Title: **Integrated and Intelligent Buildings: An Imperative to People, the Planet and the Bottom Line**

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Subjects: Building Materials/Products
IT/Computer Science/Software
Sustainability/Green/Energy
Vertical Transportation

Keywords: Environment
Sustainability
Technology
Vertical Transportation

Publication Date: 2015

Original Publication: The Future of Tall: A Selection of Written Works on Current Skyscraper Innovations

Paper Type:
1. Book chapter/Part chapter
2. Journal paper
3. **Conference proceeding**
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Integrated and Intelligent Buildings: An Imperative to People, the Planet and the Bottom Line

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With the impact of urbanization, larger cities, operating pressures and the rise of megatall skyscrapers, today's new and existing buildings are increasingly being engineered as integrated systems, linking heating, ventilation and air conditioning (HVAC), security, fire, lighting, energy management, water and elevator systems with information technology systems and controls. The proven benefits of integration include: energy savings, improved vertical transportation, and healthier, safer buildings leading to cost savings and improved occupant experience. Intelligent, integrated buildings can lead to higher occupancy and rents, lower energy consumption and more productive employees. Innovation is a key enabler in developing these high-performance buildings.

Intelligent and integrated buildings present significant opportunities for substantial

BENEFITS OF Intelligent Buildings

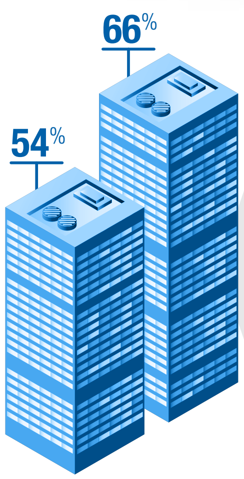
U.S. building owners spent **$432 billion** on energy in 2011. A 30 percent reduction in building energy consumption equates to a **$65 billion-per-year** savings to the overall U.S. economy (Rhodium Group, 2013).

An increase in indoor carbon dioxide levels from **600 to 1,000** parts per million can decrease occupant performance by **11 to 23 percent** (Satish, 2012).

Inadequate ventilation can cause a **50 percent** increase in employee sick days, resulting in an annual economic impact of **$400 per employee** (Milton, 2000).

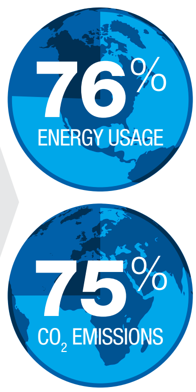
Improved air quality in offices can lead to **41 percent** improvement/ reduction in symptoms (Kats, 2005).

Contributing Factors



54 percent of the world's population lives in cities, and that will shift to more than **66 percent** by 2025 (United Nations, 2014).

Urban areas use up to **76 percent** of global energy and generate about **75 percent** of carbon emissions (IPCC, 2014).



improvement in many areas. This refers to improving the health, safety, satisfaction and productivity of the people who occupy buildings; increasing profitability for building operators as a result of reduced utility costs and optimized maintenance; and reducing the energy consumption and emissions of buildings to minimize their environmental impact on the planet.

People

Building performance and indoor air quality have a significant impact on occupant health and productivity. A Carnegie Mellon University building performance program identified 17 studies on this topic, all of which showed that improved air quality reduces occupant impacts such as asthma, flu, respiratory problems and headaches, with an average improvement in reported symptoms of 41 percent (Kats, 2005).

Other research has shown that increased indoor pollution resulted in reduced occupant productivity. Specifically, when indoor carbon dioxide levels rose from 600 parts per million (ppm) to 1,000 ppm, occupant performance related to tasks that involved strategic thinking and decision making decreased between 11 and 23 percent (Satish, 2012). Moreover, field studies in North America demonstrated that inadequate ventilation caused a 50 percent increase in employee sick days, resulting in an annual economic impact of $400 per employee (Milton, 2000).

Opposite: The benefits of intelligent buildings. Source: UTC Building & Industrial Systems

Beyond the proven examples of increased health and productivity, intelligent buildings may also help improve occupant satisfaction by reducing elevator wait times, and offering peace of mind by creating a safe and monitored environment. Access control systems, for example, can help identify suspects involved in theft, manage access for visitors and automatically disable access for employees who are no longer with an organization. When implemented for tenants in a mixed-use building, which included 10,000 employees and 15,000 visitors per month, residents felt more secure with the web-based access management (Roberts, 2005). Finally, by providing the most efficient and secure movement and vertical transportation for occupants, intelligent buildings can offer tenants an enhanced building experience.

Cost Savings

The economic impact of efficient, intelligent buildings is considerable. A recent study showed that in the U.S. alone building owners spent $432 billion on energy in 2011, which is equivalent to what U.S. businesses spend on healthcare and more than what they spend on payroll taxes (Rhodium Group, 2013). The study further concluded that a 30 percent reduction in building energy consumption is both technically viable and economically attractive today; this opportunity equates to a 28 percent rate of return for business owners and a $65 billion-per-year savings to the overall U.S. economy. In addition to operational savings, building improvements can increase rents and resale values. Based on a 2013 study, the transaction prices of green buildings are about 13 percent higher on average, and Leadership in Energy and Environmental Design (LEED) registered buildings are associated with an almost 8 percent effective rent increment (Eichholtz, 2013).

Planet

The substantial impact of buildings on the natural environment is clear. The Intergovernmental Panel on Climate Change (IPCC, 2014) suggests that urban areas are responsible for up to 76 percent of global energy use and generate about three-quarters of carbon emissions. Within the U.S. alone, commercial buildings contribute 18 percent of overall carbon emissions (U.S. Energy Information Administration, 2011). The significance of this impact is underscored by the fact that the demand for energy in dense, urban environments and the accompanying carbon emissions, will only continue to increase in coming years.

The distribution of how the energy is used in these large cities is critical to understanding how the planet can benefit from intelligent buildings. Affluent, industrialized cities of the world use the most energy to heat and light residential and commercial buildings,

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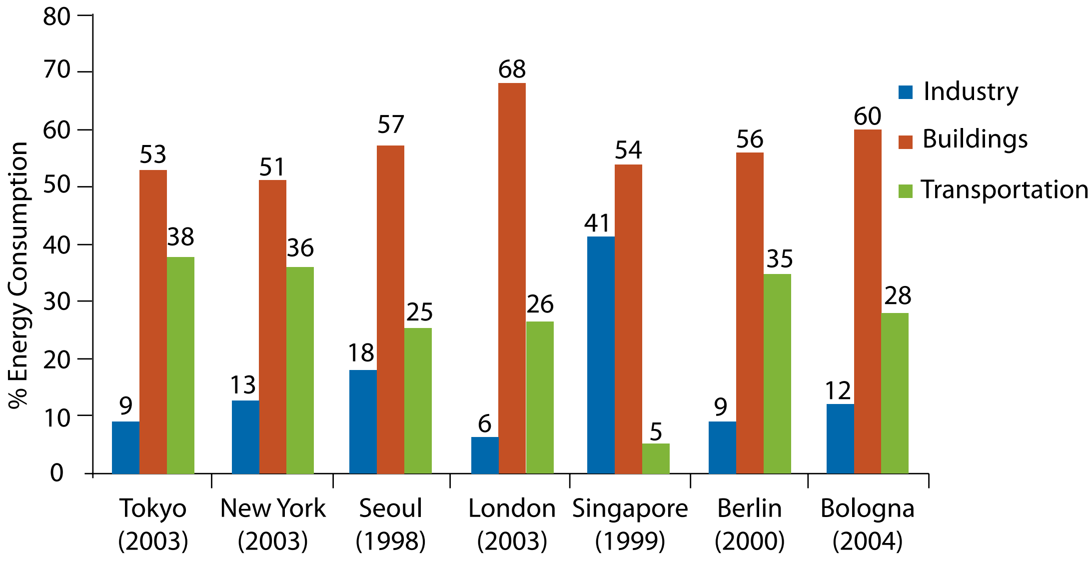


Graph 1: Energy consumption in select cities with high-income, industrialized economies. Source: UN-HABITAT Global Urban Observatory 2008. Note: Data from various sources, 1999–2004. Source: UTC Building & Industrial Systems

with transport and industry following as the second and third greatest energy consumers, as seen in Graph 1.

Clearly, buildings play a pivotal role in urban environments, and therefore offer a great opportunity to help reduce carbon emissions. The U.S. Green Building Council™ (USGBC) estimates that a green building, on average, can reduce energy use in buildings by 25–30 percent over the national average. To calculate this in more real terms, if applied in the United States, a 30 percent reduction in commercial building energy consumption would result in the elimination of 300 million metric tons of carbon dioxide emissions annually (5 percent of all U.S. emissions), equivalent to removing 63 million cars off the road for one year.

The impact of buildings and the benefits of intelligent and integrated systems is ever more important due to the rapid growth of urban centers. Various statistics from the United Nations' World Urbanization Prospects (United Nations, 2014) provide evidence for the rapid population growth in cities. Already, 54 percent of the world's 6.7 billion people are living in urban environments. By 2025, two-thirds of the world's population will live in cities. As people move to urban areas, the number of large cities is also growing exponentially. In 1990, there were 10 "megacities" with 10 million inhabitants or more. In 2014, there were 28 megacities worldwide. And, by 2030, the world is projected to have over 40 megacities. This growth has dramatic implications for buildings, which will need to support this population shift.

Why Now?

The intelligent building is not a new idea. The potential of intelligent buildings has been discussed for a few decades. So what has changed to make these solutions a reality today? In short, two factors: environmental awareness and ubiquitous, cost-effective technology. More companies are becoming aware of their energy, water and other natural resource consumption and its impact, and many are taking steps to address it. Over 60 percent of Fortune 100 companies have commitments for near-term (2015) results and 30 percent have identified goals for 2020 (Hardesty, 2012). As a long-standing Fortune 500 company, United Technologies Corp. (UTC) has set the standard for sustainable leadership, or what UTC calls "natural leadership." Since 2006, UTC has reduced greenhouse gas emissions by 30 percent and water consumption by 33. Moreover, UTC is a founding member of green building councils on five continents, and was the first company to join the USGBC in 1993. In addition to these ongoing sustainability efforts, regulatory changes are also driving awareness and transparency in commercial building energy consumption. Nine major U.S. cities (Austin, Boston, Chicago, Minneapolis, New York City, Philadelphia, San Francisco, Seattle and Washington, D.C.) have enacted policies requiring commercial buildings as small as 10,000 square feet to submit benchmarking data on energy use (Liaboe, 2014). Complementing the increased focus on the environmental impact of buildings, the information technology revolution now provides centralized access to data. When building sensors and connected devices are coupled with advanced data analytics and open protocols for communication, advanced solutions can be deployed in a cost-effective manner.

To truly understand how integrated and intelligent buildings can deliver bottom-line benefits, the remainder of this discussion will be comprised of real, relevant examples of these solutions in action across the globe.

Integrated Vertical Transport Solutions for Occupant Productivity

The safe and efficient movement of people in tall and megatall buildings presents numerous challenges. Peak loads, such as during the morning rush, tour groups and conference attendees, must be handled efficiently. At the same time, unauthorized access must be prevented to ensure the safety and protection of occupants and property. And, efficient and safe evacuation during emergency events is required. To meet these challenges, a building owner can integrate elevators with the access control system to ensure that tenants and visitors arrive at their correct destination quickly and safely. An early example of such an integration was performed at 7 World Trade Center, a 52-story, class A office tower, where the integration of the Otis elevator destination management system with the Lenel access control system and identity management database – two products of UTC Building & Industrial Systems, a unit of United Technologies – streamlined occupant ingress. When an individual swipes his or her credential in the lobby at an access-

Top: 7 World Trade Center, New York. Source: UTC Building & Industrial Systems

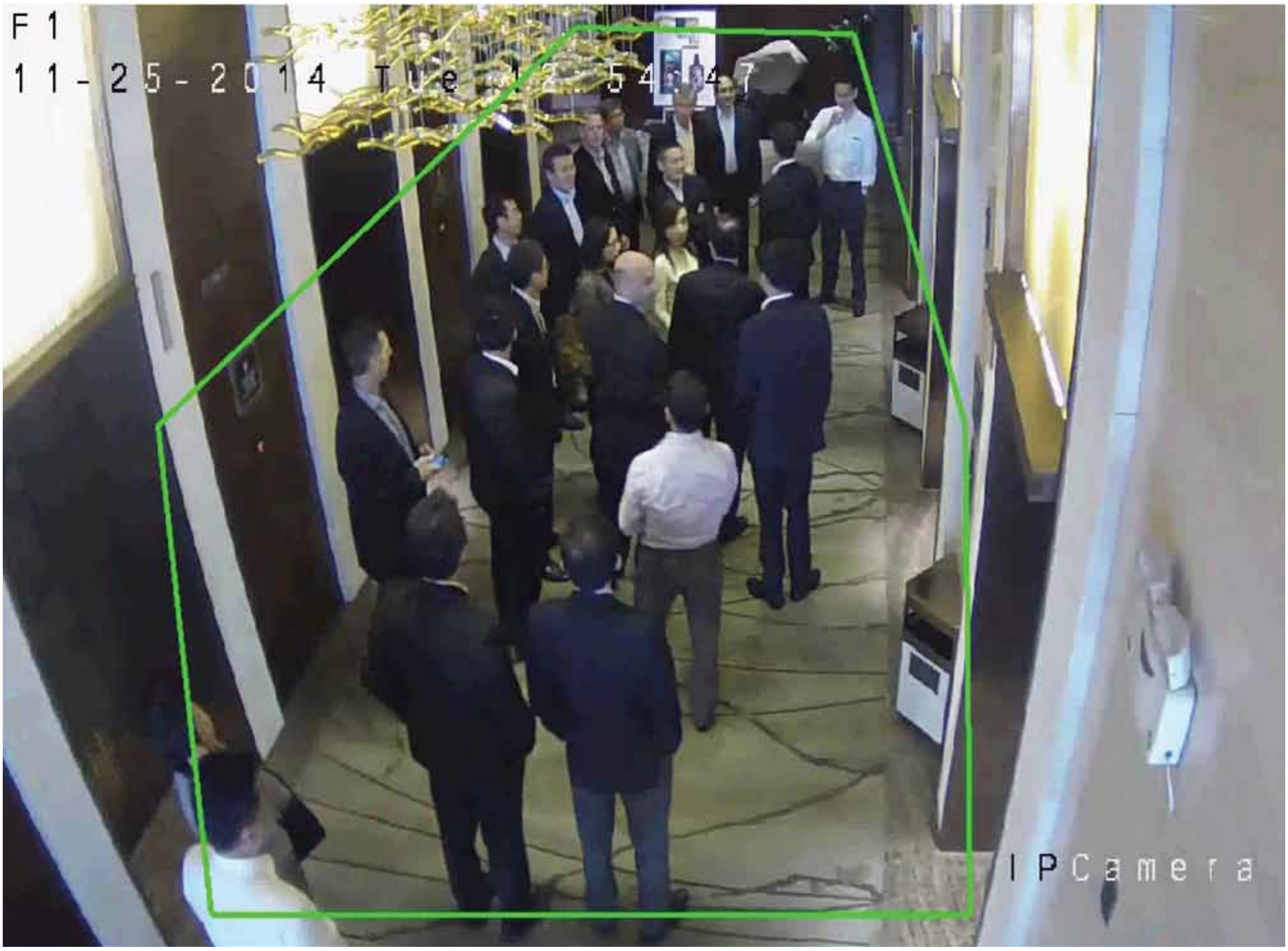
Left: Elevator bank of 7 World Trade Center. Source: UTC Building & Industrial Systems

Bottom: The Westin Pazhou hotel, Guangzhou, China.
Source: UTC Building & Industrial Systems

Opposite: Video-based crowd detection used to improve lobby elevator dispatch by calling more cabs as soon as assembling crowds are detected. Source: UTC Building & Industrial Systems

controlled turnstile, an elevator destination is assigned and communicates to the individual. The optimal elevator for each arriving person is determined and assigned based on a patented algorithm that takes into consideration the walk time between the access point and elevator cab. This results in minimal wait time at the elevator (on average less than 30 seconds) and minimal travel time (on average less than 90 seconds from arriving in front of the elevator to arrival at the correct destination floor). This system also enables any one of the 29 elevator cabs at 7 World Trade Center to be dedicated for VIP management groups. Such integrations have now evolved into seamless installations in urban buildings around the world.

In cases where large peak loads of people can occur within a building, such as conference centers and hotels, integration of the elevator system and video system can optimize people movement. The Westin Pazhou hotel is an excellent example. It is attached to the Guangzhou International Convention and Exhibition Center, which hosts the famous Canton Fair and numerous other major international events. Opened in 2011, the hotel has 325 guest rooms and suites, and a total floor area of 890,000 square feet (83,000 square meters). A large number of people stay at the hotel while attending events at the convention center, and the Westin faced the challenge of efficiently moving guests vertically during peak times while ensuring the operational and energy efficiency of the facility. To help the Westin Pazhou achieve these objectives, UTC Building & Industrial Systems strategically integrated technologies including Carrier (HVAC), Otis (vertical transportation), Interlogix (video), Chubb (security services) and Automated Logic (building automation). UTC-developed Interlogix video technologies were integrated with the Otis elevator platform as part of this pilot to estimate the density of people queuing for elevators. This helped to more efficiently and effectively move people throughout the building and addressed an opportunity for the Westin's

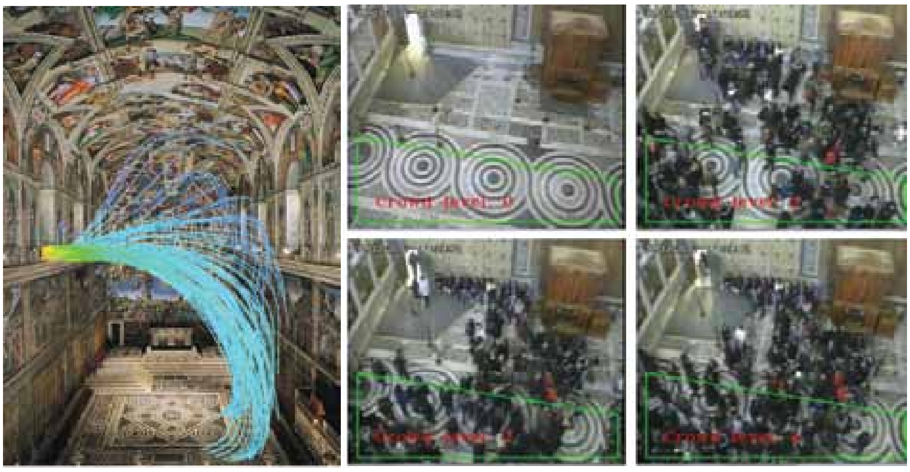


elevators to use technology to know whether the request was for a single person or a large group. With the implementation of video technology, crowds could now be detected as they assembled and extra elevator cabs could be dispatched. This integrated solution helped the hotel reduce elevator maximum waiting time for guests by up to 40 percent during peak periods over their baseline installation. Through these solutions, the hotel has been able to significantly improve the way it operates, and in turn improve the overall guest experience.

While the above solutions significantly impact the satisfaction and productivity of people within a building, in the future, intelligent vertical transport will also play an important role in ensuring safety during emergency evacuations. Surveys conducted by the Council on Tall Buildings and Urban Habitat, the Council for Research and Innovation in Building and Construction (CIB) and the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Oldfield, 2014) aimed to prioritize the research needs in tall buildings. The results helped identify that four of the five highest-priority research topics pertained to safety and security in tall buildings, especially fire scenarios. This included the need for research on the planning, design and implications of using elevators for evacuation in tall buildings. Some ways to address emergency needs include installing dynamic signage in buildings and transmitting notifications to handheld devices, which would help guide occupants. Also, video analytics can estimate elevator demand and detect if occupants are evacuating in the wrong direction. Through these types of efforts, simulations have shown elevators can be optimized not only to reduce evacuation times, but also to minimize the time occupants spend in at-risk portions of the building (Stranieri et al., 2014).

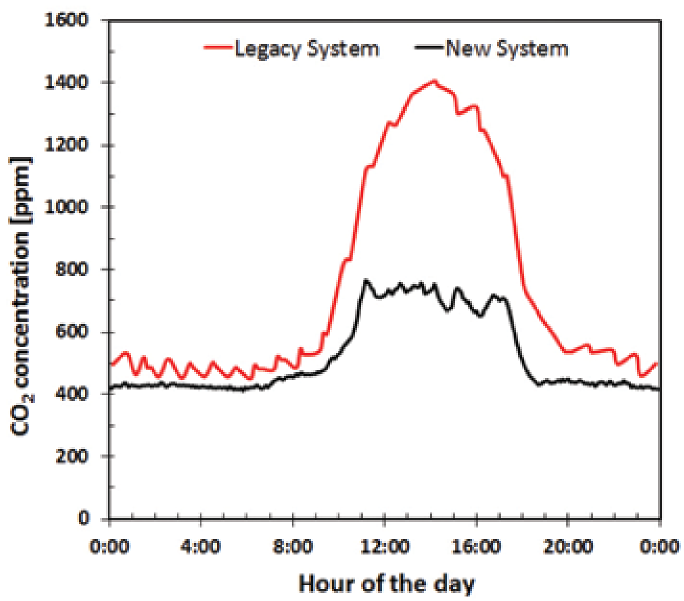
Intelligent Indoor Environmental Control for Crowded Urban Areas

Large and varying crowds in urban spaces can also present unique challenges in maintaining comfort and indoor air quality in a reliable and efficient manner. There may be no better example of this than the Sistine Chapel, located in Vatican City, where the management of large crowds is balanced with the safety and preservation of priceless cultural icons from the early 1500s. Over 5 million people visit the Sistine Chapel every year to view the frescos of Michelangelo. This can result in crowds of 2,000 people at a time within the chapel's 5,900-square-foot (550 square meters) space, or more than one visitor for every three square feet, creating large variations in humidity and carbon dioxide (over 2,000 ppm), and introducing dust and other pollutants. This can result in diminished occupant comfort and, more importantly, threaten attempts to preserve the art, exposing it to calcium bicarbonate (formed from carbon dioxide and moisture), mold and mildew, and thermally induced stresses from cyclic temperatures. Understanding that their original HVAC system was designed in 1990 for 700 occupants, the Sistine Chapel recently commissioned Carrier to design and implement an HVAC system to address the substantial increase in the number of visitors and the associated challenges by employing intelligent design and system integration (Grabon et al., 2015). Ensuring adequate airflow within the space was particularly challenging as the entire chapel is essentially covered in artwork and no new openings could be added. Computer simulations of the interior airflow ensured that more



Left: Advanced airflow modeling in the Sistine Chapel (left) and video detection of visitor levels for intelligent ventilation control (right). Source: UTC Building & Industrial Systems

Opposite: The Shanghai International Financial Center (IFC) reduced chilled water energy consumption by 27 percent, eliminating 11,200 tons of carbon per year. Source: UTC Building & Industrial Systems



Graph 2: Carbon dioxide levels in the Sistine Chapel are successfully kept to 800 ppm by the new advanced control system. Source: UTC Building & Industrial Systems

than 30,000 cubic feet per minute (which represented three times the original airflow) could be delivered to the space through the existing outlets, while maintaining both low air velocity around the fresco surfaces (to reduce erosion and the movement of dust) and low noise levels (equivalent to a whisper-quiet library).

Other improvements were needed to ensure the HVAC controls were more responsive and capable of maintaining carbon dioxide and humidity levels during dramatic increases in visitor numbers. Dynamic models of the chapel's HVAC system were developed to gain insight into how the indoor environment responded to changes in occupancy and outdoor conditions. Leveraging that data, new advanced control designs were then developed to maintain humidity and carbon dioxide levels, and actively respond to changes in load. In addition, the Automated Logic WebCTRL® building automation system integrated a video system to provide occupancy estimates. The use of video information, more commonly used in building security applications, enabled the HVAC system to track visitor levels in the chapel and enabled the anticipation and rapid response to the thermal, moisture and carbon dioxide loads. The intelligent system counts the number of visitors at any time in the chapel and automatically adjusts the ventilation.

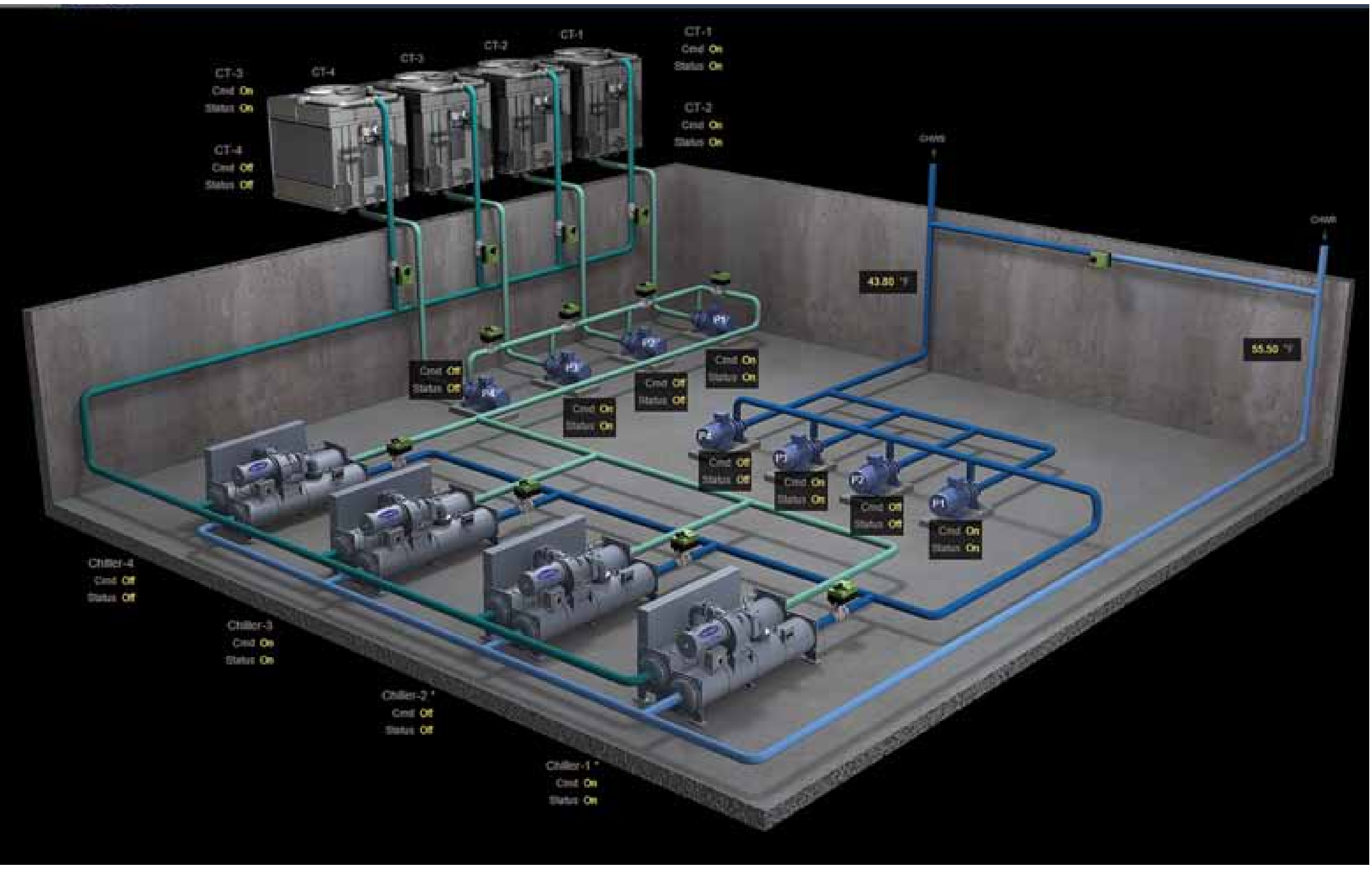
Since it began operating in October 2014, the new system has performed as designed and successfully addressed the indoor air quality concerns of the Sistine Chapel. Graph 2 shows the comparison of carbon dioxide concentrations within the chapel between the new and old systems during a day with 1,100 visitors. The system successfully adjusts the supply of fresh air based on the visitor levels from the video system to keep carbon dioxide levels below 800 ppm.

This integrated solution and the advanced tools used in the intelligent design help ensure the lasting preservation of the chapel's priceless artwork while facilitating the best possible visitor experience through improved air quality and reduced noise. As the integrated design and operation of such systems become more commonplace, intelligent solutions such as these will meet the growing need to address the comfort of large dynamic crowds in an efficient, reliable and safe manner.

Optimal Control of Building Systems

As buildings become larger and employ more complex systems, greater intelligence will be needed not only during design and installation, but also when controlling day-to-day operations. Focus has traditionally been placed on improving the efficiency of individual components. For example, HVAC equipment standards have focused on prescriptive standards of full-load metrics resulting in higher efficiency motors, fans and inverters. However, as HVAC technology matures, further improvements of the equipment itself become less cost effective. This is compounded by a push to new lower global-warming potential refrigerants that, in many cases, are not as energy efficient. Therefore, sustaining future improvements in building performance will be more dependent on achieving the optimal design and control of integrated systems. The benefits achieved by the retrofit of optimal chiller plant controls at the Shanghai International Financial Center (IFC) provide an excellent example of what is possible (Kuang et al., 2014).

“Some ways to address emergency needs include installing dynamic signage in buildings and transmitting notifications to handheld devices, which would help guide occupants. Also, video analytics can estimate elevator demand and detect if occupants are evacuating in the wrong direction.“



The Shanghai IFC, completed in 2010, is a LEED-Gold™ certified site that houses two approximately 250-meter tall Grade A towers, a hotel, shopping mall and residences. The 4.3 million square feet (400,000 square meters) of space is served by a central chiller plant that provides 20,000 tons of cooling. Prior to the controls retrofit the plant would typically consume 185,000 kilowatt-hours of electricity per day (equivalent to a daily cost of RMB 127,000 or US$20,000). A thorough, on-site investigation and review of the operating history identified a number of opportunities related to unoptimized system controls. Examples included an inefficient strategy for starting and stopping additional chillers and other equipment, continuously running the system with a constant, low-chilled water temperature set point irrespective of moderate building load or weather conditions, and no real-time monitoring of plant efficiency to measure performance. After identifying these issues, measures were enacted to address some of these inefficiencies. The chiller plant control system was upgraded to optimally coordinate the operation of the system equipment to safely and reliably minimize total energy consumption. After the retrofit, optimal chiller sequencing was implemented to ensure that the appropriate number of chillers was running based on building load and weather conditions. This can be particularly complex given the variation in chiller types, which included three, 1,000-ton, Carrier 19XR centrifugal chillers, and six 2,850-ton dual-compressor Carrier 19XRV centrifugal chillers operating in a series-counter-flow configuration. In addition to minimizing energy consumption, the sequencing scheme rotated the operation of the chillers to balance overall run time to maximize the longevity of the equipment, further reducing operating costs. In addition to the optimal chiller sequencing, a variety of optimal control algorithms for the peripheral equipment, such as chilled water pumps, cooling water pumps and cooling towers, have been implemented to improve the overall chiller plant system efficiency. Finally, a WebCTRL® energy monitoring system was installed, allowing real-time performance to be monitored and overall efficiency to be tracked.

Since implementation, the plant energy consumption has been reduced 27 percent, resulting in annual savings equivalent to RMB 10 million (approximately US$1.6 million) and the elimination of 11,200 tons of greenhouse gases.

When combined, the technologies discussed above can result in significant energy savings. For example, iSQUARE, an iconic 31-story shopping mall and office complex located at the heart of Tsim Sha Tsui, Kowloon in Hong Kong, was retrofitted with chillers, advanced video analytics for elevator dispatching and an intelligent building management system. These enhancements are projected to provide energy savings of up to 30 percent, a significant improvement for a building that first opened in 2009. For the Westin Pazhou hotel, advanced elevator dispatch combined with an Automated Logic central plant optimization system for the Carrier chillers could reduce the hotel's energy costs by a projected 20 percent. This could help put the hotel on track to meet its corporate sustainability goals.

These examples show the impact that intelligent operation through optimal control has on enterprise profit by reducing costs, and on the planet by reducing energy consumption and emissions. The

Opposite: Example of a chiller plant energy performance monitoring interface. Source: UTC Building & Industrial Systems

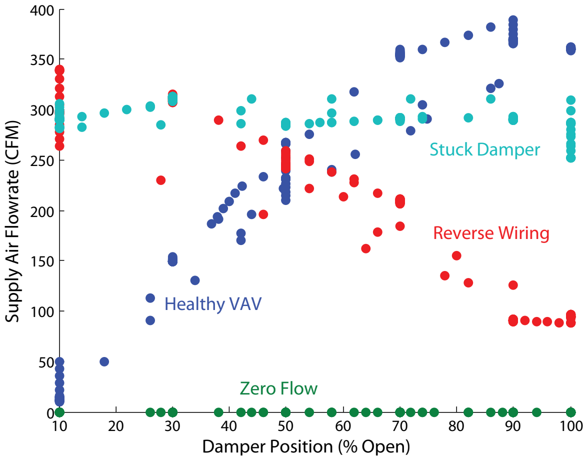
Right: UTC Building & Industrial Systems solutions are projected to provide energy savings of up to 30 percent for the iconic iSQUARE shopping mall and office complex in Hong Kong. Source: UTC Building & Industrial Systems

potential for additional savings in the future is even more encouraging. The ability to use intelligent systems to predict future building loads, which has been studied at the Shanghai IFC building (Kuang, 2014), is just one example. In the future, buildings will also play a significant and active role in the operation of the smart grid by managing energy loads to optimize the overall grid demand and enabling greater integration of renewable energy generation.

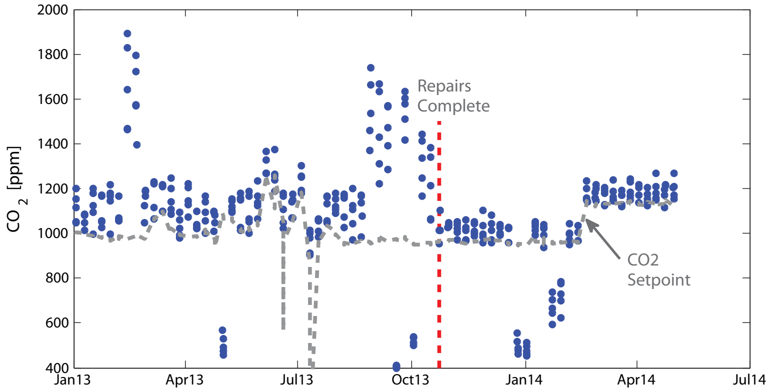
Intelligent Commissioning and Operation of Building Systems

While the intelligent and integrated solutions presented above offer substantial benefits for occupants, building operators and the environment, the complexity of these technologies, if not properly addressed, can present challenges during the installation and long-term operation and maintenance of these systems. Current research and demonstration of advanced analytics and diagnostics technologies will help address these challenges.

Incorrect installation and inadequate maintenance of existing building systems have large impacts on operating costs, energy consumption and occupant productivity. Research by Lawrence Berkeley National Laboratory has shown that proper commissioning of existing buildings can produce whole-building energy savings of 15 percent and payback periods of less than one year (Mills, 2004). However, the study cites that the "savings are also not permanent, and can erode as the building falls back into disrepair or otherwise 'out of tune.'" Lawrence Berkeley National Laboratory found that when recommissioning was combined with ongoing energy system monitoring (like the system in the Shanghai IFC building) for 24 California buildings, benefits ranged from 2 to 25 percent building-level energy savings with a mean energy cost savings of $0.25 per square foot per year (Mills & Mathew, 2009).



Graph 3: Healthy variable air volume (VAV) operation (navy blue), in comparison to a VAV that fails to communicate (green), is wired in reverse (red) or is stuck (light blue).
Source: UTC Building & Industrial Systems



Graph 4: Typical return-air carbon dioxide levels before and after the implementation of the diagnostics system.
Source: UTC Building & Industrial Systems

Demonstration of advanced building diagnostics by UTC Building & Industrial Systems has also shown that pre-existing and on-going faults can be prevalent even in modern buildings. In 2013, UTC Building & Industrial Systems implemented advanced building diagnostics in a 200,000 square foot office building with LEED-Platinum™ certification in India.

The advanced diagnostics allowed the performance of the HVAC equipment within the building to be monitored. Initial performance tests were conducted remotely with no personnel required on-site. In addition to other faults, these tests identified that more than 15 percent of the dampers controlling airflow in the building were non-operational. Typical faults included non-communicative dampers, stuck dampers and equipment wired in reverse, shown in Graph 3. Correcting these and other faults addressed excessive carbon dioxide levels (approximately 1,500 ppm) in parts of the building that have been shown to affect occupant health and productivity (by the studies referenced above).

During a six-month trial of the diagnostics system, it detected more than 45 additional equipment faults, including damper failures (stuck dampers and broken connecting rods), fan failures and communication failures. The immediate detection and correction of these faults minimizes occupant discomfort, reduces complaints due to poor temperature control and increases the productivity of the facility's staff, as less time is spent troubleshooting complaints and conducting routine inspections. The CO_2 benefits of these repairs are illustrated in Graph 4.

In Summary

The concept of integrated and intelligent buildings has evolved from a possibility to a reality. The intelligent design, operation and monitoring of advanced and integrated building systems is happening today in applications around the world, yielding proven benefits including operating cost savings, improved occupant productivity and security, and reduced energy consumption and emissions.

These solutions have been enabled not only by affordable and ubiquitous technology, such as advanced sensors, embedded controllers and hand-held devices, but also by advanced data analytics, simulation and design tools that determine how best to deploy and integrate these technologies in buildings. Solutions and methodologies aside, the most exciting facet of intelligent and integrated buildings may still be the possibilities that lie ahead. Looking to the future, the continued adoption of open protocols and standardized data semantics will support cost-effective deployment to wider segments of the building industry. These technology trends will continue to address ever more complex challenges, furthering the intelligence and integration in buildings. For example, to ensure safe egress from tall buildings, dynamic signage could work with video, access control and elevator systems to enact optimal evacuation strategies. Wireless sensing and hand-held and wearable devices could ensure personalized comfort is delivered to occupants based on their real-time location and physiological state. Finally, building systems could automatically collaborate with distributed renewable energy generation to flatten or reduce electrical load demand on the grid, offsetting power generation and transmission investment costs, further improving the effectiveness of the grid and reducing carbon emissions. While these highlight a few of the anticipated technological advances in intelligent building, there is truly no limit to what is possible. The necessity – and incentive – to reduce costs and minimize environmental impact will continue to drive the movement forward and bring big benefits to people, profits and the planet. The bottom line? The future of integrated, intelligent buildings has never looked brighter, to people, profits and the planet.

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