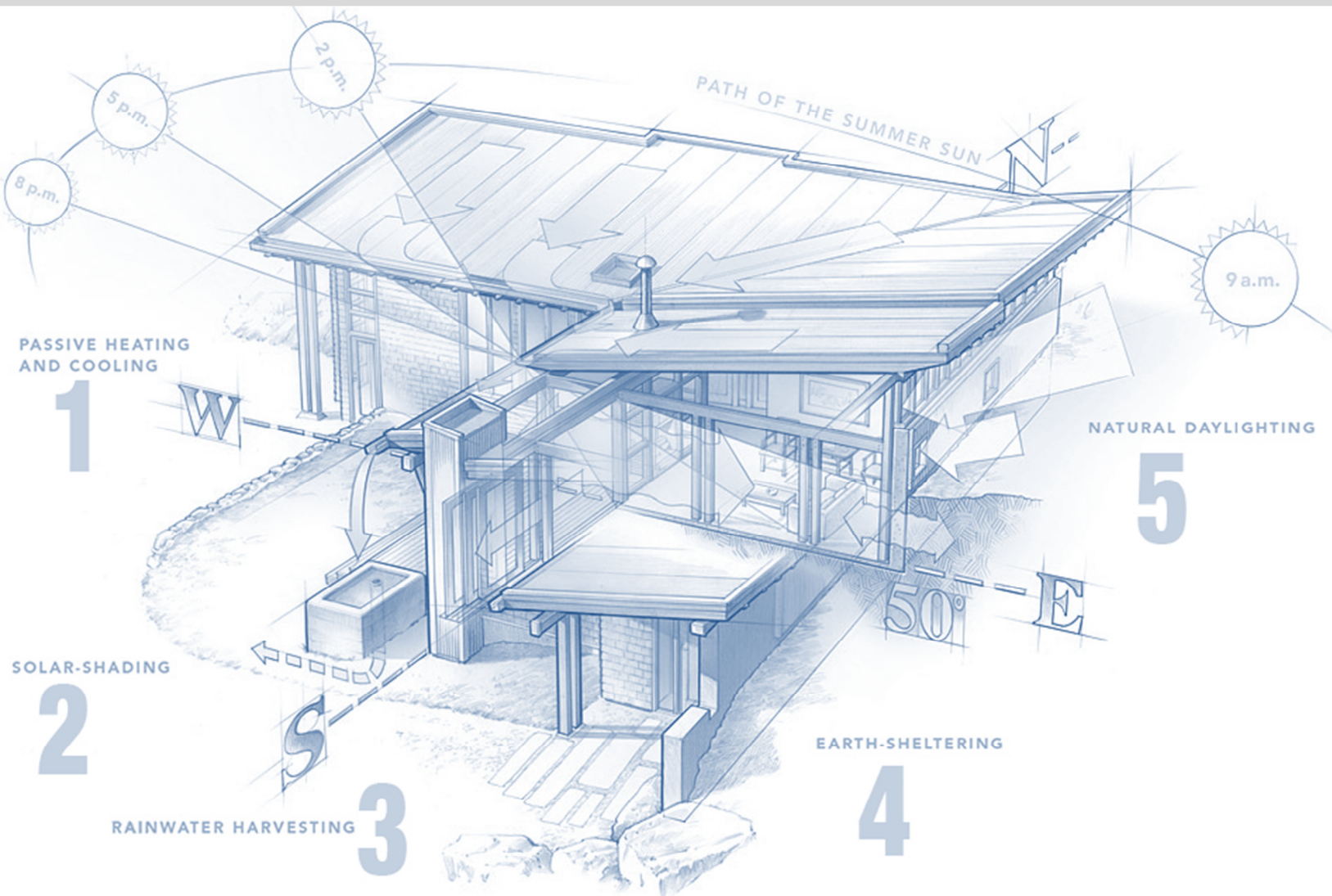


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Smart Applications for Facilities

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The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency.

- Bill Gates

1.0 INTRODUCTION

1.1 Preface

This research shares the investigation of various types of smart applications for facilities. This includes discussions regarding the primary stakeholders, technical aspects, and the financial and environmental implications with respect to their use. The research will deliberately address some topics in general terms to establish a background, while targeting other areas in more details to highlight their applications.

Throughout this document we will be exploring topics that encompass a breadth of information. Every effort will be made to summarize concepts for ease of understanding and applicability. The material is also very technical and contextual to the particular industry of facilities. A list of case studies is also provided to aid with specific and holistic applications.

For simplicity, we will refer to all autonomous systems, equipment, and components, by using the word “smart” as a prefix to any phrase of identification. The word “facilities” will also be used to refer to everything that encompasses the built environment (man-made). Also, the word “building” will be used in the traditional sense to include everything inside the building envelope. Additionally, the words “smart” and “autonomous” will be used synonymously in this report. Another distinction that must be clarified is the difference between a smart facility or building, and an application. Simply stated, the smart building or facility represents the entire network of interconnected systems, while the application is an individual system or technologically advanced mechanism within the building or facility that works in concert with the entire network.

1.2 Historical Framework

Without history, the subsequent information herein will lack a background by which to reinforce the technologies and applications discussed. According to Klaus Schwab and others^{1 2}, the first Industrial Revolution³ utilized water and steam power to make commercial production primarily a mechanical process. The second used electric power to build upon the first phase to create mass production. The third used electronics and information technology to automate production and create a globally integrated communications and digitized world of commerce. The fourth is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres, especially with the advent of artificial intelligence.⁴ When compared with previous industrial revolutions, the fourth is said to be evolving at an exponential pace, rather than a linear pace - most importantly, it is disrupting almost every industry with a depth of transformations that affect entire systems of communication, production, management, and governance.

The culmination of all these possibilities will be magnified by emerging technology in fields such as robotics, the Internet of Things (IoT)⁵, autonomous vehicles, 3-D printing, nanotechnology⁶, and biotechnology⁷. Consequently, Engineers, and Architects are combining computational design⁸ and materials engineering to test the limits of applications for facilities. Increasingly, both smart facilities and energy-based technologies benefit from computer systems executing sophisticated algorithms that replicate some of the problem-solving abilities of the human brain.⁹

¹ Outman, James. (2003). Industrial Revolution: Almanac. The Gale Group.

² Schwab, Klaus. (2016). The Fourth Industrial Revolution: what it means, how to respond. World Economic Forum.

³ The Editors of Encyclopedia Britannica. (2019). Industrial Revolution. Definition: The Industrial Revolution, in modern history, is the process of change from an agrarian and handicraft economy to one dominated by industry and machine manufacturing. This process began in Britain in the 18th century and from there spread to other parts of the world. <https://www.britannica.com/event/Industrial-Revolution>

⁴ Copeland, B.J. (Unknown). Artificial Intelligence. Definition: Artificial Intelligence is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the act of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from past experiences.

⁵ Chaouchi Hakima. (2010). The Internet of Things: Connecting Object to the Web. Wiley. Definition: In the IoT environment and daily life items, also named "things", "objects", or "machines" are enhanced with computing and communications technology and join the communication framework.

⁶ Bruus Henrik. (2004). Introduction to Nanotechnology. Department of Micro and Nanotechnology: Technical University of Denmark. Definition: Nanotechnology deals with natural and artificial structures on the nanometer scale. One nanometer, 1 nm = 10⁻⁹ m, is roughly the distance from one end to the other of a line of five neighboring atoms in an ordinary solid.

⁷ Definition per Webster's dictionary: The manipulation (as through genetic engineering) of living organisms or their components to produce useful usually commercial products (such as pest resistant crops, new bacterial strains, or novel pharmaceuticals)

⁸ Computational Design is an intelligent model-based process that provides a framework for negotiating and influencing the interrelation of internal and external building parameters. <https://academy.autodesk.com/curriculum/bim-computational-design>

⁹ Sinopoli, James. (2016). Advanced Technology for Smart Buildings. Artech House.

1.3 Holistic Foundations

An optimized design or system should reduce cost; adverse environmental impacts; energy consumption; and improve the quality of life, while having a sustainable existence. Autonomous applications should not exist without advancement towards appropriating nature's ingenuity. The remarkable intelligence of nature deliberately initiates and maintains processes that are precise in their intent - the built environment MUST do the same.¹⁰

An applicable analogy exists with the human body's complex network of interdependent systems – they have provided humans with an enduring challenge to comprehend intricate functions that enhance our health and combat illnesses and diseases. Akin to technical hardware, the human body is comprised of billions of microscopic units, each with their own unique function working in unison. The study of the individual tissues, organs, cells and interlinked system in the body is known as physiology. It is the science that has occupied some of the greatest minds throughout history.¹¹

According to James Sinopoli¹², “The whole is greater than the sum of its parts...it's not one system or attribute that makes a building smart, it is the combination of systems and practices that support its sustainment.” The same can be said of the processes executed by nature's biological systems - they operate with an inherent holistic logic. As eloquently stated by Baron d ' Holbach, “Nature therefore in its most extended signification, is the great whole that results from the assemblage of matter under its various combinations...”¹³ . Although the author's perspective may have been inspired by a philosophical perspective, it contains similarities to the way facilities function.

When it comes to the built environment, facilities do not take on the definitions of the human body, or nature for that matter, but it embodies the concepts at its core - especially, when it comes to smart facilities and applications. The recent trend of utilizing the word “smart” as a description for facilities reinforces the analogy to human intelligence as its standard of measure.

¹⁰ Stone Michael K and Barlow Zenobia. (2009). Smart by Nature: Schooling for Sustainability. Center for Ecoliteracy excerpt from The Post Carbon Reader.

¹¹ Abrahams, Peter. Dr. (2007). How The Body Works. A Comprehensive Illustrated Encyclopedia of Anatomy. Metro Books

¹² See Note #10

¹³ D'holbach Baron. (1889). The System of Nature. Published by J.P. Mendum.

Additionally, the analogy is perpetuated beyond the human body. The outside environment presents various problems to a human body that is solved via its internal and external systems. In the facilities industry, the internal environment is addressed by Engineers, Architects and various consultants. Consequently, the external environment is primarily addressed by Planners and Landscape Architects with respect to large scale integration.^{14 15}

So, what is the purpose of discussing the systems of the body, and their relationship to both the internal and external environment? Similar to the human body, the design of facilities attempt to create a state of homeostasis¹⁶ based on external stimuli. Arguably, the human body is the most intelligent and effective example of smart and interdependent systems design and operations. To design the built environment without regards for such a paragon will not only contradict the word “smart” but prove to execute actions counterintuitive to its optimization.

1.4 Technical Framework

This research provides a basic understanding of smart facilities and applications that can reduce adverse environmental impacts, and optimize facility operations and maintenance. Coincidentally, these systems are costly to maintain over the life cycle of a facility. The depth of the content includes applicable technology (present and prospective), that utilize a central database, control systems, and sensors to provide data for optimized management. Equally important, is the inclusion of beneficial passive design strategies that reflect decision-making processes that typically affect non-powered, static aspects of a facility (walls, windows, roof etc.). The breadth of information will be relevant to design, construction, and operations and maintenance. For the purpose of setting a feasible parameter that accomplishes the intent of the research, several aspects of smart buildings will not be included. Ultimately, this research reflects the discovery of an integrated approach inclusive of smart technology and passive design strategies from inception to maintenance, to enhance the quality of life and protect the environment.

¹⁴ Kaplan, Marshall. (1965). The Roles of Planners and Developers in the New Community. Washington University Law Review.

¹⁵ Langenderfer, Katrina. (2017). The Role of Landscape Architects: <http://cascadebusnews.com/role-landscape-architects/> & <https://www.asla.org/aboutlandscapearchitecture.aspx>

¹⁶ Homeostasis is defined as, any self-regulating process by which biological systems tend to maintain stability while adjusting to conditions that are optimal for survival. If homeostasis is successful, life continues; if unsuccessful, disaster or death ensues. The stability attained is actually a dynamic equilibrium, in which continuous change occurs yet relatively uniform conditions prevail. <https://www.britannica.com/science/homeostasis>

1.5 What is a Smart Building or Application?

Let's first define a few terms that will be used frequently throughout this research. Since we will be talking about smart facilities and applications which encompass "autonomous" technology, we need to define this term. According to an article written by Mikell Groover for Webster Dictionary¹⁷, operating by automation involves using a built-in microprocessor for automatic operation, for processing of data, or for achieving greater versatility. In more details, the following excerpt put it's all in perspective:

"Automation is the application of machines to tasks once performed by human beings or, increasingly, to tasks that would otherwise be impossible... automation generally implies the integration of machines into a self-governing system...The origin of the word is attributed to D.S. Harder, an engineering manager at the Ford Motor Company in 1930s. The term is widely used in a manufacturing context, but it is also applied outside manufacturing in connection with a variety of systems in which there is a significant substitution of mechanical, electrical, or computerized action for human effort and intelligence."

According to James Sinopoli, there are certain essential attributes that define a smart building. These include the installation and utilization of advanced and integrated building technology systems for management of life safety and access control; telecommunications; voice, video surveillance and data; power management and HVAC systems; and operations and maintenance management. It also provides real-time feedback information for the owner or occupant to optimize the use of its systems.^{18 19}

Concurrently, other experts offer alternate perspectives. Per David Brooks, there is no official standard definition of what constitutes a Smart Building. However, most explanations encompass several things such as disparate facility service systems controlled by a centralized mechanism; optimized facility performance via utility systems integration; a shared network for all facility-system communications; and technologies and strategies that add long-term, sustainable value to the property²⁰

¹⁷ Groover, Mikell P. (2019). <https://www.merriam-webster.com/dictionary/autonomous>. Professor of Industrial Engineering; Director, Manufacturing Technology Laboratory, Lehigh University, Bethlehem, Pennsylvania. Author of Automation, Production Systems, and Computer-Integrated Manufacturing

¹⁸ Sinopoli, James (2009). Smart Building Systems for Architects, Owners and Builder. Butterworth Heinemann. Elsevier.

¹⁹ See Note #6

²⁰ Brooks J David, Coole Micahel, Dowland Paul, Griffiths Melvin, Lockhard Nicola. (2018). Building Automation and control systems. An Investigation into Vulnerabilities, Current Practice and Security Management Best Praticce. ASIS Foundation Project.

Based on an aggregate of information, some core aspects are found to be synonymous with smart buildings. They have autonomous, interconnected systems with minimal or no human control. More specifically, they imitate the relationship of the human nervous system and the brain. They have controllers that imitate the brain's functions, and field level devices (actuators and sensors) that perform the feedback and execution functions. Additionally, they have a management capability that enables programming updates based on data analysis.

2.0 BUILDING SYSTEMS:

2.1 Building Automated Controls Systems (BACS)

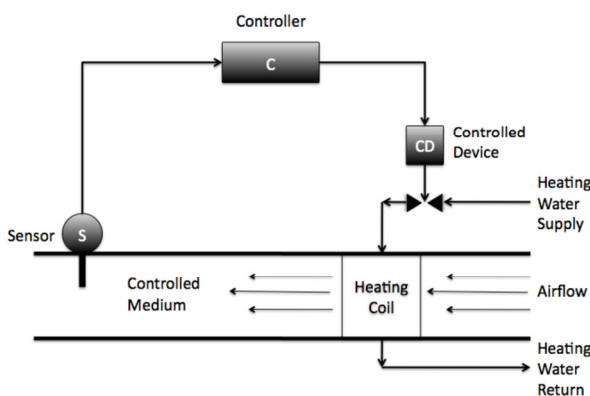
In addition to the requisite exploration needed to define “smart buildings”, BACS is a subset of smart facilities that also encompasses a layer of complexity with regards to its name and functions. The title BACS has been used by several different sources to convey similar applications of smart facility systems. According to a report by ASIS, “Building Automation and Control Systems (BACS) are known by many terms, such as Facilities Management System (FMS), Building Automation System (BAS), Building Automation and Control System (BACS), an Intelligent Building (IB), or a Building Energy Management System (BEMS).”²¹ Regardless, the concept is the same with respect to its core function. BACS entail some degree of automation by a machine or system of machines that executes certain facility functions with little or no help from a person. Therefore, the name is only a true reflection of the scope and complexity of specific applications. For the purpose of this research we will refer to the aforementioned applications of such mechanisms as BACS to simplify discussions and enhance comprehension for the reader.

A BACS enables facility systems and equipment to communicate with each other via a common operating system. It utilizes central control mechanisms to ensure effective coordination between all sub-systems when applied in complex arrangements. These systems may include utilities (gas, electricity, drainage & water supply); HVAC; security and life safety systems; CCTV and communications; conveyance systems (elevators & escalators); and automated site features (gates, fences, sprinklers, etc.).

²¹ See Note #21

As the brain function of smart facilities, it's imperative that the fundamental architecture and functions of the BACS is properly understood to apply it effectively. Among all sources sought, the most rudimentary and comprehensible explanation was presented in a report by the ASIS Foundation²². They determined that the key to understanding BACS system architecture is based on three levels: Management level; Automation level; and the Field level. In general, the Management Level contains the human interface (workstation), server, and routing devices, all connected via an appropriate communication medium. The Automation Level provides the various primary control technology devices connected via networked controllers and operating via communication protocols such as BACnet²³, LonWorks²⁴, etc. The Field Level includes devices connected to specific plant and equipment as sensors or activators.

A simple control system is described as consisting of three component functions and associated parts: a sensor for input function; a controller for decision functions; and a controlled device that provides a defined system output function (Figure 1.0). The sensor [S] measures a variable, such as the controlled medium of temperature in the duct, and sends that information to



the controller [C]. Depending on the configuration, the controller calculates the necessary output value to adjust the controlled device [CD]. Adjusting the controlled device alters the amount of heated water supply and ultimately, the duct temperature at the sensor.”^{25 26}

Figure 1: Provided by ASIS Foundation Project. August 2018.

²² See Note #21

²³ Merz H, Hansemann T, Hubner C. (2009). Building Automation. Signals and Communication Technology. Communication Systems with EIB/KNX, LON, and BACnet. Springer. Definition: BACnet (Building Automation and Control Network) is a standardized data communication protocol developed by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) for use in building automation to enable devices and systems to exchange information. BACnet is used in numerous building automation systems worldwide

²⁴ Merz H, Hansemann T, Hubner C. (2009). Building Automation. Signals and Communication Technology. Communication Systems with EIB/KNX, LON, and BACnet. Springer. Definition: LonWorks stands for local operating network. It is an open networking solution for building automation and control networks that was developed by the American company Echelon. It is designed in such a way that it can be used in centralized building automation controllers as well as in decentralized building control components.

²⁵ See Footnote #21 & #24

²⁶ The European Committee for Standardization (CIBSE, 2000), in their International Standard for Building Automation (2004)

A BACS is essentially a system that converges at a central point to integrate technologies and processes to create a facility that is safer, more comfortable and productive for its occupants. It can also be used to collect data for analysis, to drive programming that optimizes energy use.

2.11 BACS Industry Standards and Protocols

For a BACS to function effectively, it requires connectivity and a standard language for communication. Connectivity is achieved via a communication network that links and integrates many devices. Communication is achieved through standardized protocol. Such a requirement has led to several building automation network and communication protocols being established.²⁷

BACnet and LonWorks are two of the most popular BACS operating protocols. Although, the specific contextual application strongly influences the protocol selection. The BACnet protocol was developed specifically to address the needs of building automation and control systems to communicate on a single platform. Created in 1987 at Cornell University, the development of the BACnet protocol began in June that year, in Nashville, Tennessee, at the inaugural meeting of the ASHRAE²⁸ BACnet committee - known at that time as SPC 135P, "EMCS Message Protocol". It became an ANSI standard²⁹ under the auspices of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) BACnet was modeled on the Open Systems Interconnection (OSI) reference model.³⁰

BACnet ensures a high level of inter-operability in an environment that involves many vendors and various types of equipment and systems. The advance in communication capability was accompanied by software controlled connectivity for many devices. To facilitate such control, computers and controllers in the BACS can be networked to the Internet or serve as a standalone system for a local controller network.³¹

²⁷ Sinopoli, James (2009). Smart Building Systems for Architects, Owners and Builder. Butterworth Heinemann. Elsevier.

²⁸ Founded in 1894, ASHRAE, is a global society advancing human well-being through sustainable technology for the built environment. The Society and its members focus on building systems, energy efficiency, indoor air quality, refrigeration and sustainability within the industry. They also promote research, standards writing, publishing and continuing education. <https://www.ashrae.org/about>.

²⁹ The American National Standards Institute is a private non-profit organization that oversees the development of voluntary consensus standards for products, services, processes, systems, and personnel in the United States. The Institute oversees the creation, promulgation and use of thousands of norms and guidelines that directly impact businesses in nearly every sector: from acoustical devices to construction equipment, from dairy and livestock production to energy distribution, and many more. ANSI is also actively engaged in accreditation - assessing the competence of organizations determining conformance to standards: www.ansi.org

³⁰ SPC 135P (June 26, 1987). "Minutes of the First SPC 135P Meeting" (PDF). ASHRAE. Retrieved August 7, 2017.

³¹ Newman, Michael. (2013). Bacnet. The Global Standard for Building Automation and Control Networks. Momentum Press

It is imperative that security and facility professionals understand the architecture of communication protocols and operating systems to reduce BACS vulnerabilities. With the advent of the Internet of Things (IOT)³², facility designers, constructors and owners have sought to discover the benefits of interconnectivity and wireless-controlled features realized by the interoperability of smart devices connected to the internet. In the past, stand-alone systems secured from internet access were the archetype. Now the choices have expanded, but there are increased risks associated with connecting building automated systems to the internet. Some of these risks will be highlighted in the Cybersecurity and Case Study section.

2.2 Heating Ventilation and Air Conditioning (HVAC) Overview

The content herein contains discussions on HVAC equipment and applications that vary depending on several factors such as equipment, use, maintenance, budget, climate, codes, and varying local practices. These factors typically influence the outcome of each unique requirement and application. Therefore, the following information is based on generic, non-site-specific examples that are taken from both theory and practice.

The acronym HVAC typically conveys the generic application of heating and cooling, although most non-engineers overlook the “ventilation” function. Moreover, the various arrangements and parts to a HVAC system that benefits a facility are easily underappreciated. From a scientific perspective the system performs various functions through the principals of thermodynamics³³ and fluid mechanics³⁴. The partial list of considerations for designing an effective HVAC system includes life, health and safety; comfort; operations and maintenance; and energy consumption management.

³² Wikipedia & Brown, Eric (2016). "Who Needs the Internet of Things?" *Linux.com*. Retrieved 23 October 2016. The Internet of things (IoT) is the extension of Internet connectivity into physical devices and everyday objects. Embedded with electronics, Internet connectivity, and other forms of hardware (such as sensors), these devices can communicate and interact with others over the Internet, and they can be remotely monitored and controlled.

³³ Drake, W.F. Gordon on behalf of Encyclopedia Britannica (Unknown): Definitions – the science of the relationship between heat, work, temperature, and energy. In broad terms, thermodynamics deals with the transfer of energy from one place to another and from one form to another. The key concept is that heat is a form of energy corresponding to a definite amount of mechanical work. <https://www.britannica.com/science/thermodynamics>

³⁴ Faber, E. Thomas on behalf of Encyclopedia Britannica (Unknown): Definitions – the science concerned with the response of fluids to forces exerted upon them. <https://www.britannica.com/science/fluid-mechanics>

In maintaining the occupants' comfort level, HVAC needs to maintain a comfort zone for temperatures between 68 °F (20°C) and 75°F (25°C). For humidity, Engineers typically specify 20-60% relative humidity – outside these temperatures and humidity parameters, the inside conditions may be too cold, hot, dry, or humid depending on the occupancy and facility use.³⁵ This is especially important when it comes to health, where there is a need to avoid “sick building syndrome”³⁶. HVAC is also important for fresh air intake, building pressurization, and providing an optimal environment for electronic equipment.³⁷ Essentially, an HVAC system balances both internal and external inputs to provide optimal air quality and pressure. HVAC design and selection is inclusive of site-specific requirements for air conditioning; filtration; material selection; solar orientation; adjacent terrain; facility use type and frequency; equipment selection; and equipment operation and maintenance.

Since a facility represents a coexistence of multiple systems, an autonomous HVAC system requires a design based on compatible attributes. This enables interoperability with internal HVAC components and devices (thermostat, furnace, heat exchanger, chillers, pumps, boilers, conduits, dampers, etc.); occupancy sensor systems; and energy management systems³⁸ that can aid in the management of energy consumption. The HVAC control system is the brain of the HVAC equipment and systems. There are basic elements and functions common to most control systems. Several sources depict at least four basic elements to control systems: a sensor, which monitors temperature as a variable; a controller, which receives information from a sensor; a controlled device (such as valves), which acts upon the signal from controllers; and a source of energy – which is typically pneumatic or electric. Typically, the HVAC control system operates the integrated mechanical equipment and appurtenances (chillers, boilers, pumps, fans, etc.) - all of which is intended to render cost effective management by regulating temperature, pressure, humidity and ventilation.^{39 40 41}

³⁵ Invensys Building System Staff (2001). HVAC controls introduction. Invensys Building Systems. Invensys publication.

³⁶ EPA definition: https://www.epa.gov/sites/production/files/2014-08/documents/sick_building_factsheet.pdf

³⁷ Falke, Doc. (2008). Fresh Air for Ventilation and Building Pressurization. Contracting Business Archives. <https://www.contractingbusiness.com/archive/fresh-air-ventilation-and-building-pressurization>

³⁸ Laurenzano, Christian. (2017). Building Management Systems vs Electrical Power Management Systems: Is a Combination the right solution for your facility? Eaton White Paper: Definition - An Energy Management System provides information needed to identify the energy and power anomalies required to achieve cost savings, prevent equipment downtime, and operate efficiently. They can also verify that a facility's power distribution systems are installed, commissioned, and perform according to expectations and goals. However, they can also provide data on details such as circuit loading, peak demand, equipment status, and hundreds of alarms that warn building managers about underperforming equipment and conditions that threaten uptime.

³⁹ Mcdowell, Robert. (2009). Fundamentals of HVAC Control Systems. Elsevier Science.

⁴⁰ Gupton Jr. Guy. (2002). HVAC Controls: Operations and Maintenance. Fairmont Press & Marcel Dekker Inc.

The investment and maintenance costs are other easily forgotten factors that affect whether people install or upgrade to autonomous systems. According to a report by Invensys,⁴² when it comes to energy management, HVAC systems utilize several applications to achieve optimal results. These include time programmed commands, duty cycling, and optimum start-stop, etc.

Time programmed commands are used during the inactive or unoccupied periods of the facility at night, or during sustained periods of low occupancy as with schools. The intent behind this application is to reduce or turn off several equipment that provide HVAC to the facility during periods of low use. The Building Manager will then restart the equipment before the occupants return.

Duty Cycling is another procedure that cycles certain loads, such as small device or equipment to have the power turned, ON and OFF. An example would include cycling the air conditioning equipment ON for a period of time during high occupancy, and then lowering the temperature or turning it off for a period of low or no occupancy. Although this practice may seem cost effective, it will depend on the scenario. For example, if the process is attempted with large equipment such as a chiller plant, it may not be effective – this is offset due to the large current draw required for starting such equipment.

Optimum Start is another procedure utilized to save energy. It is typically used to target the times when the building is unoccupied. The system will determine the best time to start the HVAC equipment to create the optimal conditioned air prior to the time of occupation or use.

The foundation of a smart HVAC system is its network of interconnected power-based systems. The network uses its sensors as a feedback mechanism to inform the controllers on the required interior environmental conditions.⁴³

⁴¹ Carrier Corporation Brochure. (2005). Controls: Level 1 Fundamentals: Technical Development Program.

⁴² Invensys Building System Staff (2001). HVAC controls introduction. Invensys Building Systems. Invensys publication.

⁴³ Kaparaju Prasad, Howlett J. Robert, Littlewood John, Ekanyake Chandima Vlacic Ljubo (2019). Sustainability in Energy and Buildings. Proceedings of the 10th International Conference in Sustainability on Energy and Buildings (SEB'18). Springer Nature Switzerland

Modern facilities require various kinds of sensors for different reasons. These typically include sensors for temperature, humidity, water level, gas leaks, security and safety systems. They also address requirements for temperature, infrared radiation, vibration, and biometric recognition. Additionally, energy control systems require sensing for electric power, voltage, and temperature, etc. Some current trends in the industry include high performance sensors; smart sensors; multi-sensor systems; miniaturized sensors; integrated sensors; standardized interfaces; and low cost devices. Sensor accuracy and reliability have been improved in various areas with the aim of creating maintenance-free systems. Intelligent sensor systems uses algorithms and knowledge-based rules to connect sensors to the output device in autonomous methods set beforehand by users and maintainers. Inspired by high-tech sectors utilized by the aerospace and medical industry, micro-sensor systems have been more accessible. Nanotechnology for sensor systems will also promote smaller devices.^{44 45}

An emerging smart application for HVAC systems is called the Computer Vision Systems (CVS). CVS is based on concept of monitoring human movement, behavior, and use patterns inside a facility. It provides the opportunity to create optimal conditioned air to the appropriate spaces based on the precise occupant requirements. Some of these systems are available commercially from companies such as “Altais” and “Sentec”. Altaic has a proprietary program that analyzes people and their patterns via video cameras. The data collected is linked to a central device with Artificial Intelligence capability that analyzes the information. Similarly, SenTec uses a people-counting system via closed-circuit television (CCTV) cameras to accurately count the presence of people.⁴⁶

One alleged deficiency of both systems includes the inability to account for crowded spaces. Whereas dispersed use patterns make for easier data collection and interpretation, crowded spaces results in overlapping images of people. Knowing use patterns enables effective programming for thermal loads of different zones within conditioned space. The conventional systems outlined before that employ schedule-based methods do not provide real-time feedback. Instead, the process is based on use cycles or patterns over longer periods of time. In essence,

⁴⁴ Gassman O, Meixner H (2001). Sensors in Intelligent Buildings. Sensors Applications Volume II. Wiley-VCH Verlag

⁴⁵ Casini, Marco. (2016). Smart Buildings: Advanced Materials and Nanotechnology to improve Energy-Efficiency and Environmental Performance. Elsevier

⁴⁶ Lu, Siliang & Hameen, Erica & Aziz, Azizan. (2018). Dynamic HVAC Operations with Real-Time Vision-Based Occupant Recognition System. See Note #45.

this smart application provides an added layer of feedback and decision making absent human intervention outside of programming.

Recent technological advances by default represent new tools for people in the facilities industry. Although, by itself it does not represent an ideal state of optimization absent intentional and well-informed design considerations. Design and Engineering is a holistic profession and application process. There are many condensations that determine the effectiveness of HVAC systems. If we take the example of “a room” in a facility that requires HVAC, a list of considerations would include solar orientation; material selection, glazing location; door and window openings; insulation properties; air infiltration; comfort requirements; occupancy and frequency of use; adjacent spaces and location; size of air ducts, supply and return vents; heat loads; and several other factors. Essentially, an autonomous system is not mature enough at this point to navigate and apply such complex considerations of design implications. This is the quintessential “holistic concept”. In essence, this is the three-dimensional sculpting that enhances the human experience.

2.3 Utilities Overview

Utilities tend to take on a unique form that exceeds the utilization of smart systems in that it must also be responsive to the environment. There are also some less obvious applications that are overlooked in everyday use which contributes significantly to the inefficient and ineffective use of utilities.

Due to the interconnected nature of facilities and their related systems, reliable electricity is a prerequisite nowadays. An additional system commercially available is an energy management control system that examines the quantity and quality of power supplied and consumed. It also collects data that enables optimal programming for management and control. Electrical backup systems also represent an added layer required for facilities such as healthcare, data centers, and national security support facilities used by the Department of Defense. Consequently, lighting affects aesthetics and occupants’ experience towards work or comfortable living.

Similar to HVAC systems, there are also control functions and strategies that can be implemented to optimize the use of energy. Some include functions that set a predetermined schedule of when lights are used, and occupancy sensors that turn off lights when occupants are not present. Lighting systems can also be integrated with fire alarms, security systems, and emergency power systems. Most importantly, lighting systems provide a life safety function to ensure the lighting of egress routes during an emergency. In the case of a fire alarm, or loss of power, the lighting control system will turn on key emergency lighting fixtures to enable movement or egress if needed.

Smart electrical control systems distribute power and coordinate information between many devices such as the circuit breaker panel, wall switches, occupancy sensors, backup power, and lighting fixtures. It increases functionality and flexibility by providing digital control and intelligence to the overall system. There are also passive strategies enclosed in the case studies that share the results of attempts to harness maximum use of daylight to reduce the energy costs - window treatments via special coatings and louvers are examples of such strategies used to control daylighting for the benefit of the occupants.

2.31 Power over Ethernet (POE)

According to Sinopoli, one overlooked technology is the application of POE. This is a technological application where the Fiber Optic and Ethernet cable sources serve a dual purpose of carrying both power and data. This not only reduces installation costs and management costs, but provides additional opportunity for other methods of management via smart interfaces. Devices that utilize such technology include cameras, telephones, card readers, security systems, lighting systems etc. Additionally, there is software developed to manage devices remotely, such as security access control systems. This is typically underappreciated - before POE technology, cabling was more expensive due to extensive installation and coordination requirements of multiple devices.

Access card readers now do not require local AC/DC power supply. Facilities such as hospitals and schools can now utilize communication that fully integrates telephone, paging and intercom systems. This eliminates a limited number of zones and provides an integrated network capable of initiating communication between two individuals from any part of the facility.

The benefits of POE include many areas never realized before such as cable installation cost savings, and centralized power distribution instead of dedicated outlet use. It also makes for an uninterruptable power supply to critical devices with the flexibility to move, add or change devices when renovations occur. Additionally, it enables effective management when used in conjunction with a centralized management system.⁴⁷

2.32 Energy Harvesting Technology

According to Chu and Tarzano, the photovoltaic effect dates back to 1839 when a young physicist named Edmond Becquerel observed and discovered it. Since then there has been many researches and inventions that improved the technology to what we have today.⁴⁸

To some experts PV is an environmentally friendly way to harness energy from the sun with little or no maintenance, pollution, or energy resource depletion. A unique aspect of PV is that owners can decide whether they want to integrate into the utility grid or create a stand-alone system. If the system is interfaced with the grid, both the utility company and the facility owner can benefit – the harvested solar energy reduces cost, while the utility company receives solar electricity during times of greatest demands. There are two basic types of PV products: thick crystal products, which include cells made from crystalline silicon; and thin film products, which typically incorporate very thin layers of photovoltaics active materials. Additionally, an entire functional PV system typically includes the PV modules, thin or crystalline; a controller to regulate power to and from the battery storage tank (stand-alone); a power storage system; a conversion equipment to change DC output to AC for grid compatibility; a back-up power supply; and the ancillary safety, wiring and hardware.⁴⁹

⁴⁷ Sinopoli, James. (2016). *Advanced Technology for Smart Buildings*. Artech House.

⁴⁸ Chu Elizabeth, Tarzano Lawrence. (2019). A brief History of Solar Panels. Inventors have been advancing solar technology for more than a century and a half, and improvement in efficiency and aesthetics keep coming. <https://www.smithsonianmag.com/sponsored/brief-history-solar-panels-180972006/>.

⁴⁹ Strong Stephen. (2016). *Building Integrated Photovoltaics (BIPV)*. Whole Building Design Guides. Solar Design Associates.

Since the advent of standard PV panels there have been iterative advancements that favor more holistic facility integration. Unlike the typical panels that we ordinarily see on roof tops and solar farms, today's arsenal includes what the facility industry formally calls Building Integrated Photovoltaics (BIPV) or Semi-Transparent Photovoltaic (STPV). Research has shown varying views and information on the use of BIPVs to reduce energy costs and improve on site power generation towards zero-energy goals.^{50 51}

The integration of these photovoltaic systems into facilities has proven to be a viable strategy to harness the sun's energy. Several applications for this technology include skylights, walls, roofs, windows and glazing – glazing being the most promising due to its abundant surface area. It is also speculated that the most optimized systems will be those that strike a fine balance between electrical efficiency cost, and design. The appeal of this technology is its capability to integrate into a facility as a functional component that replaces conventional building materials.⁵²

A study by a team of professors in Egypt using Semi-Transparent Photovoltaic glazing on the envelope of an office building proved to improve thermal performance due to its impact on solar heat gain reduction. This was also done by taking advantage of other well-designed factors and occupant use patterns. Their efforts were driven by the overconsumption of energy in Egypt which is leading to a potential energy crisis. They concluded that BIPV can save approximately half of the energy used for cooling loads when used in concert with efficient window-to-wall ratio at 100% (WWR); and visible light transmittance at 10% (VLT), controlled by artificial lighting control systems.⁵³

Another collaborative research project in Singapore performed similar experiments to those in Egypt. In this case, the methodology included factors of building geometry, facade properties, and orientation. Although the outcome had similar results, it went a step further to

⁵⁰ James Ted, Goodrich M W, Margolis Robert & Ong Sean. (2011). Building-Integrated Photovoltaics (BIPV) in the Residential Sector: An Analysis of Installed Rooftop System Prices.

⁵¹ Eiffert Patrino, Kiss Gregory. (2000). Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures: A Source for Architects. A resource prepared for the US Department of Energy by the National Renewable Energy Laboratory (NREL).

⁵² Tina G.M, Gagliano A, Nocera F, Patania F (2013). Photovoltaic glazing: analysis of thermal behavior and indoor Comfort. The Mediterranean Green Energy Forum 2013, MGEF-13

⁵³ Faggel Ahmed, Eldin Amar Dr., Ali Rana (2019). The Impact of Using Semi-Transparent Photovoltaic in Office Building Facade on improving Indoor Thermal Performance in Egypt. Journal of Al-Azhar University Engineering Sector.

provide data that can inform the decision-making process of Architects and Engineers. Specifically, the results demonstrated that BIPV can save between 17 - 41% energy for large facade openings from 70-100% when compared to standard glazing. It was also discovered that among five investigated orientations, southeast is the optimal orientation overall.⁵⁴

OnyxSolar, a company that provides BIPV technologies has a portfolio of real-world projects that provide tangible precedence. They provide both amorphous⁵⁵ and crystalline⁵⁶ based BIPV with multifunctional properties. Their product is an energy generation material that substitutes for conventional building glazing. It is typically made of two or more heat treated panes of safety glass, and also has thermal and acoustic insulation. It provides the same natural light and filters 99% harmful UV radiation, and up to 95% IR radiation. It has the advantage of providing the same aesthetic with respect to shape, size, color, and degrees of transparency - this allows integration with retrofitting projects. Its applications include, facades, curtain walls, atriums and terrace floors. They also boast an installer-friendly system that requires the same effort as any other system.⁵⁷

2.4 Access Control Systems Overview

Access control has become a critical aspect of smart facility design. In medical facilities, it protects patients and service providers from unwanted access. In Corporate and Scientific fields it guards against unwanted attention and theft of proprietary intellectual property. In the Defense and Aerospace industry, it prevents unwanted access to systems that protect national security assets.

⁵⁴ Khai Ng, Mithraratne Nalanie, Wittkopf Stephen . (2012). Semi-Transparent Building-Integrated Photovoltaic Windows: Potential Energy Savings of Office Buildings in Tropical Singapore. Solar Energy Research Institute of Singapore, Singapore. Department of Architecture, National University of Singapore, Singapore

⁵⁵ Hart P.R. (1987) Crystalline vs. Amorphous Silicon — a Comparison of their Respective Properties and their Significance in Photovoltaic Applications. Photovoltaic Solar Energy Conference. Springer, Dordrecht. Definition – a category of thin films semi-conductor materials where one or several layers are deposited onto a flexible substrate. Generally low efficiency, but typically known to be an environmentally friendly technology.

⁵⁶ Hart P.R. (1987) Crystalline vs. Amorphous Silicon — a Comparison of their Respective Properties and their Significance in Photovoltaic Applications. Photovoltaic Solar Energy Conference. Springer, Dordrecht. Definition – the most widely used high efficiency energy conducting material, typically constructed of small or continuous crystals.

⁵⁷ <https://www.onyxsolar.com/>

It is also a prudent in some aspects to integrate access controls systems with other systems in a facility. With respect to safety, it must integrate with fire protection and conveyance systems to ensure effective egress when needed in an emergency. Exits doors must open when needed, and elevators must be secured and rendered to the fire department's control upon arrival.

Depending on security requirements, spaces and facilities can create different levels and methods of authentication with respect to access control systems. Additionally, the data and surveillance from access control systems can be collected and utilized by security personnel or smart systems. As a safety mechanism, it is prudent to have a failsafe system that integrates with a back-up power system that enables secondary offline operation should baseline systems fail. This avoids a situation where people are secured in spaces unintentionally in an emergency or loss of power.

Intrusion detection devices also help support access control systems in areas such as windows, doors and other openings such as skylights. Facility owners should spend quality time coordinating the security schematic and requirements with the design, construction and facility management team or staff. This ensures that the built end product manifests the intended requirement. Security Access System applications typically include selective access and tracking. It can also be used to regulate access based on schedule or time of day. Ultimately, such systems can be used to relay data to energy consuming systems such as HVAC and lighting to create optimal energy use and building operation. Two known disadvantages with respect to access control systems includes what called, "piggybacking" and "tailgating". Piggybacking happens when an occupant with access grants access to someone without entry authorization - tailgating happens when a trespassers enters a facility or space with someone who has access, but without their knowledge. Fortunately, there are also systems that provide fixes via biometric devices or sensors which detect the number of entrants at any given time. Another drawback of these selective access systems is in regards to emergency situations – if a bystander is screaming for help or need access to hide somewhere, or run for cover, this can prevent safety to such individuals. In an era of mass shootings this device is a two edged sword. As with all tools, it can be used for both beneficial and harmful purposes.⁵⁸

⁵⁸ John Kingsley-Hefty (25 September 2013). Physical Security Strategy and Process Playbook. Elsevier Science.

Like other smart technology, access control systems utilize servers and software to provide interface management for the facility database. Each typically consists of the records that determine access requirements, privileges, and other feedback that informs process improvement based on specific behavioral or historical characteristics. The brain component of an access control system is formerly known as the access control unit (ACU). This is the intelligent unit that provides coordination between the management and monitoring system via the interface. All peripheral installed devices such as card readers or biometric reader relay credential information to the ACU for processing.⁵⁹

2.5 Fire Protection Systems Overview

Aside from egress structures and routes, fire protection is one of, if not, the most important life safety system in a facility. These systems are designed based on specific facility requirements. For this reason, many fire protection system regulations are written to ensure their proper design, construction and maintenance. Their subsystems include extinguishers; sensors; vents; door operators and audiovisual alarms. All these parts need to perform as one system to ensure the safety of its occupants. Although fire protection systems may have unique applications, they still have some things in common. They must be compatible with other systems; accessible to first responders; and effective at eliminating false alarms, with interference from temperature and humidity. Additionally, they must be operable in the case of a power outage, which typically suggests the use of low energy requirement designs.^{60 61 62}

Since common characteristics of fire include emissions of smoke and increase in temperature, fire detection systems use these inputs to detect potential harm to occupants. Photoelectric and thermal detectors are quite common in facilities today – the former measure the scattering of light, while the latter alarms upon detection of increased temperature.⁶³

⁵⁹ Sinopoli, James. (2016). *Advanced Technology for Smart Buildings*. Artech House.

⁶⁰ The Whole Building Design Guide/Safe Committee. (2017). Fire Protection. <https://www.wbdg.org/design-objectives/secure-safe/fire-protection>

⁶¹ Suttell Robin. (2006). Planning for fire protection involves an integrated approach in which system designers need to analyze building components as a total package. www.buildings.com newsletter.

⁶² National Fire Protection Agency Codes and Standards.

⁶³ See note # 45

In residential settings, the application of fire & smoke detectors typically occur in low numbers and are detached from a central control system which disseminates information to first responders. On the other hand, in large scale commercial applications, the detectors are connected to a central system that sends information to first responders during an emergency.

The design and application of the different detector systems require expertise to account for functionality and regulatory compliance – all of which varies depending on context and location. This is one of the main reasons why government agencies review blueprint drawings prior to construction and follow-up with inspections. Additionally, several important considerations for designing a fire protection system include identifying the possible sources of a fire incident; number of occupants; facility use; type of materials; and the type of extinguishing agent.

2.51 Fire Protection Systems Case Studies⁶⁴

The fire protection domain is now incorporating smart technology that will drive the future of firefighting and facility safety. Although in a less mature state of development, this technology will eventually utilize Cyber Physical Systems Technologies (CPS) to integrate various data platforms to aid in fire protection operations. A CPS technology is known to combine the cyber and physical world in real time – this utilizes small sensors, computers and wireless technologies to improve the safety and effectiveness of fire protection. The foundation of the technology already exists in “Smart Grids” and “Autonomous Transportation”. The framework for the system includes firefighter communication systems and monitoring gear (GPS, thermal imaging & physiological monitoring); accountability systems (medical facility locations, apparatus monitoring); community scale data (hydrants and utility locations, and weather information); and building information.

Unlike the conventional methods of firefighting where first responders need to arrive at the incident to access information from emergency control panels, CPS will disseminate the building information during an emergency notification. Such information will include floor plans and firewall ratings; standpipe and sprinkler locations; egress routes and stairwells;

⁶⁴ Hamins A, Grant C, Jones A, Bryner N (2018). Fire Protection Engineering. Smart Fire Fighting and Fire Protection.

conveyance systems (elevators & escalators); occupant locations; space or zone temperatures; and Building Information Models (BIM)⁶⁵. The ability to acquire relevant and timely information is critical to fire protection. As recorded by the National Fire Protection Agency (NFPA) in 2013, fire departments responded to 487,500 fires, with an estimated 2,855 fatalities, 14,075 civilian injuries, 30,000 firefighter injuries, and an estimated 9.5 billion property damage or losses.^{66 67} The complexity of such a process begins with sensors. The intent is to leverage existing and emerging sensor technologies and other necessary building systems to support such holistic efforts.

A critical step towards the success of CPS application is Open Architectures^{68 69} – this is critical to define, and facilitate interactive functions required in a timely manner. To ensure continued progress, the subject technologies will require integration-based architectural designs. Several current CPS applications are sector-specific and fragmented, thus lacking a holistic bandwidth for integrated approach to fire fighting and protection. Some examples include network standards that would define wireless and hard-wired requirements.⁷⁰

In 2005, an early demonstration was conducted by the National Institute of Standards and Technology (NIST) to simulate CPS. Although the results of the simulation were unknown, the objective of the demonstration was to send information to first responders on their way to a simulated incident. Some of the data originated from three sensors in the target building (smoke, heat and carbon monoxide). The resulting data was used by an Artificial Intelligence program to suggest possible conditions that were transmitted to the first responders en route. Such information included location of hydrants; entrances and egress stairwells; conveyance systems; hazmat locations; and occupants' locations. Additionally, information included fire size, and its

⁶⁵ Eastman Chuck, Teicholz Paul, Sacks Rafael, Liston Kathleen. (2011). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. John Wiley and Sons. Definitions – Building Information Modeling/Models represents a technology process, of building an accurate virtual model of a building. They support design through its phases, allowing better analysis and control than manual processes. When completed, these computer-generated models contain precise geometry and data needed to support the construction, fabrication, and procurement activities through which the building is realized.

⁶⁶ Karter, M.J., Jr. and Molis, J.L., "U.S. Firefighter Injuries - 2013," NFPA, Quincy, MA, Nov. 2014, www.nfpa.org.

⁶⁷ Karter, M.J., Jr., "Fire Loss in the United States During 2013," NFPA, Quincy, MA, Sept. 2014, www.nfpa.org.

⁶⁸ Clifton A. Ericson, II (12 April 2011). Concise Encyclopedia of Safety Systems: Definition of Terms and Concepts. John Wiley & Sons. Definition - Open architecture is a type of computer hardware or software architecture that allows users access to all or parts of the architecture without any proprietary constraints. Open architecture allows adding, upgrading, modifying, and swapping components. Typically, an open architecture publishes all or parts of its architecture that the developer or integrator wants to share. The business process involved with an open architecture may require some license agreements between entities sharing the architecture information.

⁶⁹ Michael J. Miller (2011). "Why the IBM PC Had an Open Architecture". www.pcmag.com.

⁷⁰ Energetics Incorporated. (2013). Foundations for Innovation in Cyber-Physical Systems. Workshop Report. Prepared for the National Institute of Standards and Technology.

location; interior standpipes locations; firefighting and emergency equipment locations; and possible presence of flashover.⁷¹ In 2009, a similar system was tested and implemented in Frisco, TX, as part of the Situational Awareness for Emergency Response (SAFER project), a data-based system for first responders.

At this point this technology requires a roadmap for testing and implementation – to that end, NIST develop one in 2015 as a guideline. The efforts involved are based on creating, storing, sharing, analyzing, and integrating information from various databases and sensor networks. Among the key challenges is the ability to reliably design complex systems at an appropriate scale, which involves innovative design strategies. Other foreseeable challenges include the accumulation of data to drive precision reporting, and cybersecurity systems for cloud-based information protection.⁷²

Fire Protection Systems also have the potential to result in harmful events if designed and used inappropriately. For this reason, it is critical to ensure compliance with all regulatory and standard requirements such as the National Fire Protection Agency (NFPA)⁷³, National Electric Code (NEC), Underwriters laboratories (UL)⁷⁴, and American National Standards Institute (ANSI). It is also prudent to invest substantial thought into the overall safety requirements and daily operations with subject matter experts. Ultimately, building owner and first responders wish to avoid a situation where an occupant is unintentionally secured to an area of a facility where they cannot signal for help, or egress in case of an emergency – especially when it can make the difference between life and death.

⁷¹ Hamins A, Grant C, Jones A, Bryner N (2018). Fire Protection Engineering. Smart Fire Fighting and Fire Protection.

⁷² Grant Casey, Hamins A, Nelson B, Jones A, Koepke G, NIST, Fire Protection Research Foundation. (2015). Research Roadmap for Smart Fire Fighting. Summary Report.

⁷³ The National Fire Protection Association (NFPA) is a global self-funded nonprofit organization, established in 1896, devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. It established codes and standards, designed to minimize the risk and effects of fire by establishing criteria for building, processing, design, service, and installation around the world. <https://www.nfpa.org/about-nfpa>

⁷⁴ Underwriters Laboratory (UL) is a global safety certification company that promotes secure and sustainable living and working environments for people by the application of science, hazard-based safety engineering and data acumen. They support the production and use of products which are physically and environmentally safe, and to apply the efforts to prevent or reduce loss of life and property. They also advance safety science through research and investigation. <https://www.ul.com/about/mission>

3.0 CYBER SECURITY

Cybersecurity has been a serious concern since advances in technology began to connect smart devices to each other, to networks, and the internet. A corollary to this practice is the emergence of cyber security threats that accompany such applications. The list of precedence should not be a surprise considering that the very advantage of our technological advances, are also the root of their vulnerabilities. If it can connect to something else, it can possibly be compromised.

As eloquently stated by George Fragulis⁷⁵, “smart systems (HVAC, lighting, security etc.) require a network to communicate with the building operation and maintenance team, and the other installed smart systems. Due to this connectivity requirement, designers are introducing vulnerabilities into a facility.” The Stuxnet, Duqu, Flame and Shamoon malware are also known to target, disrupt or damage smart facility systems.⁷⁶ Stuxnet is known to target Supervisory Control and Data Acquisition Systems (SCADA)^{77 78} – specifically targeting programmable logic controllers (PLCs)⁷⁹, which executes the automation of mechanical processes used to control industrial equipment.

Stuxnet is believed to have been responsible for damage to Iran’s Nuclear Program in 2010. While the operator’s console showed the system operating within normal parameters, it targeted PLCs and disrupted the integrity of the uranium centrifuges - this caused them to over-spin and self-destruct. On the other hand, the Duqu malware⁸⁰ searches for industrial control systems information. Its purpose is not to be destructive - the known components are trying to gather information. These could include specifications for the devices or equipment. The

⁷⁵ Fragulis, George. (2019). The Military Engineer Magazine (TME). The Threat Within: Addressing Cyber Security in Building Design

⁷⁶ Virvilis, N., Gritzalis, D. (2013) The big four-What we did wrong in advanced Persistent Threat detection? In Proceedings of the 2013 Eighth International Conference on Availability, Reliability and Security (ARES)

⁷⁷ Rosa Tang (2012) Vulnerabilities and Attacks on SCADA Networks. Berkeley.com. Definition - Supervisory Control and Data Acquisition (SCADA) systems are computer-based control systems which uses computers, networked data communications and graphical user interfaces to monitor and control physical processes. They are usually composed of a set of networked devices such as controllers, sensors, actuators, and communication devices.

⁷⁸ Aditya Bagri, Netto Richa, Dhruvil Jhaveri. (2014), Supervisory Control and Data Acquisition. International Journal of Computer Applications. Vol 102-No.10.

⁷⁹ Gangurde Chetana, Khule Rupali. (2015). A Review: Embedded PLC. International Journal and technical Research. Definition – A Programmable Logic Controller (PLC) is a ruggedized industrial digital computer used in automation of electromechanically processes, such as control of machinery on factory assembly lines, amusement rides, light fixtures, or robot devices.

⁸⁰ Symantec Security Response team and a unknown third party contractor (2011). W32.Duqu. The precursor to the next Stuxnet. V 1.4.

Flame malware⁸¹ is known to search for technical data such as engineering drawings, specifications, and other technical details about a system or facility. Shamoon⁸² is infamous for spreading to other computers on the network, through exploitation of shared hard drives. Once a system is infected, the virus continues to compile a list of files from specific locations on the system, and then send information about these files back to the attacker.^{83 84 85}

3.1 Cyber Security Case Study⁸⁶

A team of various facility experts joined efforts in 2017 to research the vulnerabilities of smart facility systems. They conducted a three phase multi-method approach to the project. This included the introduction of applicable literature, followed by a survey that was subsequently critiqued by a focus group. The participants included professionals from diverse areas of expertise among 38 different nations. The following outlines a summary of their findings and recommendations with respect to cybersecurity.^{87 88}

Their findings highlighted a diverse spectrum of vulnerabilities due to the varying locations and communication protocols of smart systems. Although smart facilities and applications are vulnerable to technical and physical attacks, the research identified the automation level⁸⁹ to be the most vulnerable. A recurring theme that echoes here is the fact that the use of interconnected systems create an inherent vulnerability. The act of utilizing technology to reduce costs and create adaptability in an environment of diminishing resources is quite understandable. On the other hand, the integration of facility smart systems to networks and the internet creates a security challenge. Most notably is the fact that the earliest generations of smart building systems devices were developed to operate outside a network environment - this inexorably creates a severe level of vulnerability when legacy systems are modified to perform

⁸¹ Wangen Gaute, Qiong Huang, Yang Guomin. (2015). The Role of Malware in Reported Cyber Espionage: A Review of the Impact and Mechanism.

⁸² LogRhythm Security Analysis Team. (2017). Shamoon 2 Malware Analysis Report. Part 1. LogRhythm Labs.

⁸³ Chipley Michael. (2017). Whole Building Design Guide. Cybersecurity

⁸⁴ https://en.wikipedia.org/wiki/Stuxnet#Iran_as_target

⁸⁵ Schneier Bruce, Langner Ralph. (2013). To Kill a Centrifuge. A technical Analysis of What Stuxnet's Creators Tried to Achieve. The Langner Group Publication.

⁸⁶ Brooks J David, Coole Micahel, Dowland Paul, Griffiths Melvin, Lockhard Nicola. (2018). Building Automation and control systems. An Investigation into Vulnerabilities, Current Practice and Security Management Best Practice. ASIS Foundation Project.

⁸⁷ See Footnote #25.

⁸⁸ King, R. O. N. (2016). Cyber security for intelligent buildings. Engineering and Technology.

⁸⁹ See BACS section for definition

contemporary functions. The issue is amplified by the exorbitant sub-systems and applications within a BACS that encompass proprietary technology owned by specific organizations. It must also be noted that the vulnerabilities almost always align with the strength of a smart system – the ubiquitous, self-replicating, interconnected attributes are the intrinsic appeal to smart systems. Consequently, it's also what makes the impact of breaches so devastating, because it potentially gives access to many systems that can all be affected.

The automation level's most critical vulnerabilities encompass threats via physical devices, network access, wiretapping and remote connect workstations. The threat is amplified since these devices and networks are in many areas throughout the facility. The physical access vulnerability stems from the fact that automation or controller device covers are made to protect internal circuitry - they are not typically designed to prevent external entry or removal from its mounting attachments. Furthermore, the device does not contain anti-tamper or removal detection from unauthorized personnel. This can lead to the manipulation of control systems.

The network access vulnerabilities include the lack of network anti-tamper detection capability which enables unauthorized network access to open source programs that can capture, alter, and inject commands. This can result in loss of control and denial of access by the appropriate authority. The system is also vulnerable to wiretapping via covert network access that can facilitate access and control. A corollary to unauthorized network access is the possible establishment of a remotely connected workstation. This is very dangerous since the attacker now has the same or more control as the facility operators to manipulate the systems. The automation level is critical and thought to be the most important aspect due to its data processing capabilities to receive information and instruct actuators to perform actions that can have grave consequences.

As discussed previously, the management level devices include the corporate information and communications network and its hardware, such as routers and workstation operator interfaces. The most obvious means of doing harm via physical access includes attacks from malicious codes through insertion of an infected storage device or unsolicited downloads – the same can be accomplished via cyber delivery of emails.

Field devices such as control actuators and monitoring sensors also create a security challenge due to their omni-presence throughout a smart facility. They also possess vulnerabilities via physical and network access. Unfortunately, sensors are not typically designed with anti-tamper functionality for disconnections, removal or circuitry disruptions. This fosters manipulation without detection at the automation or management level.

Advanced technologies present in smart facilities sometimes contain many contextual barriers to comprehension and are not always user-friendly. It should be no surprise that the recommendations from the aforementioned research panel include topics regarding communication, training and building strategic relationships with Subject Matter Experts (SME). In conclusion, they recommended the promotion of threat awareness and risks, accompanied by non-technical user-friendly resources; cross departmental expertise collaboration and training for security; and building relationships with BACS and cybersecurity experts to leverage capability.

4.0 CONCLUSION: PASSIVE DESIGN STRATEGIES - NATURE'S CLASSROOM

While advanced technology offers great tools to advance smart buildings, stakeholders involved with the life cycle of facilities can establish a solid foundation on which technology can be used to magnify efficiencies and minimize environmental impacts. The key is to avoid solely relying on smart technology and take the steps to make smart design and maintenance decisions – it would be a mental flaw to think that technology alone represents optimization.

According to Nilesh Jadhav, and several other professional resources,^{90 91} there are several strategies and applications that should be considered and pursued at the inception of a facility. Design should be an integrated process or whole-building design concept that considers all building systems, and site considerations – both passive and active⁹². A building is similar to the human body which has a skin (for external interface), and several mechanisms inside to regulate its internal environment. A few examples of important considerations for such design approach includes the understanding and analysis of site features, the sun's path, and the location

⁹⁰ Jadhav, Nilesh Y. (2016). Green and Smart Buildings. Advanced Technology Options. Green Energy and Technology. Springer Science and Business Media.

⁹¹ Thorpe David. (2018). Passive Solar Architecture Pocket Reference. Routledge, Taylor and Francis Group.

⁹² In this document "active" refers to energized systems, and equipment.

and orientation of the building. Other considerations include the study and selection of aperture sizes, wall thickness, glazing, windows and external shading devices. These factors have a significant impact on day lighting and heat gain which both affect the overall energy performance of a facility (See figure 2). Nature has provided an exorbitant list of examples and

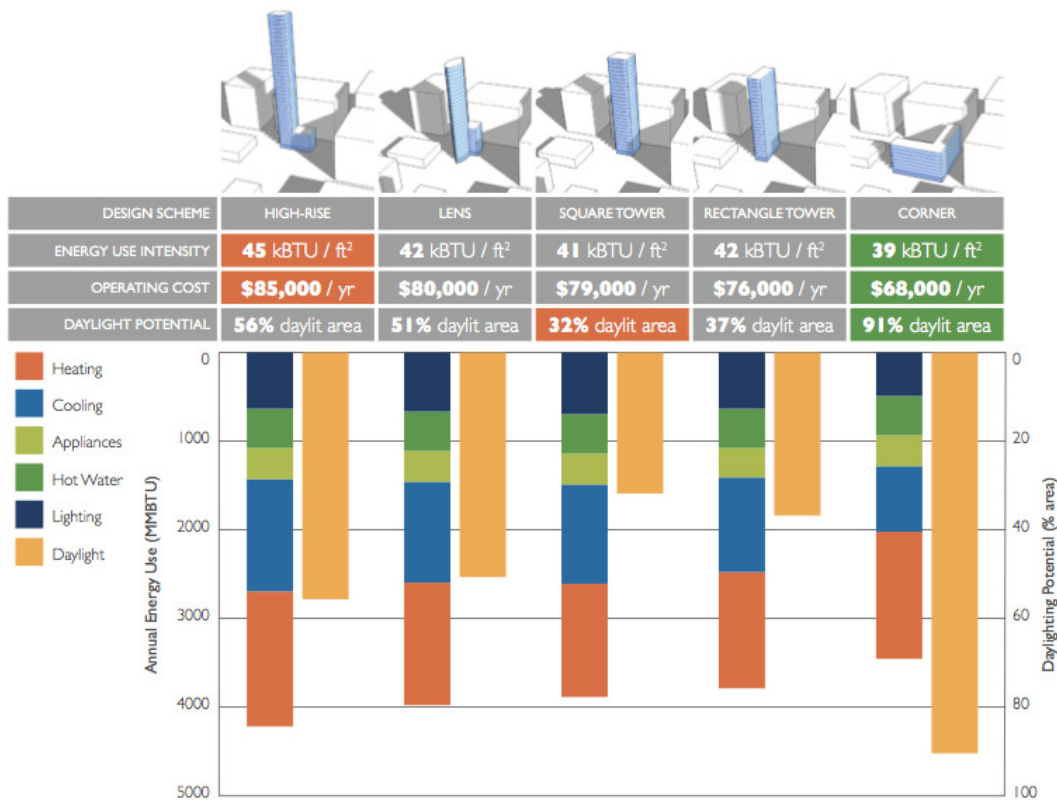


Figure 2: Figure 8: Image Courtesy of Sefaira (2013) <http://sefaira.com/resources/3-ways-to-win-more-bids/>

precedence for us to learn from, so it would behoove us to take these strategies and implement them to our advantage.

An industry term which is typically associated with the technical design decision-making process is called 'Passive Design'. It alludes to design strategies and technologies that utilize the environmental conditions to maximize the energy and cost savings while ensuring the core IEQ provisions such as indoor comfort, safety, health, etc. are not compromised. Other important areas of consideration which are quasi-passive, includes the analysis and selection of the equipment and building materials to be implemented. These decisions not only have a direct impact on the life cycle cost of the facility, but the IEQ and environmental impact.

Energy Modeling is also a specific application that can be utilized to maximize efficiency and lower cost. Location specific considerations provide insight into local climate data which influences form, heat gain, daylighting, and equipment settings. Subsequently, the facility's envelope requirements will influence window-to-wall ratios, orientation, solar absorption, thermal transmittance, solar heat gain coefficient, visible light, thermal transmittance, and shading of all glazing components. All this information is coordinated with mechanical and utility systems to determine the optimal equipment selections, costs, and applications within the facility. These include sizes of cooling and heating systems; ventilation systems; ancillary equipment such as fans and pumps; economizer and heat recovery systems; domestic hot water systems; and any integration of renewable energy sources being utilized.^{93 94 95} Ultimately, these decisions can render a final product that consumes less energy than facilities designed absent a holistic approach.⁹⁶

In addition to energy modeling, it is also important to study the air flow and distribution patterns that affect a facility's IEQ – this applies to new construction and renovations. It is no secret that the building form and shape can affect air flows through the building. This is an important factor for incorporating natural ventilation in a manner that significantly reduces HVAC costs.^{97 98} Air Infiltration is caused when air enters or leaves the building due to unintentional gaps in the building envelope. This is important because the air moving from inside to outside result in waste of energy – why cool or heat air, only to observe it's escape from a close environment. Additionally, the infiltration becomes a problem for the overall building performance as it directly affects heating and cooling requirements in buildings. The HVAC equipment will continue to condition the air in the spaces until the set requirements have been met. It is practically impossible to prevent any air leakage, but the goal is to minimize the loss to prevent waste.

⁹³ EnergyPlus by the U.S. Department of energy (free tool), available at: <https://energyplus.net/>.

⁹⁴ eQUEST, quick energy simulation tool: <http://www.doe2.com/equest/>.

⁹⁵ AIA (The American Institute of Architects) (2012) An Architect's guide to integrating energy modeling in the design process

⁹⁶ See Figure 8

⁹⁷ ERI@N (Energy Research Institute @ NTU) (2013) Nanyang Technological University (NTU), Singapore

⁹⁸ Fluent by Ansys: <http://www.ansys.com/>.

On the other hand, there are times when air movement through a building can be used to the occupants' advantage and comfort. When considering openings for doors and windows, Architects and designers enhance natural ventilation by providing pathways for airflow through buildings. A common practice is to induce cross-ventilation by intentionally placing windows or vents opposite each other to allow continuous fresh air ventilation. Though this may be contributing to occupant comfort, careful consideration must be given to climate and openings sizes. Air-mixing and circulation must be taken into consideration to reduce waste and determine hours of equipment use. Additionally, there are extreme climates in arid countries where hot air can create the opposite effect than that intended.^{99 100}

Ventilation is often responsible for the largest energy loss from buildings. To that effect, Architects treat facilities as three dimensional masses that must be designed from a holistic perspective – the infamous 'pen test' is indicative of such discipline. The pen test suggests that a professional must draw a line from one point of a sectional drawing, proceed in a clockwise or anti-clockwise direction, and end at the point where the line started. This is done via several iterations to ensure comprehensive considerations for the best design applications towards the envelope design. It cannot be overstated that reduced energy use can be accomplished by educating owners and developers about passive design strategies - especially prior to attempts to resolve all requirements via technology. Rigorous research can help execute design strategies indicative of a well-balanced passive and active systems.^{101 102}

A stellar case study that currently exists is the Sheikh Zayed Desert Learning Center in the United Arab Emirates. In addition to its sculpture-like appearance and smart building applications, the facility utilizes several passive design strategies to reduce energy use and exemplify sustainability. The building is partially submerged underground – with approximately one third of its cubic content below ground level. It accomplishes low solar heat gain from its massive concrete outer walls with insulated veneer sandstone and an air gap design – greatly reducing the required energy to cool the building. Deep recessed windows and overhangs limit

⁹⁹ Penwarden AD, Wise AFE (1975) Wind environment around buildings. BRE report, London

¹⁰⁰ See #49

¹⁰¹ Chartered Institute of Building Services Engineers (CIBSE) Team. (2004). Energy Efficiency in Buildings. CIBSE Guide F. CIBSE Publications.

¹⁰² University of Kentucky Cooperative Services. (Unknown). Design Considerations for Below-Grade Housing. University of Kentucky College of Agriculture.

direct sunlight exposure while still allowing enough daylight. A signature Austrian design technique was used to first induct warm ambient air into underground tubes prior to conditioning. This design reduces the temperature of the incoming air and the energy required to cool it before distribution inside the building. Additionally, the design team did extensive modeling to determine the optimal solar harvesting strategies and applications to supplement the grid provided power. As a result, the majority of the energy is provided by the PV panels on the roof.¹⁰³

5.0 CASE STUDIES AND EMERGING TECHNOLOGIES

5.1 Smart Sensing Approaches for Structural Health Monitoring¹⁰⁴

A facility's structural design is one of its most complex systems. It is responsible for the overall integrity of a facility to withstand both internal and external forces (live and dead loads, etc.). It also requires rigorous coordination between various professional disciplines (Designers, Engineers and Consultants) to ensure a structure can effectively integrate into a master design that creates a safe environment, and possess qualities that prolong its lifespan.

With respect to smart facility applications that can potentially reduce cost and improve safety, Dr. Chunhee Cho at the University of Hawaii at Manoa (UH) has recently been researching a Smart Structural Health System that can monitor and analyze the critical structural systems of a facility. Although his research is not complete, the following has been provided to share the prospects of future technology that can potentially change the way we approach structural engineering.

The system is inspired by the electronic maintenance indicators on the dashboard of automobiles. It tells the driver when a foreseeable problem is detected, or future maintenance is needed, to avoid future breakdowns or complex costly repairs.

¹⁰³ Waldhör, Stefanie.(2014). Building Innovations from Austria in the Arab World. Building Innovations from Austria in the Arab World. Bridges Magazine issue vol. 42, December 2014 / Feature

¹⁰⁴ Cho Chunhee Dr. (2019). Smart Sensing Approaches for Structural Health Monitoring Research. Assistant Professor Of Civil & Environmental Engineering at the University of Hawaii, at Manoa.

So why is this needed? We typically discover structural damage after the event has occurred. Many people are all familiar with the infamous leaning Tower of Pisa in Italy, but there are countless cases of structural degradation based on multiple causes. These include differential settlement from poor soil conditions, undersized members, or damage from natural disasters such as tornadoes or earthquakes. In reality all structure deforms and strain in some way over time, regardless of its initial design. Having a system that provides diagnostics for a structural system not only saves money, but can increase the longevity of the facility and save lives. This also holds potential to perform diagnostics of old facilities before renovation, and post- diagnostics on facilities that endured natural disasters. When a facility endures various kinds of stress, it can seem unaffected from the outside, but possibly have serious signs of degradation on the inside. Ultimately, each structural system has their own set of complexities that result in varying performance and degradation characteristics.

There are various applications for this technology such as bridges, overhead walkways, buildings and civil projects. When applied to these systems, catastrophes can be prevented maintenance costs can be reduced. The system components consists of (1) a mobile sensor network; (2) battery-free sensors (place at pre-designated locations); (3) and a diagnostic software-based computing damage detection system that synchronizes with BIM, and execute machine learning applications for future use. Essentially, the system can detect anomalies and compare it to a structure's baseline behavioral characteristics to determine the impacts or changes.

In general principle, the system is predicated on creating a baseline of values to determine deviations that predict changes to the original structure. Through experimental tests that use the structural characteristics similar to the real world structure, the performance of physical structural models and mobile sensors are validated. Subsequently, model updating technique is then used to synchronize the real and cyber models to enable the detection of potential damage – this is analogous to the Cyber Physical Systems concepts alluded to in the Smart Fire Protections Systems section.

First, a cyber model is built based on a real structure's attributes (tension, compression, modulus etc). The cyber and real models are then synchronized based on extensive testing and acquisition of data. This subsequently enables the cyber model to exhibit the behavior of the real model. The cyber model is then rigorously tested with random generation of load stress scenarios. The resulting analytics are then categorized as classifiers of a specific structural behavior response using the application of Machine Learning (ML) Algorithms.^{105 106 107}

The previous Static Wireless Sensors (strain gauges¹⁰⁸ and accelerometer¹⁰⁹) systems had limited deployments capabilities; power supply; communications range, and bandwidth; processing power; and low spatial resolution¹¹⁰ - this is not practical for large scale deployment.¹¹¹ Moreover, these legacy systems also had high installation and maintenance costs.

The contemporary sensor systems¹¹² involve the use of Wireless Mobile Sensors. They have flexible deployment applications and high spatial resolution. These sensor nodes are capable of detecting various events, and can change positions frequently in a specific sensing area. The flexure-based mobile sensors are capable of maneuvering on structures made of ferromagnetic materials – they also attach the accelerometer to the structural surface, and detach when necessary.¹¹³

¹⁰⁵ Nilsson Nils. (1998). Introduction to Machine Learning. A Proposed textbook Draft. Stanford University. Definition – Very broadly involves a machine's capability to change its structure, program, or data (based on inputs or in response to external information) in such a manner that its expected future improves.

¹⁰⁶ Hurwitz J, Kirsch D. (2018). Machine Learning for Dummies. A Wiley Brand. Courtesy of IBM. Definition - Machine learning is a form of Artificial Intelligence that enables a system to learn from data rather than explicit programming. It uses a variety of algorithms that iteratively learn from data to improve, describe data, and predict outcomes.

¹⁰⁷ Bishop, C. M. (2006), Pattern Recognition and Machine Learning, Springer. Definition - Machine learning is the scientific study of algorithms and statistical models that computer systems use in order to perform a specific task effectively without using explicit instructions, relying on patterns and inference instead. It is seen as a subset of artificial intelligence. https://en.wikipedia.org/wiki/Machine_learning

¹⁰⁸ Tuttle M.E. (1989) Fundamental Strain-Gage Technology. In: Pendleton R.L., Tuttle M.E. (eds) Manual on Experimental Methods for Mechanical Testing of Composites. Springer, Dordrecht. Definition - Strain gauge is a sensor whose resistance varies with applied force; it converts force, pressure, tension, weight, etc., into electrical resistance which can then be measured. When external forces are applied to an object, stress and strain is the result

¹⁰⁹ Dadafshar M. (2014). Accelerometer Gyroscopes Sensors: Operation, Sensing, and Applications. Definition – An Accelerometer is an instrument for measuring acceleration, typically that of an automobile, ship, aircraft, or spacecraft, or that involved in the vibration of a machine, building or other structure. Accelerometers are fabricated in a multilayer wafer process, measuring acceleration forces by detecting the displacement of the mass.

¹¹⁰ Collins Dictionary of Astronomy. (2006). Retrieved July 19 2019 from <https://encyclopedia2.thefreedictionary.com/spatial+resolution>
Definition - Spatial Resolution represents the accuracy or detail of a graphic display, expressed as dots per inch (dpi).

¹¹¹ Kok-Meng Lee, Yang Wang, Dapeng Zhu, Jiajie Guo, Xiaohua Yi. (2009). Flexure-based Mechatronic Mobile Sensors for Structure Damage Detection

¹¹² Ramaasamy Velmani. (2017). Mobile Wireless Sensor Networks: An overview. Intechopen.com:
<https://www.intechopen.com/books/wireless-sensor-networks-insights-and-innovations/mobile-wireless-sensor-networks-an-overview>

¹¹³ See 29.

The Wireless Battery Free Sensors include the use of Radio Frequency Identification (RFID) chips¹¹⁴. This refers to a technology whereby digital data encoded in the RFID tags or smart labels are captured by a reader via radio waves. RFID is like barcoding in that data from a tag or label are captured by a device that stores the information in a database. RFID belongs to a group of technologies referred to as Automatic Identification and Data Capture (AIDC)^{115 116}. AIDC methods automatically identify objects, collect data about them, and enter those data directly with a computer system with little or no human intervention. At the fundamental level, RFID systems consist of three components: an RFID tag or smart label; an RFID reader (also called interrogator), which converts radio waves to usable data; and an antenna. When compared to barcodes, RFID tags can be read outside the line of sight, whereas barcodes must be aligned with an optical scanner.¹¹⁷ With respect to structural performance diagnostics, Dr. Cho's research proposes to optimize RFID designs to improve strain sensitivity.

The research currently does identify some limitations and unknowns. Limitations include requirement for high computing capacity. It also requires the establishment of sufficient data via testing, to improve damage detection accuracy. Unknowns include questions such as: how will the information be extracted from the real model - a real world structure? ; will it utilize strain gauges, accelerometers?; what is the exact set of information being extracted from the real model to compare to the cyber model?; is it just comparing the Eigen Frequency¹¹⁸ (normally known after construction), to a different frequency reading captured years after the facility is built?; how will the technology compensate for the differences in a built structure?; how do you know where to place the sensors?; and how do the characteristics of individual structural members affect the characteristic of an entire assembly?

¹¹⁴ Kaur A, Sandhu M, Mohan N, Sandhu P. (2011). RFID Technology Principles, Advantages, Limitations and its Applications. Definition - Radio Frequency Identification (RFID) is a generic term that is used to describe a system that transmits the identity (in form of a unique serial number) of an object or person wirelessly, using radio waves.

¹¹⁵ Mill John, Cameron Brett (unknown). Automatic Identification and Data Collection: Scanning Into the Future.

¹¹⁶ Wamba SF, Lefebvre E, Bendavid Y, Lefebvre LA. (2008). From Automatic Identification and Data Capture (AIDC) to "Smart Business Process": Preparing for a Pilot Integrated RFID.

¹¹⁷ <https://www.abr.com/what-is-rfid-how-does-rfid-work/>

¹¹⁸ Bhatt, P. Maximum Marks Maximum Knowledge in Physics. Allied Publishers. Definition – is the frequency at which a system tends to oscillate in the absence of any driving or damping force.

5.11 Health Monitoring of Structural Materials and Components¹¹⁹

The Research and application of structural health monitoring has precedence in other industries that can be applied to facilities. In Professor Douglas's work, mechanical and structural commercial application are explored for engine components (valves, wires, harnesses); automotive accessories (wheels, spindles, suspensions, exhaust); aircraft and spacecraft components; and defense system components (body and vehicle armor). The body of work also spans the breadth of load identification, in-situ damage diagnostics, and performance predictions.

The approach is defined as a scientific process of nondestructively identifying four characteristics related to the fitness of an engineered component (or system): the operational and environmental loads that act on the component (or system); the mechanical damage and its growth that is caused by that loading; the growth of damage as the component (or system) operates; and the future performance of the component (or system) as damage accumulates.

One common application that is derived from the aforementioned concept is Condition-Based Maintenance (CBM)¹²⁰. This is the application of diagnostic technologies for the purpose of scheduling future service and maintenance for products according to the condition of those products. They can be used to assist in future structural design and implementation; to predict behavioral characteristics of various structural materials and components; and provide timely data harvesting to identify needed repairs that extend the life of structures.

Like Dr. Chunhee's research at UH, the premise for Douglas's work includes vibration-based methods for damage identification. It is based on the science that structural damage is accentuated by waves when components vibrate. The research shows that when propagating waves encounter damage, they attenuate and scatter. This event can be captured as data and used to detect structural damage by analyzing the disrupted waveforms. This research also shares similar challenges to Dr. Chunhee's. Embedded structures post-construction leads to possible

¹¹⁹ Adams E Douglas. (2007). Health Monitoring of Structural Materials and Components: Methods with Applications. Purdue University. John Wiley & Sons Ltd

¹²⁰ Kamaruddin S, Ahmad R. (2012). An overview of time-based and condition-based maintenance in industrial application. Elsevier. Definition – Conditioned Based Maintenance (CBM) is a maintenance program that recommends maintenance actions (decisions) based on the information collected through condition monitoring process. In CBM, the lifetime (age) of the equipment is monitored through its operating condition, which can be measured based on various monitoring parameters, such as vibration, temperature, lubricating oil, contaminants, and noise levels.

anomalies compared to a framework solely represented by structural members absent other building materials. If a system will be tasked to detect damage in embedded structural members, then the sources of variability due to the surrounding components must be minimized. This will require rigorous testing to avoid false readings.

When compared with other research, these concepts begin to take on a common theme. According to a conglomerate of international university students, “Most systems aim to create several algorithms to locate and determine the severity of damages in different structures based on their vibration response. In these applications, the test-structure is subjected to low-frequency excitations, and the resulting vibration responses (displacements, velocities or accelerations) are picked up at specified locations along the structure. The harvested data are processed to extract the first few mode patterns and the corresponding natural frequencies of the structure. Consequently, this data is compared with the corresponding data for the healthy state, to yield information pertaining to the locations and the severity of the damage.”¹²¹

5.2 Unmanned Aerial Vehicles¹²²



Figure 3: Image courtesy of Georgia Tech University 2019

Unmanned Aerial Vehicles (UAVs) include autonomous devices such as drones (capable of operating without people) and vehicles that can be piloted remotely. UAVs in concept has been around for a long time with respect to warfare. They are typically powered by a jet, reciprocating, or electric engine. The technology reached a point of popularity and

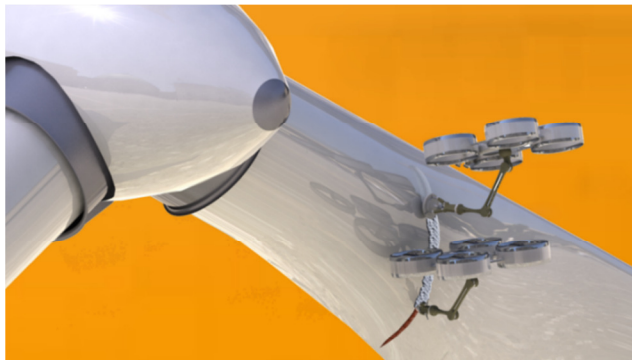
¹²¹ Chee-Kiong Soh, Chee-Kiong Soh, Suresh Bhalla. (2012). Advanced Topics in Science and Technology in China. Zhejiang University Press, Hangzhou. Springer.

¹²² Valavanis Kimon. (2007). Advances in Unmanned Aerial Vehicles. State of the Art and the Road to Autonomy. University of South Florida. Springer.

sophistication due to its widespread use in recent wars – Operational Iraqi Freedom¹²³ and Operation Enduring Freedom¹²⁴. In recent years they have also been used by the US Customs and Border Patrol agencies to monitor the border between US and Mexico¹²⁵.

Another emerging technology involves what is known as Miniature Flying Robots (MFRs)^{126 127}. Unlike their larger and less agile predecessors, they have potential for more discreet purposes and applications that require small vehicles to be successful.

To that end, they have great potential with respect to military applications; search and rescue missions; and building inspections. A byproduct of this field of study is shown in above in figure 3. Known formerly as the GT Max, this UAV was developed by the Georgia Institute of Technology. Another advanced concept stems from the collaborative efforts of the private industry and university research in Europe. Formerly known as the Collaborative Aerial Robotics Workers (CARW), the Autonomous Systems Lab (ASL) of the Swiss Federal Institutes and Aeroworks are developing MFR technology that will alter the methods of facility repairs and inspections.



Their target market is the aging infrastructure in developing and developed countries. They posit that the cost of repair and inspection tasks has been growing incessantly. To counteract such a problem, they intend to apply reliable automated

Figure 4: Image courtesy of The Autonomous Systems Lab of The Swiss Federal Institute, and Aeroworks 2019.

¹²³ 20 March 2003 marked the beginning of Operation Iraqi Freedom with preemptive airstrikes on Saddam Hussein's Presidential Palace and military targets followed by approximately 67,700 "boots on the ground" with 15,000 Navy personnel on ships in the region (Belasco). OIF was authorized when Iraq was found to be in breach of U.N. Security Council adopted Resolution 1441 which "prohibits stockpiling and importing weapons of mass destruction (WMDs). <https://www.history.navy.mil/browse-by-topic/wars-conflicts-and-operations/middle-east/operation-iraqi-freedom.html>

¹²⁴ In response to the 11 September 2001 terrorist attacks that killed nearly 3,000 people, Operation Enduring Freedom officially began 7 October 2001 with American and British bombing strikes against al-Qaeda and Taliban forces in Afghanistan. <https://www.history.navy.mil/browse-by-topic/wars-conflicts-and-operations/middle-east/operation-enduring-freedom.html>

¹²⁵ Johathan Karp, and Andy Pasztor (2006). Drones in Domestic Skies. They're in Demand for Rescue and Surveillance Missions, But Critics Question Safety". Wall Street Journal.

¹²⁶ Timmer John (2013). Researchers build miniature flying robots, modeled on Drosophila. Piezoelectric muscles flap tiny, gossamer wings. <https://arstechnica.com/science/2013/05/researchers-build-miniature-flying-robots-modeled-on-drosophila/>

¹²⁷ Jafferis N, Helbling F, Karpelson M, Wood R. (2019). Untethered flight of an insect-sized flapping-wing microscale aerial vehicle.

solutions that reduce costs and minimize risks to personnel and asset safety. They envision unique autonomous aerial robotic teams that conduct facility inspection and maintenance tasks - while simultaneously providing intuitive, user-friendly interfaces to its operators.

According to Aeroworks, “robotic teams will consist of multiple heterogeneous CARWs, a new class of Unmanned Aerial Vehicles equipped with dexterous manipulators; novel physical interaction and co-manipulation control strategies; perception systems; and planning intelligence. This new generation of worker-robots will be capable of autonomously executing infrastructure inspection and maintenance works. The multi-robot team will operate in a decentralized fashion. They will be characterized by unprecedented levels of re-configurability, mission dependability, and manipulation dexterity. Ultimately they will be integrated in robust and reliable systems that are rapidly deployable and ready-to-use as an integral part of infrastructure service operations.” The intent of the project is to take advantage of the infrastructure service market. Although, its results will need to be demonstrated and evaluated in realistic infrastructure settings to impact the service and industrial robotics sector in a way that potentially changes the parameters of how robots are utilized.^{128 129}

In the public sector, there are branches of the US Department of Defense that are currently utilizing UAV technology. UAVs are currently being used in the field by The US Army Corp of Engineer (USACE). The efforts headed by their Research and Development Center (ERDC) utilized the technology for various facility management related applications in early 2019. They utilized UAVs to conduct infrastructure inventory in Vicksburg, MS. The UAVs are being used to perform several tasks such as collecting high resolution photographs of the entire installation; thermal imagery of energy assets, to detect heat loss from buildings; and mapping areas for future master planning and site surveys, to include light poles, and utility access covers. The overall efforts will reduce employee safety risks and be less time-consuming than traditional methods.¹³⁰

¹²⁸ Aeroworks. A project funded from the European Union’s Horizon 2020 Research and Innovation Programme.<http://www.asl.ethz.ch/research/flying-robots.html>

¹²⁹ Valavanis P. Kimon.(2007). Advances in Unmanned Aerial Vehicles. State of the Art and the Road to Autonomy. Springer Publishing.

¹³⁰ Link, Lewis. (2019). The Military Engineer Magazine (TME). Technology News. Assessments from the Air.

Intelligent buildings are mostly the result of efforts by several companies and industries. Although, the foreseeable successes of these efforts include compatible standards, non-proprietary interfaces, and open architectures. Whereas the automotive industry is already heavily characterized by modular thinking and open systems, this has only just started in the building control industry.¹³¹

5.3 Case Studies by the American Council for Energy-Efficient Economy (ACEEE): Utilities and Mechanical Systems Analysis¹³²

Methodology:

ACEEE conducted research for this report through a literature review and expert interviews. The literature reviewed included articles, reports, and case studies. Experts interviewed included utility program administrators, smart technology manufacturers, and smart building practitioners. They used a combination of reported data, facts, statistics, and anecdotal evidence to formulate conclusions and recommendations. The study focused on existing commercial buildings, offices, retail, education, healthcare, and hospitality properties. The study looked at buildings with significant occupancy, excluding data centers and warehouses. Commercial buildings were divided into two size categories: large (greater than 100,000 square feet, such as a high-rise office building); and small and medium (100,000 square feet or smaller). Additionally, they placed a slightly greater emphasis on small and medium buildings because they represent nearly 98% of US commercial buildings and typically lack smart building technologies; as such, they represent a large opportunity.

The paper's scope included the entire US commercial building stock, including about half of all buildings aged 35 years or older (constructed pre-1980) and half of the newer buildings (constructed after 1980). Building age was determined to be strongly correlated with the types of building construction and installed equipment; this had implications for the types of building data that could be collected, and the processes that could be made smart. Each US region was included in the analysis.

¹³¹ See Note # 45

¹³² Perry Christopher, King Jennifer. (2017). Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings. American Council for an Energy-Efficient Economy: Report A1701

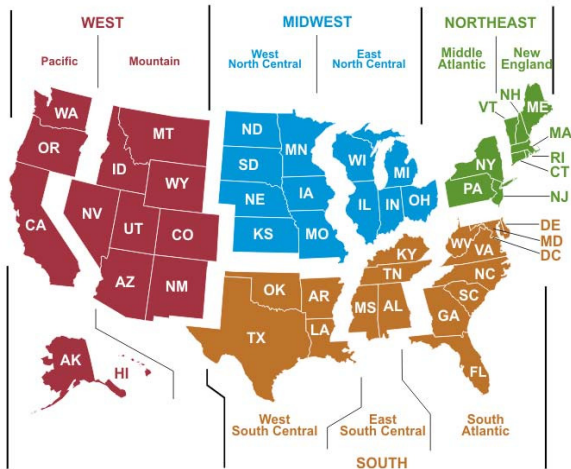


Figure 5: Image courtesy of ACEEE

The South had the greatest number of commercial buildings (approx. 40% of the total stock), while the West and Midwest represent about 23% and 22%, respectively. Additionally, the Northeast represented the remaining 15%. These regional distinctions were important, as each region has unique weather patterns, income levels, building stock, and available utility programs. See Figure 4 for regional demarcations.

They examined the key building systems to evaluate and document the opportunities for smart technologies: The following aggregate of data was the result:

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

Table 1: Commercial building subsector energy savings from smart building technologies: Includes both electricity and natural gas (converted to kWh) consumption.

Category	Technology	Components	Cost	Energy savings	Simple payback	Measure life
Building automation	Traditional BAS	Sensors, controllers, automation software	\$1.50–7.00/sf	10–25% whole building	3–5 years	10–12 years
Analytics	Cloud-based EIS	Sensors, communication systems, web-based software	\$0.01–0.77/sf + service contract	5–10% whole building	1–2 years	Length of contract

Table 2 : Retail costs and savings estimates for Building Automation Systems(BASC). Excludes installation costs. Sources: Traditional BAS costs: FPL 2016. EIS costs: Granderson, Lin, and Piette 2013. Energy savings: Gilliland 2016. Simple payback: ACEEE analysis. Life expectancy: ACEEE analysis, ASHRAE 2013. Traditional BAS life expectancy: Winkelman 2009, Tatum 2011.

Category	Technology	Components	Cost	Energy savings	Simple payback	Measure life
Window shading	Automated shade system	Shades w/ automatic controls	\$375 (motorized shades)	21–38%	4 years	10–20 years
Window shading	Switchable film	Self-adhered	\$15–20/sf	32–43%	2–3 years	10 years
Window shading	Smart glass	Thermochromic Electrochromic	\$40/sf \$61/sf	20–30%	21 years 33 years	30 years 50 years

Table 3: Retail costs and savings estimates for window shading technologies: Excludes installation costs. Sources: Window shading costs: GSA 2014, Wagner 2016. Energy savings: Lutron 2014, InvisiShade 2016, SageGlass 2016, RavenWindow 2016. Simple payback: ACEEE analysis. Life expectancy: ACEEE analysis, ASHRAE 2013. Switchable film life expectancy: InvisiShade 2016.

Category	Technology	Components	Cost	Energy savings	Simple payback	Measure life
Plug load	Smart plug	120v 220v	\$100 each \$200 each	50–60%	4–12 months	9 years
Plug load	Advanced power strip	Tier One types	\$45–50 each	25–50%	8–18 months	10–20 years
Lighting	Advanced lighting controls	Occupancy/vacancy, daylighting, task tuning, lumen maintenance, dimming, daylighting	\$2–4/sf	45%	3–6 years	10–20 years
Lighting	Web-based lighting mgmt system	Software and hardware	\$1.15/sf	20–30% above controls savings	1–4 years	10–15 years
DER	Smart inverter	Smart inverter	\$0.16/watt	12%	4–5 years	10 years

Table 4 :Costs and savings estimates for plug load, lighting, and DER technologies. Excludes installation costs. Sources: Advanced lighting controls costs: Gilliland 2016, DLC 2016. Plug load energy savings: Boss 2016, GSA 2012. Advanced lighting controls and management systems savings: BEEEx 2015. DER savings: Berdner 2015. Simple payback: ACEEE analysis. Life expectancy: ACEEE analysis, ASHRAE 2013. APS life expectancy: NEEP 2012, Huffstetler 2016. Smart inverter life expectancy: Chung et al. 2015b.

Category	Technology	Components	Cost	Energy savings	Simple payback	Measure life
HVAC	Wired sensor	Energy, temperature, flow, pressure, humidity sensors	\$50–100/sensor + \$1.60/linear foot wiring	Not applicable	Not applicable	15–30 years
HVAC	Wireless sensor	Energy, temperature, flow, pressure, humidity sensors	\$150–300/sensor	Not applicable	Not applicable	15–30 years
HVAC	Variable frequency drive	Variable frequency drive (pumps and motors)	\$125–250/ hp	15–50% pump or motor energy	1–2 years	7–10 years
HVAC	Smart thermostat	Smart thermostat	\$150–330/ thermostat	5–10% HVAC	3–5 years	10 years
HVAC & lighting	Hotel guest room occupancy controls	Door switches, occupancy sensors	\$100–500/ guest room	12–24% HVAC, 16–22% lighting	2.5–3.0 years	10 years

Table 5: Retail costs and savings estimates for smart HVAC technologies. Excludes installation costs. Sources: Wireless sensors costs: ACEEE analysis, Shoemaker 2015. Wired sensors costs: Kintner-Meyer et al. 2002). Smart thermostats costs: Grant and Keegan 2016. VFDs savings: ACEEE analysis, Hydraulic Institute, Europump, DOE 2004. Smart thermostat savings: DOE 2016b. Simple payback: ACEEE analysis. Life expectancy: ACEEE analysis, ASHRAE 2013. VFDs life expectancy: Delta Automation 2010. Smart thermostats life expectancy: Harder 2016. Hotel occupancy controls (all): CPUC 2011.

5.4 Case Study 00: Microsoft case study Redmond Campus:¹³³

Sometime between 2009 and 2010, Microsoft initiated a project to focus on the management and improvement of energy use and building operations. It involved the integration of seven building management systems used on the Redmond campus, and the effective deployment of fault detection and diagnostics systems (FDD)¹³⁴. The campus consists of 15 million square feet of space in approximately 120 buildings. The initial pilot application consisted of 2.5 million square feet of space, where three potential contractors showcased their software, prior to selecting a contractor and deploying the application across the campus.

These buildings stretched across 88 acres of Microsoft's Redmond campus; hence the pilot's name, 88 Acres. Using existing wireless networks and internet connectivity, techs worked to integrate tens of thousands of HVAC component sensors, collecting data under a single cloud-based software layer and enabling a holistic operational view of all HVAC systems. Although early tests convinced execs that it made fiscal sense, HVAC techs initially found it hard to welcome a tool whose job was to highlight inefficiencies within the systems. However, as time progressed, they began to embrace the ESB's contribution troubleshooting time reduction.

They defined a fault as a deviation in the value of at least one characteristic variable from its normal expected behavior. Faults that were detected include:

- HVAC systems that improperly simultaneously heat and cool
- Excessive outdoor air intake and conditioning
- Under-utilized free cooling potential
- Equipment malfunction (such as broken/leaking valves, broken/stuck dampers, sensors out of calibration)
- Systems with the wrong setpoints and operating schedules
- Unintentional manual overrides
- Lack of energy-saving control sequences (such as chilled water reset)
- A bad bearing in a motor or compressor (the bearing then can be replaced before the whole gear box fails and becomes an emergency repair)

¹³³ Guttapalem, Mohan R. (2017). When Buildings Talk: The Story of Microsoft's Energy Smart Building Initiative

¹³⁴ Dewan L, Sharma RS. (2015). Fault Diagnosis Methods in Dynamic Systems: A Review. Definition - A system that combines the capabilities of detection, isolation and identification or classification of faults is termed as a fault diagnosis system.

- Misaligned motor, rotor imbalance, or cracked rotor bar
- Dirty filters or strainers
- Incorrect refrigerant or oil levels
- Pumps with throttled discharges
- Short cycling of equipment
- Excessive oscillation (hunting) of control points and/or control loop
- Tuning needs
- Incorrect fan and pump speeds, pressures, or low flow rates.
- Improper building or space pressurizations (negative or positive)
- Inefficient boiler combustion
- Excessive building peak electrical demand

When the ESB became operational, the central interface highlighted real-time faults, potential problems, and notable wastes of energy. In one building, the software reported a pressurization problem in a chilled water system - an issue that took less than five minutes to fix but would've wasted \$12,000 a year had it gone undetected. Indeed, the results from the early pilot compelled Microsoft to adopt the solution across its 118- building Redmond, Washington campus, saving the company \$700,000 the first year. With the estimated reduction in energy consumption at 20% in 2017, Microsoft implemented its ESB platform at its various campuses in Silicon Valley, CA and Los Colinas, TX. It has also been deployed globally, most recently in Shanghai and Beijing.

Microsoft claims to benefits from the third lowest utility rates in the country. They claimed they were able to save over \$1 million in energy cost the first year. They invested 10% of the yearly energy costs in the deployment of the application, and had a payback of less than 18 months. The predictive approach is how Microsoft manages its building systems. The company views the ESB as a technological application that supersedes the quaint reactive model where occupants complain; then service people respond, diagnose and repair.

5.5 Case Studies: The Eelume Concept^{135 136 137}



Figure 6: Image courtesy of Norwegian University of Science and Technology NTNU, Kongsburg Maritime and Satoil. 2019

Until recently, underwater inspection and repair operations have been executed by Remote Operating Vehicles (ROVs). An underwater vehicle is typically used to carry the ROV to its location, where it is lowered into the sea. Subsequently, the inspection work is controlled by an operator on board the sea going vessel.

Eelume was established in 2015 as a byproduct of the Norwegian University of Science and Technology (NTNU). Following a decade of research on snake robots in collaboration with the research organization SINTEF¹³⁸, they decided to pursue industrial subsea applications. Eelume is a snake-like robot that was developed for inspection, maintenance and repair of undersea oil and gas infrastructure. What makes this underwater repair technology unique is the fact that it is self-propelled, and therefore does not need the support of a remotely operated

¹³⁵ Ship and Offshore Magazine (2016). Offshore & Marine Technology. Industry News

¹³⁶ Owano Nancy (2016). Swimming robots perform snake-like movements for subsea tasks. <https://techxplore.com/news/2016-04-robots-snake-like-movements-subseataasks.html>

¹³⁷ Nielsen, M. C. (2018). Modular Underwater Robots - Modeling and Docking Control. Technical University of Denmark, Department of Electrical Engineering.

¹³⁸ SINTEF is one of Europe's largest research organization: <https://www.sintef.no/en/>

vehicle (ROV). For this reason, the Eelume is seen as a disruptive technology that will greatly reduce the costs of first-line inspection and maintenance of undersea installations.

Eelume robots are designed as modular combinations of joints, thrusters and various payload modules. Their slender body permits for precision hovering and maneuvering, even in strong ocean currents. Sensors and tools can be mounted anywhere along the flexible body. A dual-arm configuration is achieved by mounting tooling in each end and forming the vehicle body into a U-shape. One end of the arm can grab hold to fixate the vehicle, while the other end can carry out inspection and intervention tasks. One end of the arm can also provide a perspective camera view of a tool operation carried out at the other end.

Per to the robot's developers, the primary cost factors in undersea maintenance are impacted by the increasing depth of new installations and the aging of existing infrastructure. The developers envision Eelume being stationed at an undersea facility and activated for maintenance activities as required – this can greatly improve efficiency and reduce inspections and repair time.

A proposed list of tasks to be conducted by the Eelume will include visual inspections, cleaning, and adjustment of any functional part of an underwater equipment or mechanical system. Its snake-like shape enables it to access hard to reach areas of underwater infrastructure. Also, due to their pre-staged presence underwater, the Eelume can be used to respond to emergency situations, possibly mitigating a problem before it exacerbates.

The technology is being developed to live permanently under water, where they can be mobilized 24/7 regardless of weather conditions. An ever present capability near undersea installations without the need for surface vessels can result in greener, safer and less costly underwater operations.

5.6 Case Studies: Intel Office Building in Bangalore India:^{139 140}



Figure 7: Image courtesy of Intel Corporation Case Study by Srimi. 2017.

In 2016, Intel created its first Internet of Things (IoT)^{141 142} smart building in India. The building is a 10-story, 630,000 sq. ft. structure that was outfitted with approximately 9,000 sensors used to track and optimize temperature, lighting, energy consumption, and occupancy in the building. The sensors, of which 70 percent are located in the ceiling, provide 24/7 real-time data. Analytics¹⁴³ is run on the data gathered from sensors to generate actionable insights for Intel's facilities operators.

Intel's goal was to reduce resource usage, increase operational efficiency, and improve occupant comfort. The typical Intel office utilized static building management systems (BMSs) that had limited capabilities to intelligently control utility systems and equipment. They also wanted to utilize a mobile cubicle model to accommodate more employees. Additionally, they needed to eliminate oscillating temperatures in the building which led to employee complaints about their zone being either too hot or too cold.

¹³⁹ Khandavelli, Srimi. (2017). Case Study. Intel Creates Smart Buildings Using IoT. Intel's Smart Building Increases Energy Conservation, Operational Efficiency, and Occupant Comfort.

¹⁴⁰ Intel Corporation calculation from building drawings.

¹⁴¹ Brown, Eric (2016). "Who Needs the Internet of Things?". *Linux.com*. Retrieved 23 October 2016.

¹⁴² Brown, Eric (20 September 2016). "21 Open Source Projects for IoT". *Linux.com*. Retrieved 23 October 2016.

¹⁴³ Marr Bernard. (2013). What the Heck is...Analytics. LinkedIn. Definition - analytics refers to our ability to collect and use data to generate insights that inform fact-based decision-making.

The solution was to employ several applications that would optimize use building systems and increase occupant comfort. They installed advanced building analytics tools to reduce energy and water usage by better controlling building systems using automation rules generated from sensor data. They increased cubicle utilization rates by employing occupancy sensor data to help employees find vacant cubicles. Intel also utilized Machine Learning algorithms^{144 145} to maintain a constant temperature in all building zones by taking more environmental factors into account.

The impact of such efforts resulted in utility savings, and productive workers. Future savings were forecasted to be \$645,000 per year with a return on investment (ROI) payback period of less than four years. They estimated that temperature control would lead to increase in worker satisfaction with thermal comfort by 83 percent¹⁴⁶, and increase employee capacity by approximately 30 percent.

Intel's goal was to equip its facilities managers with the vital information they needed to make informed decisions. The first step was to assess the incumbent building systems that were generating massive amounts of data, without presenting it in a user-friendly manner. The large numbers of stand-alone and proprietary interfaces were known to impede data sharing required to thoroughly analyze building performance. These systems resulted in inadequate, inflexible, and costly operations - partially due to their vendor-specific, proprietary technologies. Many vendor solutions were found to be hardware-based, which generally made it more complex to deploy new features and upgrades, compared to software-focused solutions. As a result, modifying a legacy BMS often required customization by the manufacturer - a costly and time-intensive process.

In this smart building, closed areas, such as conference rooms, represent approximately 18 % of the total floor space. These areas were determined as good candidates for energy conservation. When they are vacant, the HVAC and lighting systems can often be powered down

¹⁴⁴ Machine learning (ML) is the scientific study of algorithms and statistical models that computer systems use in order to perform a specific task effectively without using explicit instructions, relying on patterns and inference instead. It is seen as a subset of artificial intelligence.

¹⁴⁵ Bishop, C. M. (2006), Pattern Recognition and Machine Learning, Springer.

¹⁴⁶ Kevin Powell, Green Proving Ground program director, "Green Proving Ground: Smart Temperature Control Optimizes Comfort and Saves Energy." (April 18, 2016). <https://gsablogs.gsa.gov/gsablog/2016/04/18/green-proving-ground-smart-temperature-control-optimizes-comfort-and-saves-energy>.

to save energy. In that case, the booking status of each conference room is collected from the IT corporate calendaring system, and room occupancy status is obtained from the IoT-enabled PoE lighting fixtures in each room. These parameters are subsequently fed to the HVAC system to efficiently modulate the variable air volume (VAV) boxes in the conference rooms. By doing so, they projected a savings of 4% of its total HVAC costs, allowing the solution payback period to be less than two years.

Intel's smart system also controls several energy sources: diesel generation, solar, fuel cells, and the grid. It enables the facility maintainers to remotely read energy usage. Both energy consumption and generation are monitored and controlled to meet an energy load profile that satisfies the utility's demand-response requirements. With this capability, Intel's smart building can take automated actions to reduce energy consumption when the 90 percent threshold of the permitted load has been exceeded.

Figure 8 shows an illustration of the IoT architecture. The Intel processor-based IoT gateways¹⁴⁷ act as the "central nervous system"—essentially enabling interoperability and data integration of the entire system. They securely connect to a variety of smart sensors that monitor building systems and ensure an uninterrupted flow of data between them. The gateways also have built-in enterprise-grade security features that provide security protection for the network, building systems, and data.

Although the building is equipped with an on-site BACS that handles the usual building automation tasks for various subsystems (e.g., HVAC and lighting), Intel added advanced building analytics via an integrated building energy management system, called iBEMS. Intel's BACS also reconcile the different communications protocols¹⁴⁸ used by the various building systems. This is where the Intel® processor-based IoT gateway acts as a central coordinator with its ability to ingest messages on a variety of protocols such as Modbus* TCP/IP and BACnet-IP.

¹⁴⁷ Rouse Margaret. (2017). IoT Gateway. Definition – A network Gateway is a point of entrance to and exit from a communications network. Viewed as a software or hardware entity, a gateway is that node that translates between two otherwise incompatible networks or network segments. Gateways perform code and protocol conversion to facilitate traffic between data highways of differing architecture. An Internet of Things (IoT) gateway is a physical device or software program that serves as the connection point between the cloud and controllers, sensors and intelligent devices. All data moving to the cloud, or vice versa, goes through the gateway, which can be either a dedicated hardware appliance or software program.

¹⁴⁸ Definition – Communication Protocol is a set of rules governing message exchange over a network or internetwork.

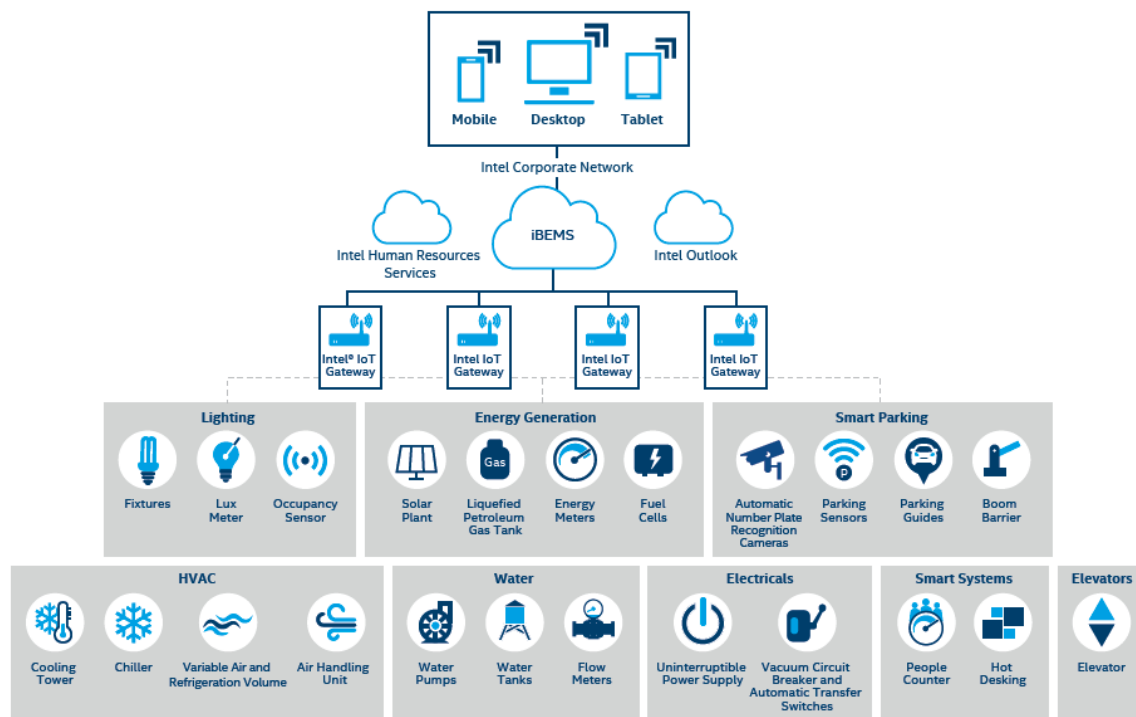


Figure 8: Image courtesy of Intel Corporation. 2017.

Intel employed network and security policies specifically designed to protect against hackers trying to access the corporate network. The system physically isolates the sensor network from the corporate network using a gateway that bridged the two networks using separate interfaces. As a security policy, the iBEMS software running on the corporate network server is protected by a firewall.^{149 150} No Internet connections from outside the firewall to iBEMS are permitted.

The Intel smart building in Bangalore India implemented a complex set of systems to focus primarily on energy conservation, operational efficiency, and employee satisfaction. It also illustrates a case study that goes against the use of closed and proprietary BACS systems, and towards open systems in order to reap benefits from the latest technologies.

¹⁴⁹ Definition - In computing, a firewall is a network security system that monitors, and controls incoming and outgoing network traffic based on predetermined security rules. A firewall typically establishes a barrier between a trusted internal network and untrusted external network, such as the Internet.

¹⁵⁰ Boudriga, Noureddine (2010). *Security of mobile communications*. Boca Raton: CRC Press.

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