have a smart building system for each building with each of these interfacing with a digital system that remotely monitors and manages the buildings from the perspective of a full portfolio. This would enable a company to have an overview of major concerns and functions - a "dashboard" so to speak of energy and water usage, maintenance, the status of various accounts and the asset utilization. It would also enable management to "drill down" into specific issues at each building. The portfolio smart building digital manager could also interface with accounts to conduct transactions rather than the individual building smart systems, depending upon the specific needs of the client. Analytics and reporting, fault detection, alarm notifications, and artificial intelligence, social responsibility and energy reporting, utilization and inventory management could all be integrated into the digital system that houses the dashboard.

The dashboard can be accessed from various devices remotely, and functions can be controlled and systems monitored.

Data Analytics - Turning Data into Knowledge

Data can be collected and stored locally and/or on the cloud. Using cloud storage from major vendors (Microsoft, Amazon Web Services, Google, or others) will enable data to be stored with the benefit of state-of-the-art security systems but also with state-of-the-art analytics. Data analytics are used to improve operations or even to identify reasons for performance shortcomings. For example, in one building equipped with a Verdicity system and photovoltaic energy generation it was possible to identify the reason for a shortfall in PV performance. It was determined that shade from a nearby building impacted the PV system performance during certain times of the year, which impacted the goal of the building being certified as zero carbon. Having identified the reason for the shortcoming, it is possible to identify ways to address it.

Knowledge Produces Results

Behavior change among building occupants is facilitated by readily available, real-time data. In the State of Missouri case study described above, the data showed building occupants how their building was performing in real time, through a kiosk in the lobby. People responded to this information, modifying their energy use and working to reduce it, resulting in about 6% reduction in energy consumption. Modern analytical platforms can take this a step further by identifying opportunities that are not readily observable and even automating improvements to building operation.

Verdicity's Volttron-based applications use Microsoft cloud storage and Microsoft Azure analytics. This permits users to have secure and reliable cloud-based storage with state-of-the-art analytics. Local storage is also available to address situations when internet connectivity may be temporarily unavailable. The *cost of data storage* will be largely determined by the amount of data, which is determined by the frequency of data collection and the "look back" period of data storage. Therefore, for each data stream the frequency of data collection and storage needs to be determined by balancing the desire for more frequent and longer-term data collection and storage to enhance analytics versus the desire to minimize the cost of storage. For analytics that are impacted by seasonal effects, a year or more of data is useful for most data streams to address seasonal effects. Data frequency for each data stream is determined by the variability and uses of the specific data source.

Machine Learning and Artificial Intelligence

Machine Learning (ML) is a form of Artificial Intelligence (AI) where data is stored and analyzed to search for specific trends that might not be discernible to a human observer. There may be trends in temperature, flow or some other machine behavior or performance that may indicate the need to perform maintenance or repairs on the machine. Or, data trends may provide insight to improved ways to operate the building systems. Strong AI, or AI that is highly cognitive and not preprogrammed with specific rules for a specific function, can be used to develop greater insights to building performance and provide recommendations for improved building operation. Weak AI systems can be used to improve specific tasks using preprogrammed rules for specific functions.

For ML or AI to be useful, it is important to define the problem, identify what is to be monitored, train the model, and then verify the results. Sometimes the model can return an incorrect result, and the model will therefore need to be adjusted. It is an iterative process that is necessary to make the most of the model. Once the model is refined, it can use information to develop improved methods for building operation or even anticipate how to improve operation based upon, for example, weather forecasts, energy future contracts, or other public data feeds.

COVID-19 Implications
Suddenly and unexpectedly, many businesses' priorities are shifting and are deeply affected by the coronavirus pandemic. A few implications specific to this novel situation are:

- Health safety and prevention of disease spread will likely drive towards improved ventilation and monitoring of spaces within a facility and personal monitoring of personnel to include monitoring employees for symptoms, social distancing and contact tracing..
- Occupancy rates for commercial office buildings are down, driving a need for improved turndown of equipment to reduce energy consumption when occupancy is lower.

The new, open-source, inexpensive Volttron sensors and controls are ideally suited to quickly retrofit into existing buildings to acquire and analyze the data needed to improve and manage both of these issues.

Closing thoughts

Advances in digital technology, sensors and telecommunications have facilitated the ability to monitor and control buildings in ways that are far more efficient than in the past. At the same time there is greater need for no or low carbon solutions for building energy management, and greater potential for buildings to take a producer role in self-generation or providing energy to the grid. Smart building management systems have been used in the past to more effectively satisfy the building functional requirements and to reduce energy cost. These systems have generally been proprietary systems and were largely limited to very large buildings or large collections of buildings due to the cost of implementing these proprietary systems.

Smart building systems that are available today offer security with the benefits of open-source architecture - lower cost, greater flexibility, and protection against obsolescence. Lower cost, WIFI and wireless connected sensors and controls have also made it possible to easily collect data on and control more aspects of building operation. Volttron, a platform that was developed by the United States Department of Energy, offers a secure means to monitor and control building functions. The Volttron platform also facilitates secure transactions with the electric utility, enabling DR and DER. These technology developments enable the value of smart building management systems to go well beyond energy savings. User-friendly interface dashboards offer improved decision-making tools for building owners, managers and users.

In the future buildings will play a greater role in the generation and supply of electricity. Self-generation, especially with renewables in combination with energy storage, will allow buildings to supply their own load and perhaps even to the grid or other users to meet demand. Electric vehicles can be integrated into the energy storage system. Environmental goals and resiliency will also increasingly be incorporated into building design and building management as zero carbon buildings are increasingly required and as buildings are designed to accommodate severe weather events or other disruptions.

Machine learning and artificial intelligence can offer means to analyze the building data to improve the performance of the various building functions as well as the ability of the building to generate revenues. Through analytics it may be possible to identify inefficiencies in functional performance, identify equipment in need of repair or maintenance, and find means to improve revenue or meet health, safety, environmental or resiliency goals. In the current uncertain and rapidly changing environment, these systems can obtain the necessary data, leverage it into usable information, and apply the new knowledge to meet companies' goals.

Acronyms used in this paper:
ADR - Automated Demand Response
AI - Artificial Intelligence
AWS - Amazon Web Services
BAS Building Automation System
B2G - Building to Grid
CAV - Constant Air Volume
DER/DG - Distributed Energy Resources or Distributed Generation
DOE PNNL - Department of Energy Pacific Northwest National Laboratory
DR or DSM - Demand Response or Demand Side Management
EV - Electric Vehicle
HVAC - Heating Ventilating and Air Conditioning
IEB - Information Exchange Bus
IIoT - Industrial Internet of Things
LEED- Leadership in Energy and Environmental Design Standards
ML - Machine Learning
NWS - National Weather Service
PV - Photovoltaic
REC - Renewable Energy Credit
ROI - Return on Investment
VAV - Variable Air Volume
VIP - Volttron Internet Protocol
VRF - Variable Refrigerant Flow

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