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Green, Clean, & Mean: Pushing the Energy Envelope in Tech Industry Buildings:

Permalink
https://escholarship.org/uc/item/50n5n7nj

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Publication Date
2015-05-01

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

Green, Clean, & Mean: Pushing the Energy Envelope in Tech Industry Buildings

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Environmental Technologies Area

May, 2015

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Executive Summary

"We don't want to debate climate change. We want to stop it."

- Apple (2015)

"Every year we strive to outdo ourselves in operating sustainably."

- Adobe (2013)

"We leverage our unique assets and role in the global marketplace to influence Earth-positive impacts along the commerce value chain."

- EBay (2015)

Context and project goals

When it comes to innovation in energy and building performance, one can expect leading-edge activity from the technology sector. As front-line innovators in design, materials science, and information management, developing and operating high-performance buildings is a natural extension of their core business.

The energy choices made by technology companies have broad importance given their influence on society at large as well as the extent of their own energy footprint. Microsoft, for example, has approximately 250 facilities around the world (30 million square feet of floor area), with significant aggregate energy use of approximately 4 million kilowatt-hours per day (Figure 1).

***Figure 1.** Microsoft's global energy footprint.*

There is a degree of existing documentation of efforts to design, build, and operate facilities in the technology sector. However, the material is fragmented and typically looks only at a single company, or discrete projects within a company. Corporate social responsibility reports provide a useful overview of goals and initiatives. Databases of LEED and Energy Star buildings provide insight into the outcomes for individual buildings. Various news and trade press reports occasionally fill in missing details. Yet, there is no single resource for corporate planners and decision makers that takes stock of the opportunities and documents sector-specific case studies in a structured manner. This report seeks to fill that gap, doing so through a combination of generalized technology assessments ("Key Strategies") and case studies ("Flagship Projects").

The technology sector is making up for lost time when it comes to high-performance buildings and infrastructure

According to industry observers and the companies' own statements, many tech firms are only recently hitting their stride when it comes to managing energy use and carbon emissions. This may in part be a reflection of the industry's posture towards facility design and master-planning more generally. According to David Radcliffe, Google's VP of real estate development: "Tech really hasn't adopted a particular language for buildings. I mean, we've just found old buildings, and we've moved into them, and made do best we could."
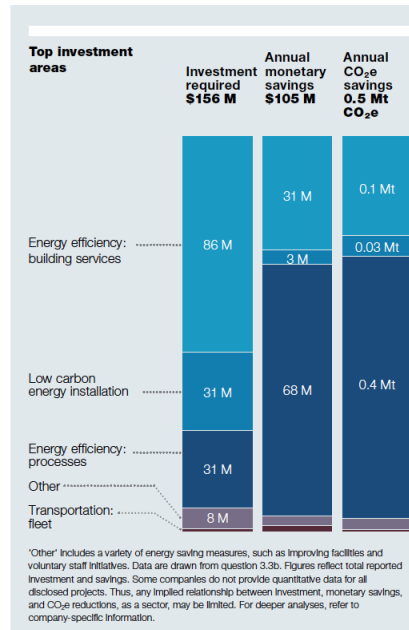
Top investment areas

	Investment required $156 M	Annual monetary savings $105 M	Annual CO_2e savings 0.5 Mt CO_2e
		31 M	0.1 Mt
Energy efficiency: building services	86 M	3 M	0.03 Mt
Low carbon energy installation	31 M	68 M	0.4 Mt
Energy efficiency: processes	31 M		
Other			
Transportation: fleet	8 M		

'Other' includes a variety of energy saving measures, such as improving facilities and voluntary staff initiatives. Data are drawn from question 3.3b. Figures reflect total reported investment and savings. Some companies do not provide quantitative data for all disclosed projects. Thus, any implied relationship between investment, monetary savings, and CO_2e reductions, as a sector, may be limited. For deeper analyses, refer to company-specific information.

Figure 2. Energy efficiency gains captured within the Information Technology sector by the 30 leadingCDP responders. "Energy efficiency processes" are assumed to be primarily data centers.

The primary source of information on the industry's progress is through voluntary information-gathering initiatives such as the Carbon Disclosure Project, CDP. Historically, the information technology sector had lagged most others in terms of emissions reductions, progress towards targets, and related disclosures (PwC 2011).

While data centers readily come to mind as the driving force behind the technology sector's carbon footprint, reports from the leaders in this space suggest that about one quarter of potential savings and one-third of energy cost savings are found not in servers but in buildings (Figure 2). Microsoft reports that nearly 40% of its entire corporate carbon footprint (including business travel) is attributed to its buildings (Accenture 2011). In contrast, Facebook reports that 96% of its energy use is in data centers. Ebay estimates that about 26% of its carbon footprint is attributable to its office buildings, and 50% to its data centers, and 16% to warehouses.

While not always first-movers, tech companies have engaged in significant efforts to manage energy use in their buildings. For example, building on efforts begun in 2006, 70% of Adobe's floorspace has been LEED certified.
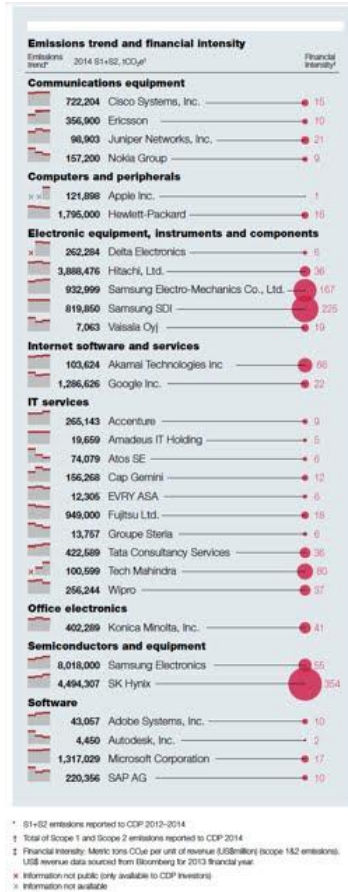
Figure 3. *Excerpt from Carbon Disclosure Project listing 30 companies comprising the "Climate Performance Leadership Index" within the IT sector.*

Information Technology sector by the 30 leading CDP responders. "Energy efficiency processes" are assumed to be primarily data centers.

Carbon-neutrality has also become a widespread goal in the technology sector. While companies have made significant strides by reducing energy use, they have also in many cases made up the difference by purchasing third-party carbon offsets. Tech companies such as Adobe and Google have fully offset all emissions by combining on- and off-site approaches; Apple is close behind already having done so in its US operations. Many of the companies have pursued a broader array of sustainability objectives (water, materials, waste, etc.), including focus on supply chains "upstream" from their customer-facing operations.

Pulse of the Industry: Evidence from Carbon Disclosure Project Reporting

The global Carbon Disclosure Project (CDP) deploys an annual survey to over 5000 of the world's largest companies on behalf of approximately 767 institutional investors (asset managers, asset owners, banks, insurers, and others) representing $90 trillion under management as of 2014, or one-third of the world's invested capital. This voluntary survey seeks information on respondents' perceived risks and opportunities associated with climate change, energy use and

carbon footprint, and investments and progress in reducing emissions. The results are compiled, analyzed, and communicated to the marketplace.

Approximately 40% of companies opted to respond to the latest survey (2014). Facebook is the only company among our case studies that receives invitations but has not as of the latest CDP cycle responded.

The CDP's "Climate Performance Leadership Index" (CPLI) represents the extent of corporate awareness of the issues, efficacy of efforts manage climate risks and opportunities, and progress towards targets (CDP 2015). The latest CPLI includes four of the eight companies for which we have developed case studies--Adobe, Apple, Google, and Microsoft (and Infosys was on the 2013 list).

Figure 3 shows the 30 highest-rating IT industry respondents to the CDP. The index represents the extent of corporate awareness of the issues, efficacy of efforts manage climate risks and opportunities, and progress towards targets. Across all sectors, approximately 10% of responding companies attain inclusion in the index (the value for the technology sector is not known).

Corporate campuses are integral elements of broader urban systems

Technology company facilities are tightly connected with the surrounding urban infrastructure. However, facility developers and operators have historically tended to focus more inwards than outwards, making only limited efforts to optimize the broader connections. This dynamic is rapidly changing.

The scale of some of the technology industry's projects creates a potentially constructive tension regarding the owner's needs and its relationship to the broader urban system in which its operations are nested. In perhaps the most prominent example of this, Apple is investing in community-scale energy as well as recycled water infrastructure (Love 2015) to help run their proposed expanded facilities by contributing to upstream capital projects that serve the larger community. Apple and First Solar announced in early 2015 that they are paying $848 million for 25 years of the output of a 130 MW block of First Solar's California Flats project in Southeast Monterey County. In the same vein, Google has invested $1.8 billion to date in solar and wind energy infrastructure projects. Many corporate campuses are seeking to reduce the overall building footprint while increasing vegetated and porous surfaces while better managing runoff. In its Hyderabad campus, Infosys states that such efforts have actually helped to raise the underlying water table.

In another example of community-scale considerations, at Ebay's Draper UT Customer Service Center LED parking lighting was used with peer-to-peer controls, reducing light pollution and meeting Dark-Sky Society standards for light pollution.

Key strategies can be implemented at all scales

There are a wide array of key strategies for achieving increased building performance. At the highest level these break down into the broad domains of energy demand, energy supply, and indoor environment. Once energy efficiency is maximized, renewable energy resources can then

be cost-effectively marshaled to serve the remaining energy needs. Supply and demand necessarily interact, not only with respect to the provision of on-site heat and power, but also in the ability of buildings to communicate and interact with the electric grid in which they are nested. Indoor environment is a cross-cutting consideration, and one that is closely tied with tech companies' goals for creating desirable work environments to help attract and retain talent.

We identify twelve broad areas of focus (Table 1) including discrete demand-side technologies, integrated systems (assemblages of technologies and their controls) at the individual building level, and multi-building or campus-level perspective where resources are shared or otherwise interact. Within these areas, we have delineated 61 established best practices and 70 emerging opportunities. Key attributes for many of these are delineated in Table 2. These attributes include market readiness, ROI, energy savings potential, water savings, acoustics, maintenance implications, influence on quality of indoor environment, and institutional considerations.

Flagship projects demonstrate key strategies in practice

To complement the wide-ranging "generic" discussion of best practices and emerging technologies that are raising the bar, we have assembled real-world profiles of eight leading technology companies. These begin with brief overviews of enterprise-wide goals and initiatives, and then focus on a single "Flagship Project" to illustrate specific implementations of key strategies.

These companies represent a combined workforce of about 400,000 people, 860 locations, and over 50 million square feet of floorspace. The specific flagship projects we have described represent 36 buildings and 9 million square feet of floor area. The profiled companies and the highlighted Flagship Projects are shown in Figure 4. Table 3 summarizes and provides a side-by-side comparison.

Figure 4. Flagship projects, interactive map here.

The flagship case studies vary in nature. Some (Apple, Ebay, Genentech, and Infosys) are new construction, while others (Adobe, Facebook, and Google) are retrofit. The Genentech new-construction case delves into the underlying design process, illustrating how setting specific performance goals helped to steer an iterative design process driven very strongly by a desire to maximize energy performance and workplace environmental quality, informed by the latest energy research and testing facilities and verifying predicted performance with measured data. In some cases (particularly Ebay and Google), relatively little information was available in the public domain. The Apple case illustrates how the development of particularly large projects has compelled the developer to partner with other entities to increase "upstream" water and energy resources, in this case recycled water infrastructure and central PV power stations. Infosys is the only case that provides publicly available post-occupancy evaluation, and the results showed significantly higher occupant comfort and satisfaction with the greener building than with an otherwise identical comparison building.

While these companies also own and operate data centers and manufacturing facilities, the focus here is on corporate spaces. We also note examples of how the companies have made efforts to improve the efficiency of water use and to provide more environmentally friendly transportation options for employees.

One somewhat surprising observation is that the companies have made only modest efforts to have their buildings formally rated. Apple has not obtained Energy Star ratings for any of their buildings (per the official database). While all have some LEED-rated buildings it is a small

number in most cases and only one of the selected flagship projects is LEED-rated. There is also little evidence of systematic in-house benchmarking practices.

These projects achieved very significant resource reduction goals. Energy use was reduced from 30% to 44%, and water was reduced by 50% to 76%. Most aspired to achieve zero net carbon emissions through a combination of on-site efficiencies and renewables and the purchase of off-site clean power or carbon credits. No doubt reflective of the view of many companies, Google has clearly stated that one of the prime drivers of its aggressive push towards renewables is the hedging value offered against future fossil-fuel price spikes.

Institutional Considerations: Buildings are places where people work and innovate

While manufacturing and data-processing facilities may represent the majority of a tech company's total energy footprint, the driving innovations and productivity trace to the people who occupy the built environment.

Technology companies see these as important factors in attracting and retaining a talented, motivated workforce. With this in mind, technology companies are paying close attention to indoor environmental considerations in their facilities. Our analysis finds that high-performance buildings can yield two-fold benefits in terms of energy and operating cost savings as well as improved occupant satisfaction. A concrete example includes improved occupant comfort in radiantly-cooled spaces (Infosys) and ability to avoid costs and business disruptions by proactively addressing risks associated with poorly commissioned control systems.

Building occupants and managers must be motivated to help achieve sustainability goals. It is notable that some technology companies--Infosys among our case study examples--actually link renumeration to measured progress towards sustainability performance.

A key institutional innovation strategy is that the performance of each new building should be a significant improvement on that of its immediate predecessor - a process of learning from each new building. Only Infosys seems to have formalized this practice.

Green, Clean, and Mean – Stretch Goals for the Future

The technology industry has broadly demonstrated an ability to mobilize existing technology to achieve net-zero large energy facilities and campuses. The partial reliance on purchasing carbon credits is diminishing as more aggressive levels of energy efficiency are obtained and larger dedicated renewable systems are implemented. A new generation of emerging energy-efficiency strategies—at the level of individual buildings as well as campus scales—presents another level of savings potential.

Not all challenges are technological. For example, Adobe, Ebay, and Facebook are among the few tech companies participating in a new 25-company initiative championed by the World Wildlife Fund and World Resources Institute to promote Corporate Renewable Energy Buyer's Principles, setting aggressive renewable energy goals, addressing barriers, and collaborating to drive change in policy.

While this report represents the most exhaustive effort to date to compile the experience and remaining opportunities for buildings in the technology sector, much information remains outside the public domain. LEED scorecards hold some of the more detailed information we could locate, but this is relatively high-level, with the underlying reports remaining proprietary. A strong movement among technology companies to track and publicly disclose the energy intensities of data centers (see opencompute.org) has not yet been matched by similar efforts focused on office environments. More effort in this regard can be expected, compelled in part due to local and regional disclosure ordinances, as well as the increasing trend towards corporate social responsibility reporting.

The performance and well being of building occupants is recognized to be a prime driver for seeking high-performance buildings. However, we have found little rigorous evaluation of these desired outcomes. Better data acquisition and evaluation based on measurable metrics, coupled with increasing awareness of the linkages between building performance and occupant performance are likely to spur renewed efforts in this area.

The mobilization of more and better information will also be facilitated by steadily improvements in data-acquisition and analysis platforms (Accenture 2011), and more sophistication in terms of bringing a risk-management perspective to the energy management process in order to ensure performance and persistence of energy savings, in tandem with work environment that is maximally conducive to productivity and innovation.

ACKNOWLEDGMENTS & DISCLAIMERS

A Discrete Technologies

1 HVAC
By Philip Haves

Applications

The main areas of opportunity to improve the performance of heating, ventilating and air-conditioning systems are alternative methods of cooling of occupied spaces, and central plant design. Alternatives to the conventional method of cooling spaces using overhead mixing ventilation involve use of hydronic systems, including radiant systems, natural ventilation, and exploitation of temperature and contaminant stratification using underfloor air distribution or displacement ventilation. Choices in central plant design include energy source - fuel vs. electricity, with its implications for carbon emissions now and in the future - and the use of thermal storage to shift electric load to off-peak periods or to match heating and cooling loads in time, particularly in milder climates, to enable use of heat recovery chillers. Related topics are covered under the sections on District-level Energy Services, Waste Heat Recovery, HVAC Controls, Commissioning, and Envelope and Lighting.

Radiant slab heating and cooling is a strong candidate to be considered best practice in new construction for larger buildings or campuses, particularly in climates with little or no latent load, including the western part of the US. In a side-by-side comparison in a large office building in Hyderabad, India, which has a summer climate similar to that of Fresno, CA, radiant slab cooling used 1/3rd less HVAC energy than a conventional variable-air-volume (VAV) system (see Infosys flagship project) (Sastry and Rumsey 2014). The top surface of the slab is exposed to conditioned space above or the bottom side is exposed to the space below, or both. Typically construction is cross-linked polyethylene (PEX) tubing placed in the structural slab or a topping slab before concrete is poured, as illustrated in Figure 1. Because of the large surface area of the slab, the chilled water supply temperature is relatively high (~65°F), allowing good use of water-side free cooling. Similarly, the hot water supply temperature is relatively low (~80°F), allowing the use of low grade waste heat. The slab smooths and shifts load but is, consequently, more difficult to control and size than radiant panels or air systems. Ventilation can be provided by a dedicated outdoor air system (DOAS) in which outside air is tempered and/or dehumidified, as required using an air handling unit designed for the purpose. Ceiling fans can be used as necessary to extend the ASHRAE comfort zone and enhance convective transfer from the slab. There are number of examples of radiant-slab buildings, in locations ranging from Cupertino (Roberts and Nqvi 2010) and Palo Alto (Center for Global Ecology n/d) to Hyderabad (Sastry and Rumsey 2014).

Figure 1. *Radiant slab tubing, prior to concrete being poured (Photo courtesy of Infosys Limited)*

Radiant cooling and heating can also be implemented using light-weight panels, typically mounted at ceiling height. It is much easier to retrofit radiant panels than a radiant slab, although they lack the thermal storage capability of slabs and hence cannot be used to shift and smooth load without some other form of thermal storage, e.g., chilled and/or hot water tanks.

Air systems that exploit vertical stratification in occupied spaces, such as underfloor air distribution (UFAD) systems and displacement ventilation (DV) systems can also use less HVAC energy than VAV or other systems that are designed to mix the air in the space. DV systems introduce the supply air at very low speed. The air is then entrained into buoyant plumes, which are exhausted near the ceiling as shown in Figure 2. UFAD systems introduce air into the space through swirl diffusers that induce a modest amount of mixing near the floor. Savings arise in two ways: (i) the supply air temperature is higher (~68°F for DV and ~64°F for UFAD, compared to 55-60°F for VAV or other mixing systems), allowing greater use of air side free cooling and correspondingly less chiller use, and (ii) the fan power requirement is reduced because the air is supplied at lower speed. The effect of the plumes is to remove contaminants as well as heat from the occupied part of the space, improving air quality. However, both systems have their challenges. Displacement ventilation systems can be difficult to set up correctly in normal height spaces, although they work reliably in higher spaces, such as auditoria, airports and industrial buildings. UFAD systems use the voids below raised floors as pressurized supply plena and careful construction is required to ensure that they do not leak. Free cooling can be increased by using indirect evaporative cooling in air handling units and roof-top package units, at the cost of greater pressure drop and, hence, increased fan power. Simulation-based analyses are required to identify the lowest energy solutions for a given cost, aggregated over a typical year.
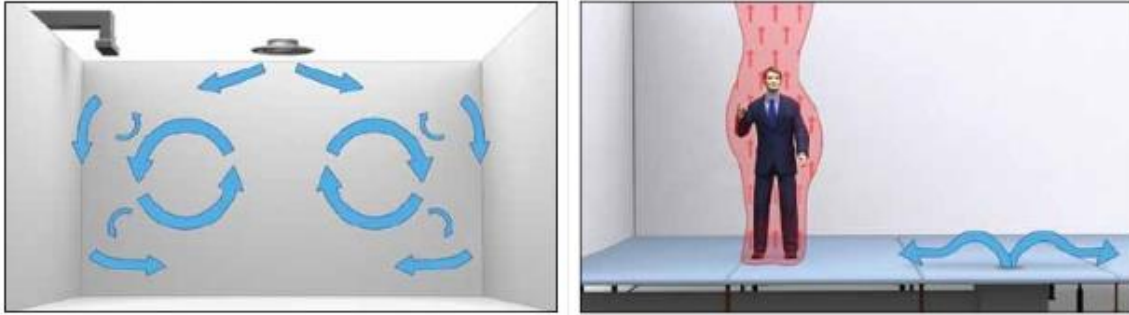
Figure 2. Mixing ventilation (left), displacement ventilation (right) (Images courtesy of Price Industries)

Further energy consumption reductions can be obtained through the use of chillers with magnetic bearings, which have significantly higher efficiencies than conventional chillers, particularly at lower part loads (these were applied by the Infosys flagship project). A Navy study found savings in chiller plant efficiency of 40 to 50% (Naval Facilities Engineering Command 2012). Chillers whose performance is optimized for low lift, i.e., relatively small difference between the temperature at which heat is removed and the temperature at which that heat is rejected to the environment, are starting to emerge onto the market. Such chillers would be well matched to applications, such as radiant cooling, that require relatively high chilled water temperatures.

Depending on the level of internal heat gains, it may be possible to achieve comfort using natural ventilation, with air flowing in through operable windows or other openings and exhausted through other windows or openings in occupied spaces or at the top of an atrium or draft tower. Simple methods for assessing the viability of natural ventilation for different building types in different climates are described by McConahey (2008). Flow can be driven by wind or by buoyancy ("stack effect"). In general, natural ventilation using operable windows requires a shallow floor plan. One additional advantage of a shallow floor plan is the increased opportunity for daylighting and corresponding reductions in energy use for artificial lighting. In 'cross-flow' ventilation, air may flow through multiple spaces between entering and exiting at different sides of the building. In single sided-flow, air enters and exits through openings in the same facade, typically in the same space. Flow can be wind or stack driven - usually flow rates are lower than under cross flow ventilation but easier to implement in terms of space planning, particularly for existing buildings. A further advantage of natural ventilation using operable windows is that thermal comfort can be based on the empirically derived Adaptive Comfort extension to the ASHRAE comfort standard (ANSI/ASHRAE 2013), in which the range of acceptable indoor temperatures is related to a recent average of the mean daily outside temperature. One explanation for this relationship is that occupants modify their clothing level based on recent weather.

'Mixed mode,' or 'hybrid' systems combine natural ventilation and mechanical cooling, using natural ventilation when and where possible and mechanical cooling when and where necessary (Center for the Built Environment 2015). A particular synergy is possible when the mechanical cooling is provided by a radiant system (Roberts and Nqvi 2010; Center for Global Ecology n/d). Since the design provides for outside air distribution that is adequate to provide the required sensible cooling under mild weather conditions, natural ventilation should be more than adequate to meet fresh air requirements when the sensible load is met by the radiant system. Such designs avoid the various costs (and space requirements) associated with the provision of a duct system as

long as the outside air is never so hot that it cannot be sufficiently tempered by contact with interior surfaces or mixing with the air in the space.

There is not a complete consensus that hydronic systems are superior in performance and cost to conventional variable-air-volume (VAV) systems (Stein and Taylor 2013), though here the comparison is with active chilled beams rather than radiant slabs. Careful design of VAV systems can enable zone air flow rates to be turned down by as much as 10:1, significantly reducing the reheat required when there is substantial diversity in zone loads. There is a trade-off between increasing the depth of the coils to increase the difference between the supply and return water temperature; this increases chiller COP and reduces pumping costs but increases air pressure drop and hence fan energy use. As with radiant slabs, though to a lesser extent, increasing the coil depth allows higher chilled water supply temperatures, increasing the opportunities for water-side free cooling, and allowing lower hot water supply temperatures, increasing the opportunities to make use of waste heat.

The solutions discussed so far all assume 'built-up' mechanical systems based on chilled water and hot water from a central plant or boilers and chillers in each building or groups of buildings. An alternative approach is to use packaged units with direct expansion (DX) cooling, typically installed on the roof. Roof-top package units are effectively restricted to low-rise buildings and cannot make use of chilled or hot water thermal storage, though they do not incur the pumping and thermal losses associated with district heating and cooling systems, in particular.

All the technologies discussed above, with the exception of DV, are well established and are starting to be accepted as best practices for commercial new construction, at least in the Western US.

Economics

Infosys Limited has performed a study of the construction costs and operating costs for radiant slab and VAV systems in two identical halves of a building in Hyderabad, India (Sastry and Rumsey 2014). The construction cost for the radiant slab system was slightly lower and the operating cost was consistently ~34% lower over a period of several years. The economics of natural ventilation vary significantly. The most favorable case is new construction where the use of natural ventilation can avoid the need for mechanical cooling. In retrofit, replacement of fixed windows with operable windows is typically not cost effective unless the windows need to be replaced for other reasons. Mixed-mode systems may not be cost effective unless the use of natural ventilation allows the mechanical system to be downsized significantly. A more favorable case would be the combination of radiant cooling and natural ventilation if the natural ventilation system can obviate the need for a mechanical ventilation system.

As regards magnetic bearing chillers, a study by the US Navy indicated payback periods ~1 year, depending on the utility rate and the hours of use (Naval Facilities Engineering Command 2012). Maintenance costs are substantially reduced because of the lack of need for lubricating oil and the reduced weight of the compressor.

Other considerations

Hydronic systems typically have lower fan noise due to the lower air flow rate in the DOAS compared to conventional systems. However, systems with exposed ceiling slabs require careful incorporation of measures to reduce sound generated in the occupied space. Noise problems are a major source of complaints in many commercial buildings (Jensen and Arens 2005).

Institutional requirements & capacity

Because they incorporate thermal storage, radiant slab systems are more difficult to size, control and operate and so care is required to select mechanical designers and controls contractors that have previous experience with successful radiant slab systems. Special training for operators is even more important, to ensure that they understand how such systems operate, in particular, the long response times and how to deal with them.

2 Electronics and Networks
By Bruce Nordman, Evan Mills, and Jessica Granderson

High-tech companies are defined by the intellectual output their employees create with their IT devices and other electronics. These include computers, displays, network hardware, small power supplies, imaging devices vending and beverage machines, among others. New ways are emerging to control, monitor, and power devices.

Depending on the definition, these loads account for on the order of 20% of total energy use in commercial buildings. The range of typical to best practice diversified power density ranges from 2 to 0.25 W/ft2 at peak, contributing on average about 0.75 kWh/ft2-y to overall building energy use (Wilkins and Hosni 2011). The presence of even small server rooms significantly increases these values. Because of the speed of technology development in this area, capabilities can transition from speculative to widely available in just a few years, introducing a fundamentally different set of opportunities and challenges. Because network-based technologies derive much of their value from computation and communication, many capabilities can be added or upgraded in the field via software updates. The ability to communicate through open and standard protocols is an essential foundation.

Applications

Many companies have policies to purchase only ENERGY STAR(R) compliant products. This is a needed foundation, but must be accompanied by processes to ensure compliance, address product types not addressed by Energy Star, and be attentive to product-specific opportunities to go beyond this relatively modest "top-25%" threshold, to procure best-in-class products and components (e.g., using the Top-10 system depicted in Figure 1). Attention should also be paid to products with low standby power requirements. In some cases, timers can be deployed to ensure no after-hours and weekend operations.
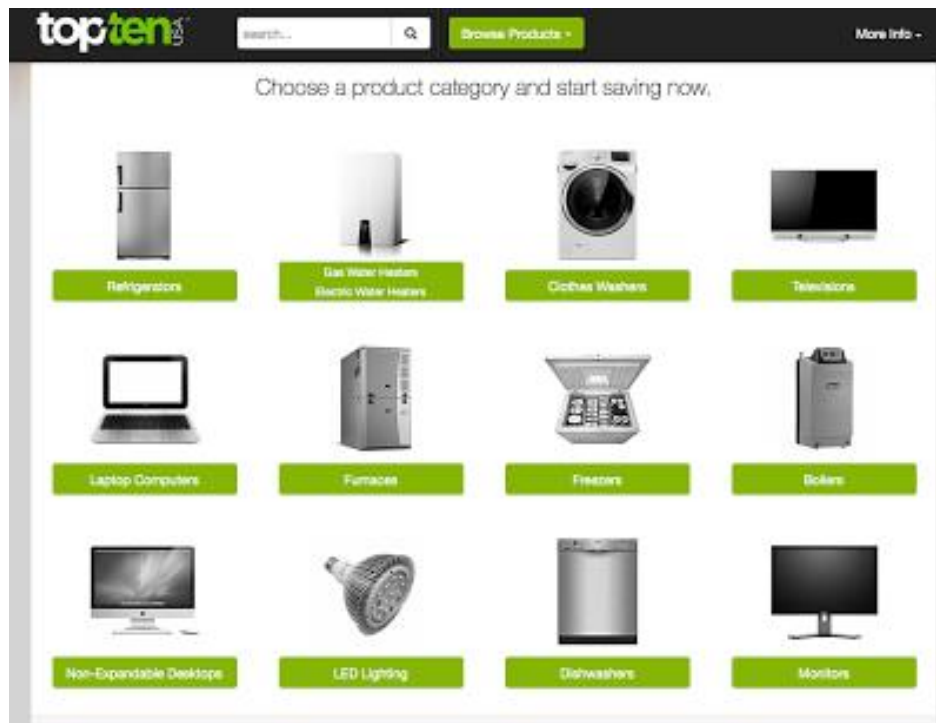
Figure 1. Top-ten identifies products at the very high end of the efficiency spectrum (http://www.toptenusa.org).

Electronics and other miscellaneous loads of course have direct impacts on space-conditioning energy, and thus understanding and managing them is important at the building level. Maximizing efficiency as well as diversity are additional important determinants of design loads. Rules of thumb tend to over-estimate demand (historically 3 to 5 W/ft2 in many cases) and lead to HVAC over-sizing and consequent excess capital and operating costs.

As electronics' energy use is a product of both power levels and operating patterns, assuring optimal device operation is a critical strategy. In many buildings, most energy used by PCs, for example, occurs when no one is present or when the user is not performing computational tasks. While many devices have the ability to power down--from electronics that can go to sleep, to coffee machines that can turn themselves off, to dimming of computer displays, to vending or beverage coolers that can turn off lights when not needed --these abilities are often crudely configured or disabled entirely. Food- and beverage-related devices can be particularly energy-intensive and so should be a target for savings. The IT network is a potential, already existing mechanism to make visible such problems, distribute better operational policies, and track their results.

Advanced power strips are a technology that has been successfully applied to manage the energy use of electric plug loads in commercial buildings. Three modes of control are offered, alone or in combination: schedule-based timers, load sensing, and occupancy/vacancy sensing. Many offerings exist on the commercial market. In addition to power strip controls, these loads can be reduced through explicit target setting, workplace policies, and design choices in new construction projects (Lobato et al, 2011): computer monitors can be specified to use LED backlit

LCD monitors can be used instead of fluorescent backlight or CRT monitors; personal copiers, printers and fax machines can be centralized into common multi-user stations; laptop computers can be used instead of desktops, for employees who do not need maximum computational power; the number of break rooms and kitchens can be optimized to serve maximum numbers of employees, reducing unneeded redundancy in appliances; elevators can be equipped with occupancy-controlled high-efficiency lighting and fans, and in some building designs hydraulic models can be replaced by regenerative traction models.

An emerging feature of networked devices is their ability to track their own energy use and report it to the local network (Nordman 2014). This is called "Energy Reporting" and can be used to understand and track energy use and key performance indices. Energy Reporting has been available for many years in some data center and telecommunications equipment, since these are critical services and highly managed. Standards are emerging, for example ANSI CEA 2047 defines Energy Reporting for appliances or any other device that chooses to use it. Electronic devices can use existing network interfaces to report energy data. While some devices may include hardware to measure power levels directly, many can reliably estimate their consumption. Building owners will be increasingly able to track energy use of each device in a building with as fine a time resolution as desired. The market is also seeing the emergence of integrated monitoring and control solutions; two examples are Budderfly (which includes lighting and thermostats) and Enmetric. An illustrative example of monitoring and reporting offered in the Enmetric platform is shown in Figure 2.

In addition to providing energy use data, this capability also automatically provides a detailed and dynamically updated inventory of the devices in buildings, and can show their operating pattern over the course of a day, week, or year (Nordman et al., 2014). This can reveal the existence of savings opportunities, provide quantitative evidence of how much potential savings is at stake, and show the presence of energy-using devices that are no longer needed. This new information can enable more energy saving measures to be implemented, and more rapidly than would otherwise be the case. Energy use data reporting can be aggregated across an entire campus, for greater visibility, while maintaining desired detail such as disaggregation by device type, time of day/week, or business function.

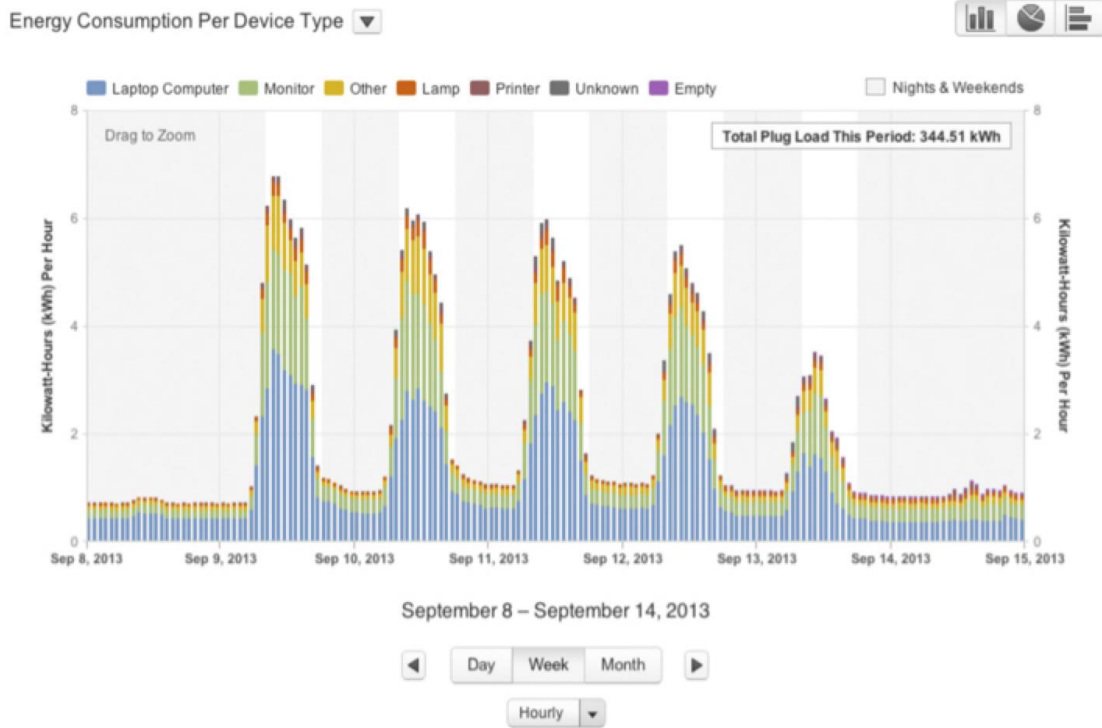**Figure 2.** *Screenshot of a plug load monitoring and reporting application*
(https://www.enmetric.com/platform)

Another opportunity is Direct DC powering (Garbesi et al., 2011). This takes advantage of the fact that all electronics and most miscellaneous devices (and many others such as fluorescent and LED lighting) are already DC internally. Commercial buildings have used DC powering for years for niche applications such as phones, Wi-Fi access points, and small USB devices. Industry groups such as the Emerge Alliance are working to develop standards to facilitate increased uptake of DC power distribution systems in commercial buildings. Direct DC can avoid hardware and losses from multiple AC/DC conversions, enable simpler integration of local generation and storage, and reduce installation and maintenance costs. DC devices can be integrated incrementally over time in addition to large-scale introduction when a building is undergoing a significant retrofit. Since DC power distribution usually includes communications, it is synergistic with the other technologies discussed in this section. DC datacenters have been demonstrated.

The wire for network and phone communications in buildings is already suited to being used for DC powering. However, the future wire and cable types best suited to DC are not yet certain, so for new buildings or significant renovations, building owners should ensure that new wiring or

other infrastructure can be readily added at low expense. Any time that local generation or storage are added to buildings is a good opportunity to consider DC powering to take advantage of and be integrated with these systems.

DC powering can be used effectively within an individual building, or portions of a building. However, it may be desirable on a campus level to establish DC links among buildings to more efficiently share local generation and storage resources, and for local reliability. Vehicles, both corporate and personal, are another excellent candidate for DC integration as they are internally DC.

Economics

The energy savings from strategies such as advanced power strips depend on the space types in which they are implemented, the types of loads that they are deployed to control, and the specific control strategy adopted. Savings can reach 25-50%, with schedule based control solutions particularly cost effective when appropriately applied; retail prices are approximately $20, possible paybacks of two-years or less (Metzger et al., 2013). While energy management techniques such as monitoring and reporting do not directly produce savings, they enable insight into consumption and efficiency opportunities. These approaches are most cost effective when integrated into a holistic organizational approach to energy performance monitoring. The ROI of emerging networks-based communications and sensing that can be leveraged by other applications is not yet known, and general-purpose DC-power based applications are not yet mainstream.

Other considerations

All of these technologies have many non-energy benefits that by themselves may justify the investment, significantly outweighing the benefit of energy savings. In addition, some high-tech companies may be able to integrate the more emerging technologies discussed into their own hardware and software products. Energy Reporting capabilities can automatically create inventories of devices present in buildings, and track them at no additional cost. DC powering offers safety and resiliency benefits, from widespread use of voltages less than 60V and the ability to power select devices during utility grid outages at low cost. These data may also have value in augmenting existing security systems.

Institutional requirements & capacity

While many of the strategies discussed are readily commercially available, those on the more bleeding edge of the spectrum would require in-house staff engagement and direct involvement to define many of the technology details. This should not be a problem for technology companies, given that IT is their core business. For example, large enterprises have the option to custom-build PCs in order to ensure that high-efficiency components are specified. This can be particularly impactful where high-performance PCs are in use (Mills and Mills 2015). EBay has instituted just such a policy for their server arrays, maintaining a degree of choice while helping standardize maintenance and enhancing purchasing power (Schuetz et al., 2013). Corporate and building-based facility management and operational staff who are designated as responsible for

these end uses, can receive periodic reports and address changes in devices or technologies as they arise.

3 Integrated Systems Within Buildings
Action-oriented Benchmarking

By Evan Mills

Energy benchmarking is a powerful way to educate and inspire occupants and other decision makers seeking to improve energy performance and ensure persistence over time. By enhancing the transparency of the energy management process, benchmarking plays an important role in reducing real and perceived risks in market transactions that depend on the comparative valuation of energy use and savings. Buildings energy disclosure ordinances are now requiring benchmarking in some markets (Figure 1), and voluntary efforts such as the Open Compute Project are taking hold in other parts of the technology sector.
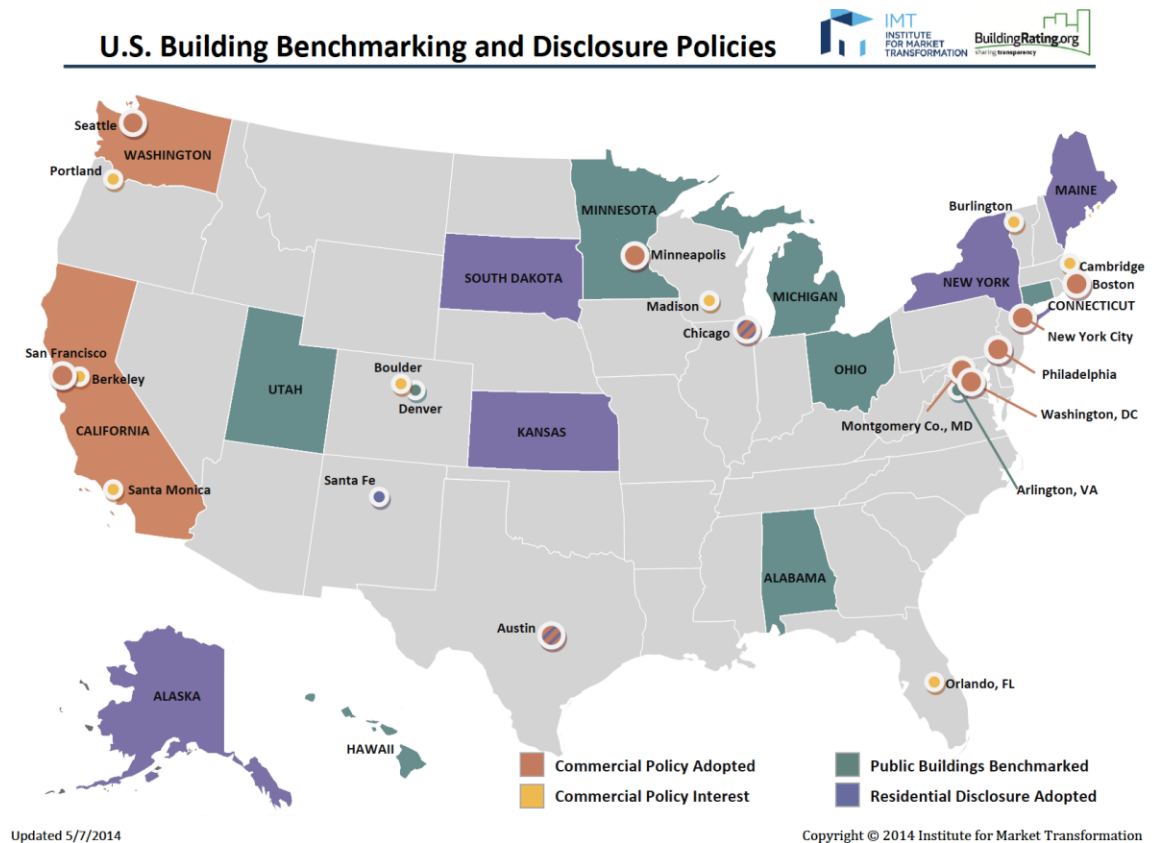

Figure 1. There is a trend towards mandatory energy benchmarking and disclosure.

Applications

Energy benchmarking has come to be recognized as an integral part of the process of managing energy use of a facility's entire lifecycle. Benchmarking the performance of average and exemplary buildings can be used to inform design intent with respect to aspirational energy savings. Best practice technologies and operational procedures can be identified by delving into the design choices and performance outcomes in other facilities. Once design has commenced, model-based benchmarking can be used to compare predicted performance of the subject building to peer groups or specific targets. These benchmarks can continue to be used once a facility is operational (recurring, longitudinal benchmarking over time) to verify attainment of design objectives, to diagnose performance problems, and to track progress towards performance improvements over time and the persistence of savings achieved by physical or operational changes intended to save energy. For all use cases, outliers can be studied to identify best practices as well as critical causes of energy inefficiencies. The University of California Merced Campus has made a substantial investment in building a site-wide benchmarking platform and integrating the information into operations, performance tracking, and decision making (Mercado and Elliott 2012).

A caveat in benchmarking actual measured energy use is that user "behavior" or other operational choices influence the patterns observed as much as do physical attributes of the subject facility. Other confounding factors include variations in weather. Such "operational" variations are one reason that energy intensity is not equivalent to intrinsic efficiency. An alternative to such ratings is to benchmark performance associated only with the facility's fixed elements (HVAC equipment, envelope, etc.). This is referred to as an "asset" rating, and must be performed using simulation. To use the vehicle analogy, official fuel-economy ratings are derived using a highly standardized test procedure, while the actual performance of a given car often varies significantly from the standard value depending on vehicle loading, how the car is driven, driving conditions, maintenance, etc. Both approaches have value, and it must be kept in mind that, while eliminating various forms of noise from their assessments, asset-based techniques by definition do not capture the very real effects of building operations and management.

At one end of the buildings benchmarking spectrum lies whole-building benchmarking (e.g., ENERGY STAR's Portfolio Manager), where all forms of energy and all end uses are aggregated into a single metric and compared against loosely similar types of buildings. EPA reports that about 40% of the building stock by floor area has been assessed with Portfolio Manager, and 25,000 buildings have received EnergyStar ratings (as of year-end 2014). The appeal of this approach is that it is conceptually simple and takes less time than other approaches. The limitation is that less actionable information is yielded. While the relative performance of a given building may broadly suggest a potential to save energy, the specific pathways for doing so remain unclear. Leveraging Portfolio Manager's API, some utilities offer "automated benchmarking" using customer data.

At the other end of the spectrum, the most rigorous pathway to identifying applicable energy efficiency measures is through in-depth energy audits and intensive simulation modeling. However, this is a costly proposition and requires considerable engineering expertise. Midway between these extremes is the "action-oriented" benchmarking approach in which specific fuels and end uses are analyzed and logic applied in order to identify candidate energy efficiency

recommendations (Mills et al., 2008) (Figure 2). EnergyIQ is one such tool, including application programming interfaces to allow the underlying data and benchmarking engine to be used in any website. EnergyIQ takes advantage of "features benchmarking" (presence/absence of specific features and their efficiency levels) to inform an opportunity assessment process and recommend specific actions. Examples include lighting ballast upgrades where non-electronic ballasts are existing, hot water water pipe and water-heater tank insulation where none is present, HVAC efficiency upgrades, constant- to variable-air-volume systems, etc.
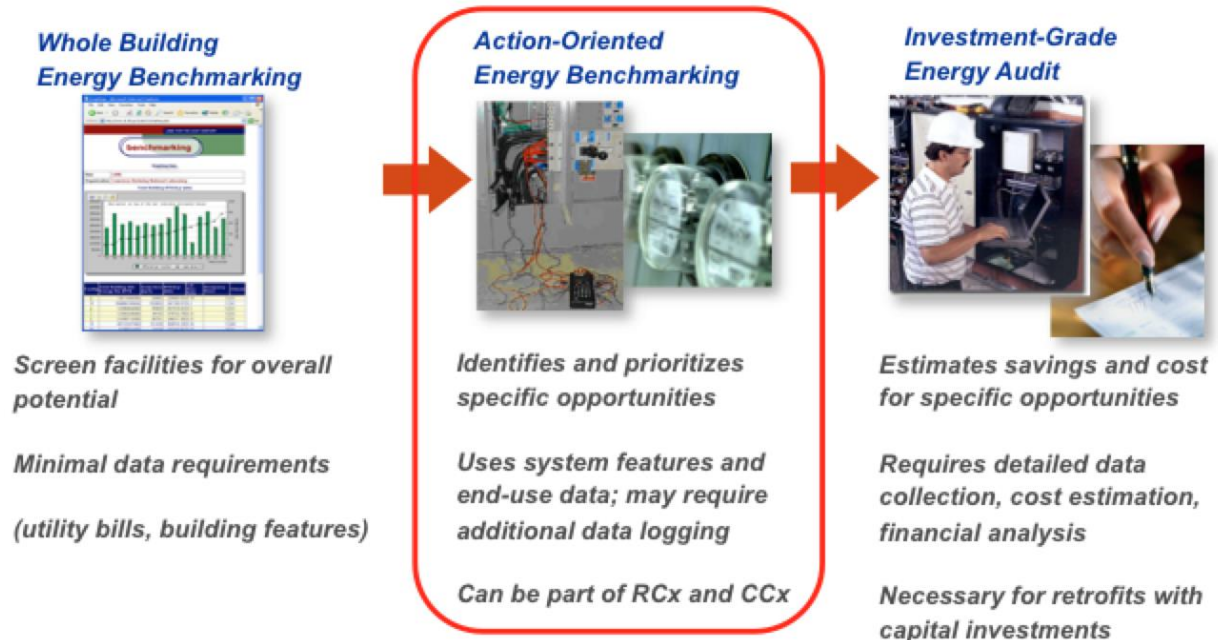
Figure 2. Action-oriented benchmarking is nested along the spectrum between light-touch, whole-building analysis and investment-grade audits.

Many building energy benchmarking procedures have been suggested, spanning a range of analytical techniques and data requirements (Li et al., 2014). One review identified 47 protocols for benchmarking non-residential buildings and 31 that applied to residences (Glazer 2006). The diversity of protocols reflects in part the evolving nature of the space and a degree of fragmentation in efforts, as well as a diversity of facility types and use cases that call for varying approaches. For example, specialized tools are available for datacenters and laboratories.

Benchmarking Mechanics

Of central importance in the benchmarking process is the assembly of a comparison peer group of facilities. Poor peer group specification can easily lead to a distorted view of how the subject building is performing. More subtle considerations also come into play, for example the operating hours, geography, building size, or vintage. Peer-group definition is an ongoing area of

research (Gao and Malkawi 2014), as are methods for ensuring quality data, particularly when disparate sources are combined (Brown et al., 2014).

An example of the influence these considerations can have on how a given subject building is "rated" against given peer groups is shown in a case study of the California Energy Commission's headquarters (Figure 3). While the peer group sample size necessarily falls as stricter filters are applied, as the peer group becomes more aligned with the subject building the results become more meaningful. In this case, results for the most loosely defined peer group suggest that the subject building was not a particularly good performer. However, upon improving the filtering, relative performance improved considerably.
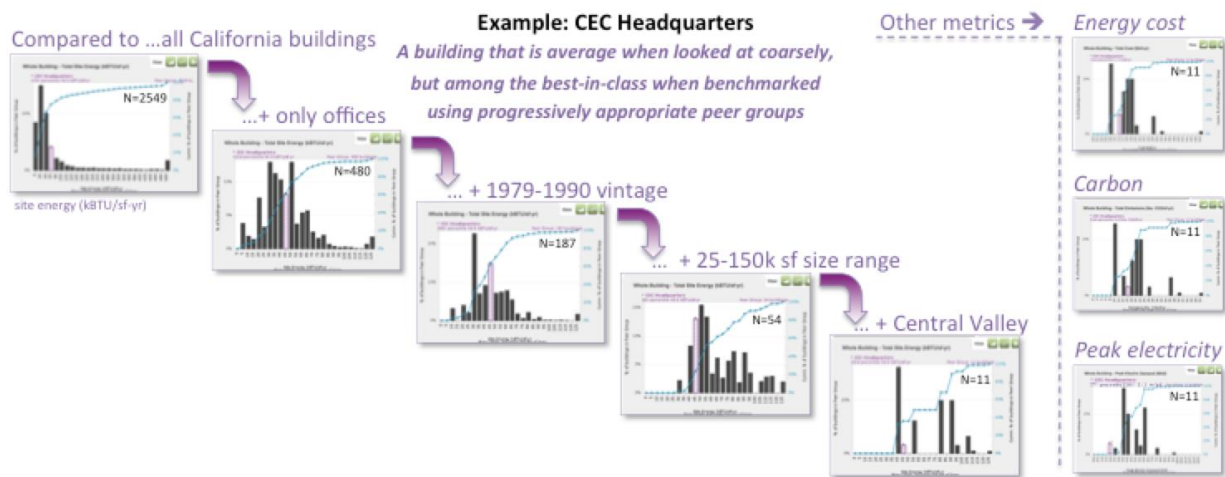
Figure 3. Illustration of how relative benchmarking outcomes can shift as the peer group dataset is refined.

Peer groups can be derived from statistical surveys of a given building stock, or managers of real estate portfolios can also benchmark within their enterprise, rather than to a broader more varied population of buildings. Individual buildings can be "self-benchmarked" over time in order to track actual changes in performance. The determination of an appropriate peer group is context-sensitive. Most benchmarking tools suffice for common peer groups such as office buildings. In some cases specialized building types (or particular regions) are less well represented.

Once a reasonable peer group is defined, and one or more filters applied to account for characteristics such as location, a benchmarking metric is then computed. The metric's numerator could be energy or some other quantity of interest such as cost or greenhouse-gas emissions. The denominator is important for normalization. While floor area is widely used, other factors may better characterize activities that occur in the building, such as number of employees or meals served for a restaurant.

The choice of metrics is important, and are sometimes highly specialized. In the case of datacenters, the ratio of total facility energy to the IT-related subset, known as the PUE (Power Usage Effectiveness), is widely used. A self-benchmarking protocol is available for data centers [Greenberg et al. 2006]. Benchmarking can even be performed at the equipment level. For example, special-purpose benchmarks can be computed for high-performance computers such as those used for gaming and special effects. These can be extended even to sub-components such as graphics-processor watts per unit of rendering performance, e.g., watts per frame-per-second (Mills and Mills 2015). Metrics are beginning to be applied to other green attributes, as illustrated by Facebook's benchmarking of "water usage effectiveness" (liters/kWh) in their datacenters.

Improved peer-group data sets are critical. The advent of public-domain "big data" and its application to the buildings energy arena through projects such as the Buildings Performance Database (Brown et al., 2014) is yielding new sources of peer-group data and larger datasets that promise to enable more fine-grain filtering than is currently possible.

An exciting frontier is occupancy-based dynamic load-shape benchmarking, using, for example, mobile phone data to track occupancy loads within a building or campus. Mathieu et al. (2011) illustrate a variety of ways to use 15-minute-interval load data, primarily in the context of demand response decision making.

Institutional Requirements and Capacity

To achieve its full value, benchmarking should inform action. Whole-building benchmarks are highly constrained in this respect because they do not disclose the reasons for particular energy outcomes. A layered approach, however, differentiating types of energy sources by end use, together with a profile of building characteristics and modes of operation begins to form the basis of analyses that can inform the identification of energy efficiency opportunities.

While improved information does not in and of itself achieve energy efficiency improvements, it is critically enabling. A more nuanced view is that benchmarking enables the identification and ranking of opportunities, creates awareness and attention, and provides intelligence that enables building operators to remain vigilant and ensure that intended performance targets are met and persist over time. Benchmarking also builds confidence about performance levels and savings claims, hence managing investment risks. For maximum value, benchmarking should be continuous and the resulting data streams tightly integrated into broader business practices. Disparate audiences—from financial to technical—must be engaged and find value.

The integration of benchmarking with energy data acquisition, visualization, and building management systems has been pursued for some time. Much more can be done to integrate benchmarking into the process of operating buildings and diagnosing deficiencies that lead to energy waste. To be more broadly adopted, benchmarking user interfaces (and associated data visualizations) must be designed with target users in mind, with an emphasis on usability and application to diagnosing and correcting deficiencies.

In parallel with a benchmarking system's analytical underpinnings is its user interface through which users conduct the benchmarking process. More than a decade ago, Orlov et al., (2003) reviewed the state of the art, including surveys of 22 early-adopter companies that were using computer based information dashboards (for a variety of purposes, outside of the energy domain). They found that these systems were often "tentative and not linked to business processes" and contained "passive displays meant for executive eyes only." If dashboards aren't connected to the people who "own" the processes they are evaluating, then the information does not become actionable. A metric that does not fit the need is of little value, and can even be counterproductive.

4 Commissioning
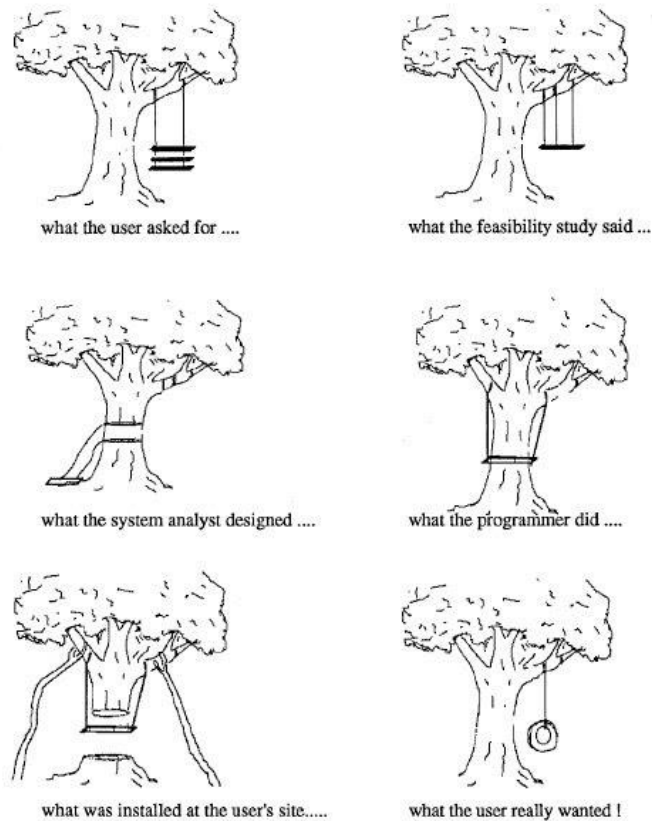*By Evan Mills*

Applications

Figure 1. Commissioning can preempt problems caused by poor communication during design, construction, and operations.

Trust but verify.

It is a rare building project that runs free of communications problems. Misunderstandings or ambiguities regarding design intent, materials or equipment selection, acceptance testing, or training for ongoing operations and maintenance often translate into missed goals and extra capital and operating costs (Figure 1).

The best-practice process of commissioning ("Cx") seeks to avert these problems through rigorous design review, construction observation, and a performance-focused acceptance testing process. The commissioning provider is an owner advocate from the earliest stages of design through occupancy and ongoing operations.

A commissioning mentality can be applied to all aspects of sustainable facilities (energy, water, indoor environment, materials, site planning). The focus here is commissioning with respect to energy, within which there are many fields of application. Energy savings cannot be expected to persist without attention. Commissioning helps ensure that savings are maintained, and even deepened over time.

Commissioning is a systematic, forensic approach to quality assurance, rather than an energy-saving technology. Commissioning is data-driven. The practice is trending towards a monitoring-based paradigm in which instrumentation is used not only to confirm savings, but to identify opportunities that would otherwise go undetected. Establishing ground truths with energy models during design and conducting performance benchmarking after operation are integral to the process.

New-construction "commissioning" and existing-buildings "retro-commissioning" were originally viewed as separate activities, but they are more usefully viewed as a continuum through which maximum value is obtained. Of key importance is the continuity of the practice throughout the facility's life cycle. For example, high-value equipment (e.g., chillers) may be initially commissioned at the factory (early acceptance testing), but continued scrutiny during installation and start-up is essential. And, as space uses evolve, recommissioning (including operational review) may be required in order to adapt and ensure energy-use minimization together with occupant comfort. A system such of this cannot be considered in isolation. The commissioning process seeks to ensure proper sizing in light of all impinging loads. In operation, sensor placement and calibration is scrutinized. During commissioning, control sequences are reviewed and operators trained. While commissioning can be viewed spanning design, construction, and operations, it is important to take maximal advantage of corrections that can be made through acceptance testing during building and subsystem warranty periods.

While commissioning originally emphasized individual HVAC systems, it has been successfully extended to central plants, envelope, lighting (Figure 2), and control systems. Onsite energy supply systems also require commissioning. With emerging technologies, new domains of commissioning must be developed, including integrated systems, vehicle-building interfaces, waste-heat recovery, energy storage systems, wireless controls, renewable energy systems, and demand-response technologies. Commissioning scope is infrequently extended to building envelopes, and this is an overlooked opportunity. Elements of the practice are evolving towards

self-commissioning hardware and software. More than a hardware focus, best-practice commissioning incorporates design intent documentation, benchmarking, and training of in-house personnel. Specialized facilities such as Laboratories and data centers require highly tailored approaches. The commissioning of these energy-intensive facilities regularly obtains the largest absolute energy savings and fastest payback times.   An important trend involves increased use of monitoring infrastructure to inform commissioning (Mercado and Elliott 2012; Mills and Mathew 2014).
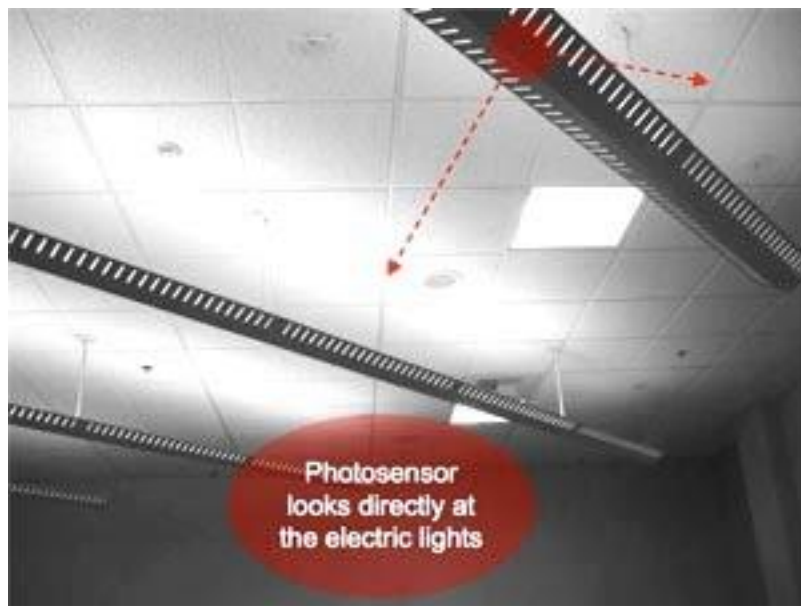
Figure 2. In this photo, the sensor intended for sensing and "harvesting" daylight by dimming the electric lighting, is installed incorrectly and always "sees" the electric light, never allowing it to sense and take advantage of the dimming capability of the system.

Economics

Commissioning offers highly compelling engineering economics. This arises largely because commissioning focuses on operational optimization rather than capital improvements. Buildings included in a national database of 100 million square feet of floor area in existing buildings attained median whole-building energy savings of 16% at a cost of approximately $0.30/sq, achieving median payback times of approximately one year, respectively. The upper quartile of buildings save in excess of 30%, and even the lowest quartile saves almost 10%. These value ranges could be applied as reference points in benchmarking commissioning costs. The more thorough the commissioning process, the greater the savings. Contrary to a common perception, cost-effectiveness is often achieved even in smaller buildings.

In new construction, commissioning routinely pays for itself via capital cost savings arising from equipment right-sizing and avoided construction defects. In many cases, these savings far surpass the cost of commissioning.

There is a second layer of value that is arguably even more substantial. Commissioning manages performance risk, and thus financial risk (Figure 3). Capturing this value requires vigilance over time and tracking. Energy management and control systems have been used in tight coordination with commissioning, often called monitoring-based commissioning. This can detect certain faults [see Diagnostics section], as well as tracking savings persistence. On the one hand, if buildings are unattended, energy use will rise as systems come out of "tune". At the other extreme, vigilance can deepen savings as new opportunities are identified and emerging defects corrected. That said, visual inspection suffices for many commissioning opportunities such as misplaced sensors, malfunctioning dampers, or ductwork or piping layouts with excessive pressure drop.
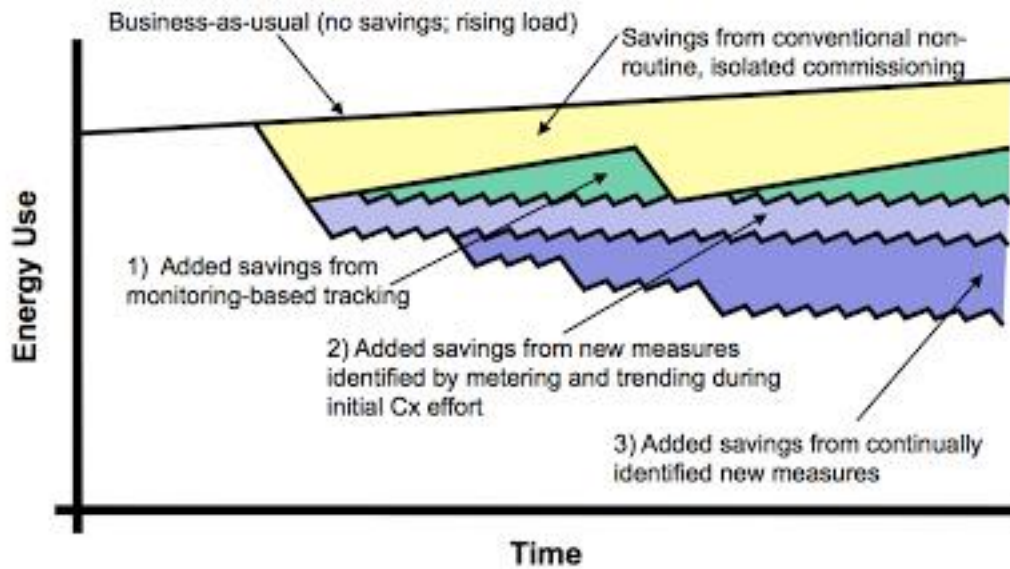
Figure 3. Conceptual illustration of the potential for recurring commissioning to deepen and ensure the persistence of energy savings and other benefits.
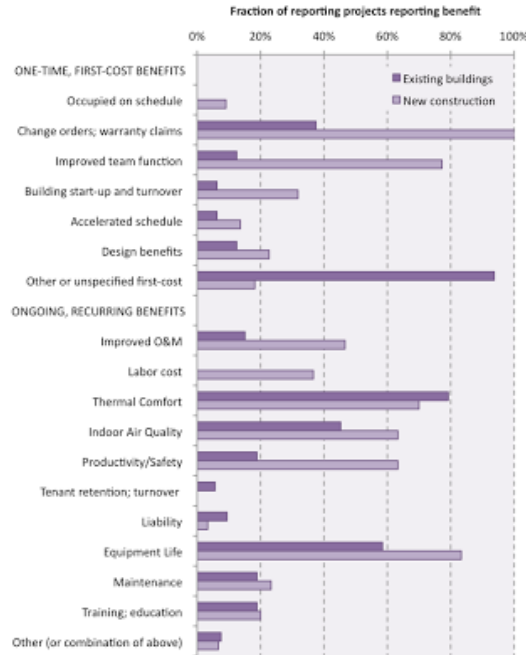
Figure 4. Commissioning co-benefits (Mills 2011).

Other considerations

An additional tier of benefits transcend conventional engineering economics. These benefits manifest in multiple ways, including enhanced indoor air quality, reduced noise, improved equipment service life, fewer change orders, and averted contractor call backs and litigation. By virtue of proactively detecting and correcting deficiencies, insurance companies have concluded that commissioning would have averted liability claims associated with construction projects. Commissioning ensures attainment of project goals, and intrinsically brings more cohesion to the in-house and external teams working on a project.

These co-benefits are often captured as a byproduct of the commissioning process (Figure 4). More proactive commissioning could focus deliberately on detecting and correcting the causes of important non-energy problems. For example, improving and ensuring indoor environmental quality could be an organizing principal for focused commissioning exercises. Here, emphasis would be placed on evaluating surface temperatures in a space, air movement and moisture content, as well as key aspects of HVAC systems such as morning start-up sequences or sensor location and calibration. Similarly in the case of visual comfort, focused commissioning of illuminance levels and distribution could be done to determine whether changes in space uses or activities may dictate adjustments in illumination. Occupant changes in spaces (window treatments, task lighting, changes in decoration) may also call for adjustments in lighting.

Institutional requirements & capacity

Commissioning intrinsically complements the "bricks-and-mortar" dimensions of energy efficiency projects (Figure 5). No significant project can fully succeed with some level of commissioning. Commissioning minimizes downside performance risks and maximizes achieved energy savings.

Commissioning has an institution-wide footprint, from planning, to design, to operations, to finance, to workforce. Instilling an institutional appreciation for what commissioning entails and how it creates value is critical to success. While commissioning is often out-sourced, for larger portfolio owners it can make good sense to create and maintain an internal capacity. This enables more continuous attention, and manages the risk of workforce constraints that have vexed this market.
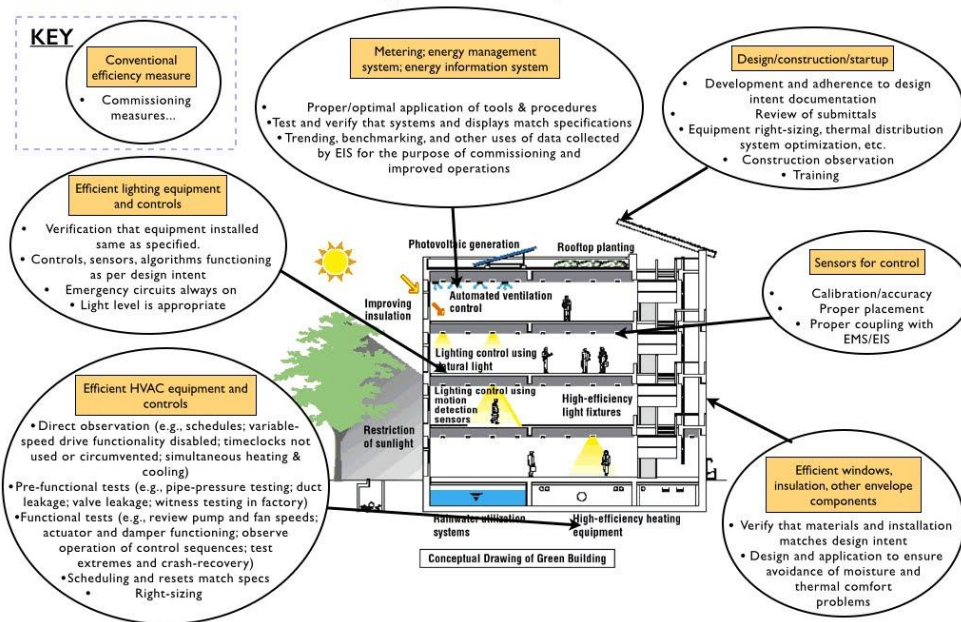
Figure 5. *Commissioning enhances success of virtually any energy efficiency project.*

5 Diagnostics

By Jessica Granderson

Applications

Marrying bottom-up and top-down performance analytics

Best practice in building energy and operational diagnostics begins with setting efficiency, demand, and energy consumption targets at the whole-building, system, and end-use levels. Performance is tracked relative to those targets on a monthly and annual basis. Continuous fault and energy anomaly detection is applied to hourly or sub-hourly data – again at the whole-building, system, and end-use levels, and also for specific components or pieces of equipment. The outputs of these continuous diagnostics are used in daily and weekly operational assessments to maintain persistent operational efficiency.

In a top-down approach, whole-building energy use is analyzed, followed by 'drill-down' investigations into systems and end uses, to gain more granular insights. In a bottom-up approach, the focus is on the constituent systems and end-uses. The most effective campus and building diagnostic strategies integrate both top-down and bottom-up approaches into a holistic data-driven energy management process.

Setting targets and tracking performance

Building targets might be set relative to existing portfolio energy use (for example, twenty percent below current consumption), or relative to national benchmarks (See Action-oriented Benchmarking). System and end-use targets can be set using energy metrics, or specific efficiency metrics such as watts per cubic feet per minute for fans (Figure 1). Submetering is implemented to disaggregate whole-building level energy use into more granular subtotals of system, and end-use, or even component level energy consumption. In best practice applications, performance with respect to targets is reviewed approximately monthly, using a 12-month rolling window for metrics that are expressed as annual totals or peaks.
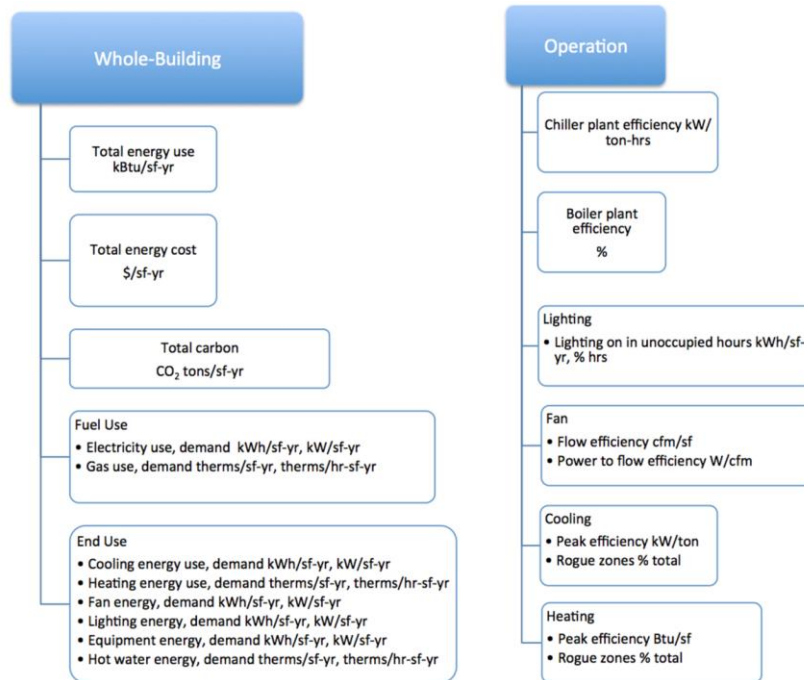
Figure 1: Schematic illustration of energy, demand, and efficiency metrics used to establish performance targets.

Continuous diagnostics

Complementing performance tracking, diagnostics are applied to hourly or sub-hourly energy data streams, and operational trend logs from building automation systems (BAS). The results are viewed daily. These diagnostics are referred to in many ways; commonly used terms include fault detection, energy anomaly detection, exception reporting, monitoring based commissioning, and ongoing commissioning [see Commissioning section].

Today's commercially available analytical software tools typically offer some combination of the following three diagnostic approaches.

1. Rule-based diagnostics are often specific to certain equipment or systems, and their associated control logic. They focus on *operations* as opposed to energy consumption, and are not generally applied at the aggregated end-use level. BAS trend logs are the primary source of data for rule-based diagnostics. Figure 2 shows an example of the graphical output from a rule-based automated fault detection diagnostic module.
2. Empirical energy and demand baseline models (for more info refer to Granderson et al. 2013) can be applied at the whole-building or submetered level to perform energy anomaly detection. These approaches focus explicitly on identifying periods of abnormal or excessive energy use, relative to typical historic usage patterns, while accounting for factors such as weather and time of day.
3. Like-equipment benchmarking is form of peer-to-peer, or "cross-sectional" benchmarking. Applied at the system, end-use, or component level, parameters such as energy use or run time hours are compared. These approaches are most effective in environments such as campuses, where there are sufficient numbers of like equipment to conduct the required comparisons.

The AFDD engine identifies operational inefficiencies in air handler units (AHUs).

(A) A plot of damper position vs. OAT is color coded to show faulty and correct operations.

(B) The light blue points show when the dampers are closed, even though "free cooling" is available.

(C) Green points correspond to fault-free operations.

(D) Yellow points indicate cooling lockouts, and red indicate heating lockouts.

Though not present in this example, purple is designated for scheduling faults.
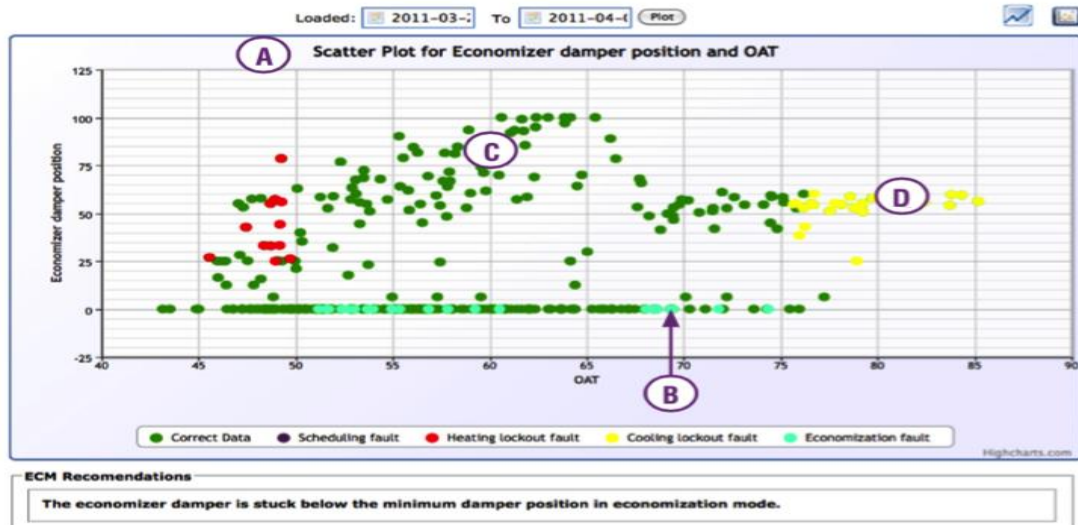
Figure 2: *Automated fault detection in a rule-based commercial diagnostic tool (Granderson et al. 2013). The y-axis shows economizer damper position as a percent of fully open, and the x-axis shows outside air temperature. Note: Points labeled "B" appear light green on some displays.*

For each approach, a key technical issue is to determine the thresholds at which a fault is triggered. For example, in a rule-based system that stipulates that one parameter should be "greater" than another, it is necessary to determine how much greater, given uncertainties in sensor measurements. In baseline model approaches, and like-equipment comparisons, the same types of thresholds must be determined. To avoid false positives, thresholds are set more loosely, whereas to avoid false negatives, thresholds are set more tightly.

Continuous measurement and verification

'Cumulative sums' (CUSUM's) are a best practice diagnostic to quantify energy and cost savings, and therefore the effectiveness of data-centered energy management practices. They are also used to track and maintain savings persistence by identifying periods of abnormal energy consumption. CUSUMS plots provide a powerful at-a-glance view into: (a) whether savings or energy use is increasing, decreasing, or stable, and (b) the total accumulated value of energy or cost savings, over time (Figure 3).

(A) The CUSUM indicates 15,000 cubic meters (m³) in total savings.

(B) After one month the CUSUM indicates 30,000 m³ in savings.

(C) The slope changed, indicating waste, and an automated alert was generated.

(D) A leaking valve was identified and repaired, leading to a new period of savings.
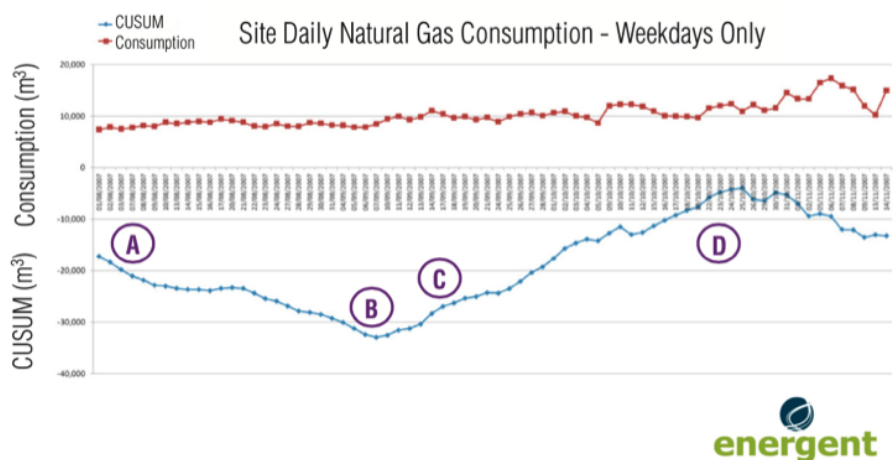
Figure 3: *Use of cumulative sum diagnostic plot to continuously track savings and to identify energy waste, due to a component fault (Granderson et al. 2013).*

Bleeding Edge (emerging technologies and practices)

Linking diagnostics to controls

A limited number of commercial tools deliver automated control optimization based on continuous analytics and two-way integration with building automation systems (BAS). BuildingIQ's Predictive Energy Optimization, Enerliance's LOBOS, and Optimum Energy's OptiCx are a few examples. These tools are still 'emerging', and their costs and benefits have not been widely demonstrated; however optimal control and the implementation of continuous corrective action-based on diagnostics, represent the future of advanced buildings. Model-predictive controls will becoming increasingly critical as the industry moves to more dynamic, grid-integrated buildings [See section on Demand Response & Electric Vehicles].

Virtual sensing

Virtual sensing refers to the use of available data to estimate the value of variables that are too difficult or expensive to sense directly. Today's building monitoring systems commonly use calculated virtual sensors, for example adding or subtracting one electric meter from another or calculating thermal energy based on temperatures and flows. More sophisticated approaches such as CO_2 or IT network traffic traffic might be used to derive information about occupancy. Ongoing LBNL research is showing that network traffic data can in some cases be used as an

effective proxy for building occupancy, can improve the accuracy of baseline load prediction models.

Physical model-based diagnostics

Best practice diagnostics used today are based on measured data from sensors and meters. Bleeding-edge applications such as that shown in Figure 4, are beginning to demonstrate hybrid empirical/physical simulation based approaches. Whereas purely data-driven approaches permit analysis of current vs. historic performance, and representation of engineering-based operational rules, diagnostics that incorporate physics-based simulation models enable representation of first principles and design intent. (Bonvini et al. 2014; Bailey et al. 2011).
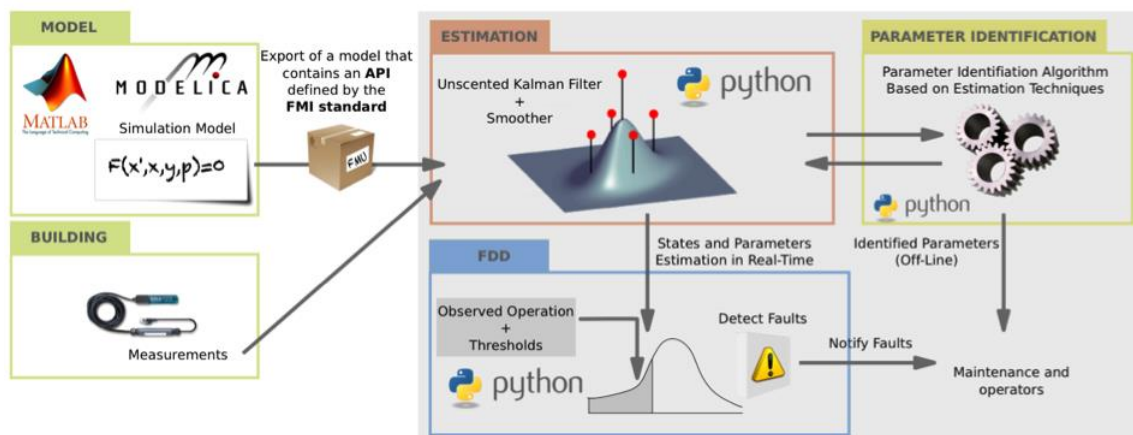
Figure 4. Design of a model-based diagnostic application demonstrated in partnership with the Department of Defense. Estimation-based diagnostic algorithms are used with physics-based Modelica models and measured equipment data, to identify operational faults; faults are output to maintenance and operations staff through a graphical user interface.

Economics

Over a decade of case study research has shown the value and rapid payback associated with whole-building and system level diagnostics. Site energy savings from 10% to over 20% have been reported in the literature, with paybacks often ranging from one to three years (Granderson 2011; Henderson 2013; Motegi 2003; Smothers 2002).

The cost of end-use submetering can be minimized by employing 'design for meterability' in new buildings. This approach makes an effort to design electrical distribution systems in which end use loads are disaggregated, and therefore measurable with fewer meter points. In most existing buildings, end-use loads are mixed within electrical panels that serve areas of the building, as opposed to specific end-uses.

Some of the highest costs in implementing advanced diagnostics are associated with BAS trend log integration. Tremendous time and cost may be required to (a) commission BAS sensor data to ensure accuracy and quality, (b) map trend log names to the associated variables required for

diagnostic algorithms, and (c) integrate data from multiple vendors' BAS for use in central diagnostic tools. To minimize these costs, procedures that standardize data protocols, naming conventions, and BAS vendors across buildings and campuses are critical.

If cash flow and capital availability are constrained, it may be practical to implement top-down, phased metering and diagnostics, beginning with whole-building diagnostics and modest submetering, ad exiting BAS-based diagnostics. After savings begin to accrue, more granular submetering can be implemented to enable persistence and deeper savings.

Other considerations

The most significant co-benefits of a comprehensive diagnostics strategy include improved occupant comfort and indoor environmental quality, the ability to ensure persistence of savings over time, and the availability of data that to streamline reporting practices. For example, enterprises may use the data from their diagnostics platforms to support ESCO contracting or to calculate and report Scope 1 and 2 greenhouse gas emissions associated with building operations. In addition, the metering, communications and software infrastructure used for energy and operational diagnostics may be leveraged and extended to support monitoring of all 'WAGES' resources (water, air, gas, electricity, and steam).

Institutional requirements & capacity

User expertise and training are important considerations in the successful deployment of diagnostics. While some diagnostics are fully automated, others require a 'human-in-the-loop' to view and interpret data. Given the many possible ways to 'slice and dice' data, it is critical to establish a comprehensive plan to meet organizational energy performance goals, including which diagnostics will be employed and how frequently, and what data is required.

The industry is beginning to more tightly couple diagnostics with maintenance, for example by integrating analytical tool outputs with work order systems. This is usually achieved through work stream process standardization (although customized system/platform integration is possible). Although it has long been acknowledged that ongoing diagnostics can extend equipment life and improve maintenance costs, condition-based maintenance and prognostic solutions are not yet as common in building applications as they are in other engineered systems.

6 Integrated Building Envelope, Daylighting, and Lighting
By Stephen Selkowitz

The interior floor space beside windows is the most "valued" space to employees who desire a view and connection with the outdoors. The intrinsic physiological and psychological underpinnings for these preferences are not fully understood although their consequences are clear. It is not an accident that "corner" offices with two windows are the prized upper-management spaces in a building. In European countries some unions require that all workers have a view of windows from their workstation.

Building perimeters are defined by the envelope that encloses them as well associated illumination. The envelope is often part of a much larger "design" statement linked to the overall building footprint, the "architectural statement" being made by the building owner. Smart owners ensure that design decisions around the external and internal building design and the relation to occupants have positive implications for energy use, load shape, and operating strategies within the building. Historically, the glazed building envelope was the weak thermal link in the building. This persists to a significant degree today, exacerbated by the architectural and owner preferences for highly glazed facades in many modern buildings. These designs admit more daylight and provide better connections with the outdoors from deeper in a space, but also become extreme challenges for energy efficiency and comfort if not designed and operated properly. Like the transparent envelope, lighting serves not only functional roles but helps define the aesthetics and ambience of building spaces for occupants. Since many business tasks are built upon "seeing" and visibility the role of lighting remains critical to occupant performance as well as comfort, even as the visual practices change i.e. from paper to VDT to laptop to tablet to phone) and the technology undergoes dramatic changes i.e. gas discharge lamps to solid state lighting with smart controls.

Applications

Proper envelope design begins with exploration of the footprint and orientation of the building. When placed on a green field site without constraints there are many opportunities to site the building and shape the floor plan to minimize purchased energy use and maximize comfort. The bigger challenges occur where site conditions constrain choices, as is common in urban environments. These site planning impacts of building footprint and envelope have an impact of the design of the overall campus, e.g. taller buildings in a denser planning mode provide less solar access and daylight but may reduce travel time and related energy use.

It is technically possible to make the envelope of the building a "net zero energy element" -- this is a stretch goal that supports efforts such as California's 2030 building performance targets. (CPUC 2011) While the fundamentals (minimize heat loss, manage solar gains, utilize daylight) are consistent across all building types and climates, the important details and design drivers change dramatically among climates based on temperature, cloud cover, and sunlight. The building envelope includes both vertical and horizontal elements, where the ratio is driven by density, design and cost issues for a given site. A low-rise suburban campus will have a very different ratio than an urban campus. The relative importance of "roof" surfaces and "wall" surfaces is thus initially driven by these planning and design issues. Best practice today for opaque surfaces provides a highly insulating, low air/moisture permeability envelope and membrane. Surface optical properties are important: buildings with large flat roof surfaces, particularly in existing older buildings with sub-optimal insulation levels, will benefit from sunlight-reflecting "cool surfaces" (Heat Island Group website). Particularly in hot climates, these roof systems or overcoats should reflect the maximum solar energy, using a variety of spectrally selective surfaces that reject near infrared energy but allow colors. In a highly glazed envelope (50 to 80% of total envelope) the challenges can be even more severe. Best practice for minimizing winter heat loss consist of multiple-glazed insulating glass units (IGUs) with low-E coatings and gas fill, placed within thermally broken metal frames. Triple-pane units are heavier, wider, and more costly, but are routinely used in Canada and Europe, and available in most of the U.S. as special-order items. (Carmody et al 2004)

Operable windows allow occupants (or automated systems) to open the sash to provide fresh air and potentially cooling for many operating hours of the year. The framing systems are more

expensive than fixed glazing and reliable operation may be a challenge. Automation is an option although one that can add significant cost. In all curtain walls uncontrolled air leakage must be minimized. Shading and daylighting are managed by "multiple" layers or defenses (Figure 1). A best-practice solution uses a spectrally selective glass with a high light transmittance and low solar heat gain coefficient (SHGC) to minimize cooling. Exterior shading is most effective and most costly; and most useful to minimize cooling in severe climates. Current practice includes fixed louvers and fins as well as operable, motorized units. Interior shading (blinds, roll-up shades) provide some sun control but also glare control for occupants. These can be manually operated or motorized and automated, at additional cost. While exterior shading and all motorized systems are rare in the U.S. they are widely used in Europe and are proven strategies where owners care about energy and resilience. As real and perceived cost and risk are reduced, industry leaders are (slowly) moving in the direction of delivering higher quality systems at lower cost.

Figure 1. Example of high performance façade used on the New York Times HQ tower in NYC. Consists of "layered" design solutions, A) inside-to-outside and B) floor-to-ceiling. A) consists of 1) External fixed ceramic rods for shading for solar control and daylight diffusion; 2) High performance insulating glass unit with spectrally selective low-E coating, argon gas fill and low-iron glass, including some fritted sections for glare control; 3) Interior automated, motorized roller shade with shade material selected to balance daylight admission and glare control. B) consists of 1) plenum and upper glazing zone for glare control and light diffusion; 2) central unobstructed vision area; 3) lower partially shaded zone that admits daylight to bounce off the unoccupied floor area adjacent to window. (Lee et al, 2005)

The integration challenges of motorized systems with sensors linked to a BMS should not be underestimated. These solutions are bleeding edge today but should become more mainstream with time, as they have already in Europe. Smart glazings -- electrochromic and thermochromic – are now technically viable, but costly options, and require careful integration to optimize energy, daylight and comfort (Figure 2). Cooling cost tradeoffs apply to these as with other dynamic shading.

The final piece of the puzzle is daylight utilization -- both to enhance the workspace and offset electric lighting. The same shading and glazing must allow sufficient daylight to penetrate ideally 15 to 30 feet into the space, with photocells dimming the interior lights to continuously meet

design illluminance levels (~300 lux for general office lighting). The window (or skylight) must be managed to minimize glare e.g., with shades or blinds. All too often manual shades are closed to control glare, and then never re-opened, with loss of daylight savings. On-off switching is not a satisfactory occupant solution, and the cost of daylight dimming is coming down as LED dimming is cheaper than dimming fluorescents and controls and sensors can be linked with cheaper wireless links and better user overrides. Daylight systems (dimmable fixtures and sensors) in practice today are often hit or miss in real offices due to design, installation and commissioning challenges. Competent design teams can make them work and they are deemed sufficiently robust that Title 24 requires it in all new California construction.
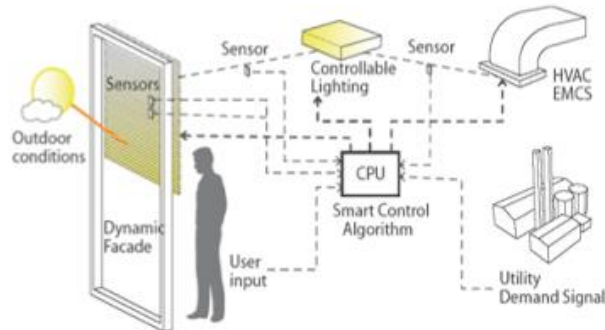
*Figure 2. Emerging Smart Building Solutions. Schematic of "future proof" integrated solutions that link envelope and lighting solutions. Concept integrates four key features: 1) **Operable façade components**: Motors or actuators for shading devices, light-redirecting elements, operable windows, or switchable glass coatings; 2) **Responsive lighting systems** with dimmable output to match daylight, task needs and occupancy; 3) **Occupant and sensor driven input** for all systems control; 4) **BMS controls integration** that optimizes for comfort, owner cost, utility DR/price signals. (High Performance Building Facade Solutions, website)*

Electric lighting has been a slowly changing landscape for many years with incremental improvements in the standard fluorescent lamp and fixtures. However, over the last decade the industry has been changed dramatically with the advent of white LED sources. While these add improved efficiency (moving well above 100 lumens/watt) the more transformative impacts are the provision of a wide range of lighting spatial distributions and intensities, the ability to provide more spatially granular solutions, the ability to dim lights smoothly and relatively cheaply, and the ability to sense and control these low voltage sources with wireless networks. Manufacturers are exploring future office environments with DC power distribution infrastructure to support low voltage lighting and a wide range of office computing and display equipment. (EMerge Alliance, 2015) As the efficiency of LED sources increases and net lighting power densities drop below 0.5W/sf, the traditional electric supply to lighting may be entirely displaced by a "power over ethernet" infrastructure. (Wikipedia, 2014) The overall control can be driven by local needs of occupants, automated occupancy and demand response, cost optimization from building automation systems, or any other facility manager need. As the controls industry matures, best practice should include automated commissioning, and other flexible control options to address functional changes in spaces, office churn, etc. Perhaps the biggest obstacle today is the lack of experience, skills, and infrastructure to rapidly absorb all the new technology and systems and ensure that they are properly specified and implemented. There are also a number of important technical subtleties that the industry is slowly addressing such as flicker, color temperature, color

consistency, real lifetime and output, etc., and any proper LED based design needs to properly address all these factors for a successful solution.

Economics

The cost effectiveness of these individual and integrated solutions varies widely across a wide range of costs and benefits. Most of these systems can be "cost effective" when competitive markets offer them and first-cost savings for heating/cooling are accounted for, as well as changes in maintenance costs, e.g., due to longer-lasting LED light sources (Figure 3). Since the envelope is typically part of the overall architectural design, significant resources are often spent on design features independent of energy features. While building envelopes are relatively costly, they can have lifetimes of 50 years or more. There are a number of potential offsets noted in the text above in terms of chillers and cooling system rightsizing that bear consideration in the context of carefully and fully integrated system. While the sources/fixtures are more expensive than conventional sources, the systems solutions, including dimming, often are not and the new form factors of the lighting can make installation cheaper as well.
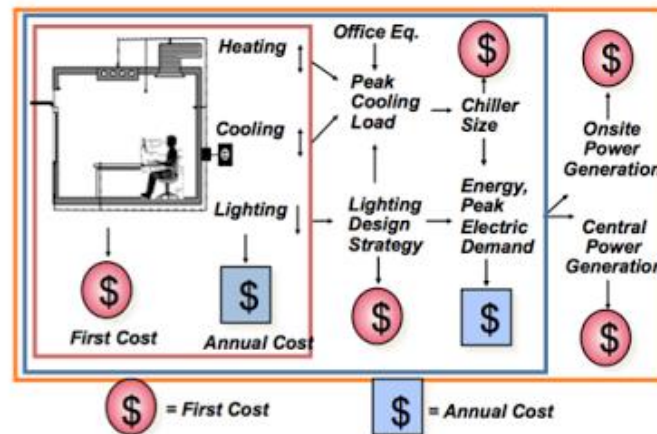
Figure 3. Perimeter-zone impacts on building systems. Design decisions made in the perimeter zone with respect to glazing, shading, lighting are often "Optimized" in a limited first cost/payback perspective (within the red box). A better solution is to optimize against "whole building investments" for building Chiller/HVAC sizing and on-site or off-site power investments (blue and orange boundaries), allowing tradeoffs in first cost of chiller/HVAC system and power supply against an investment in high performance façade and lighting.

An additional potentially large benefit is that the high-performance, integrated, automated systems outlined above should deliver high levels of comfort and productivity immediately adjacent to the windows. Interior designers often push desks back 3 to 5 feet as a precaution against the expected discomfort immediately adjacent to the glass. The high performance systems described here can potentially recapture 2 to 4 sq ft of floor space per lineal foot of curtain wall [see Genentech case study]. At current construction costs this more than pays for the full cost of the high performance glazing, shading and lighting controls. Costs today for the controls infrastructure for these systems are highly variable, ranging from $2 to $8/sf (Wei e al 2012, Robinson et al, 2014), including not only the controls infrastructure with sensors but the need for dimming ballasts, fixture by fixture communications, installation and commissioning labor and integration with BMS or other building controls. However these costs are falling

rapidly toward the low end of that range for new construction using LED fixtures with lower cost dimming and built in fixture by fixture sensors and wireless communications.

Finally the envelope and lighting designs have important impacts on occupants in terms of health, comfort and productivity, even when these are hard to measure. Since salaries are a factor of at least 100 greater than energy on a per square foot basis there are powerful economic drivers to invest in high performance solutions as a risk reduction strategy, even if the impacts cannot always be accurately quantified.

Institutional requirements & capacity

Mainstream conventional products can be obtained via multiple competitive channels but more innovative options are frequently more costly due to lack of competitive markets, complex supply chains, and added risk and uncertainty that comes with the use of new and unproven solutions. There are new procurement strategies that can in part address these challenges. The design - build - commission - operate paradigm is still a source of constant challenges as one moves across these life cycle stages.

Most decisions about the building envelope and lighting are driven by style, appearance, and other business image concerns as well as the more functional issues surrounding energy use. Internally the comfort and amenities offered to staff are crucial to a successful building design, and both the glazing/shading/daylighting features and the lighting solutions offer very strong positive reinforcement when done well but generate powerful negative effects when done poorly.

7 HVAC Controls
By Philip Haves

Applications

Conventional HVAC controls consist of cascaded single-input controllers, generally proportional-plus-integral (PI) feedback controllers at the lower levels ('local loop control') and controllers based on heuristic logic at the higher levels ('supervisory control'). Current systems do not include the more sophisticated types of control found in other industries, e.g., multiple input, multiple output controls, whose skill requirements exceed those found in the buildings industry. In general, packaged roof-top air-conditioning units have their own, dedicated controls whereas the 'built-up' systems typically found in larger buildings have programmable controls, usually configured using a graphical programming language.

Best practices in HVAC controls include:

- Sequences of operation produced by the mechanical designer in the case of one-off system designs or selected from a set of standard, previously tested sequences for routine design
- Commissioning by an independent third party provider hired at "arms length" by the architect or the client, rather than the mechanical contractor

- Performance monitoring using either the building control system or a separate system for data acquisition, archiving, visualization, benchmarking, performance analysis and diagnostics,
- Full documentation for all systems and comprehensive training for operators and other facilities staff, with unrestricted access and all programming tools required to make changes throughout the life-time of the system.

Anecdotal evidence indicates that it has become common for mechanical designers not to provide sequences of operation and to rely on the controls contractor, in practice a technician, to generate the control program. The programming used in a new project is typically based on previous projects involving the same types of system, a practice that works to the extent that the current project and associated occupancy and user needs are similar to the previous project and the extent to which the original sequence of operations was adequate. Further anecdotal evidence indicates that this practice has become engrained to the point where, in cases where sequences of operation are provided by the mechanical designer, these sequences are usually ignored in favor of previously-used sequences.

Specific sequences of operation are likely to be provided when the mechanical design is innovative in some way; ignoring these sequences can lead to a combination of frustration, delay, and poor system performance (with adverse consequences for occupants). If the project is commissioned, it typically falls to the commissioning provider to resolve inconsistencies between the design intent and the sequences of operation as implemented by the contractor. There are exceptions to this pattern but it is pervasive enough that the owner or the owner's representative needs to take steps to ensure that it does not occur if good performance is desired. Keys to ensuring a good outcome are explicit specifications and careful selection of the controls contractor and the commissioning provider.

To address the common situation of conventional systems, ASHRAE commissioned a research project (1455-RP) to develop standard sequences of operation for air-based secondary HVAC systems (Hydeman et al. 2015). The maintenance and dissemination of these sequences, and any sequences developed in the future, will be under the auspices of the new ASHRAE Guideline Project Committee (GPC) 36 High Performance Sequences of Operation for HVAC Systems. It is expected that the major controls vendors will create libraries of these sequences of operation, anticipating that designers will start to specify them in controls bid packages. In addition to these sequences being directly usable in many projects, they will provide good starting points for sequences for somewhat less conventional systems. The deliverables from 1455-RP are available on the GPC 36 website (ASHRAE GPC n/d). It is expected that validation and demonstration of the 1455-RP sequences and development of standard sequences for primary HVAC systems will be addressed in future research projects. It is anticipated that sequences for innovative systems will be developed as and when these systems mature and become standard practice.

Despite the success of delivering automated facades and dimmable lighting in a large class A office building over a decade ago, e.g. the New York Times headquarters building (Lee et al. 2013), and the positive results from other underlying field studies that support these potentials, these controllable facade and lighting systems are still only occasionally implemented in buildings today due to costs and the complexity of integrating sensors, controls and dynamic

system elements, which are compounded when HVAC controls are also integrated. By default, facade and lighting systems use separate controls, so integrated control requires data communication among the controls. Possible technical solutions are (i) to use an integration platform, such as Tridium's Niagra framework, (ii) to use BACnet to implement simple data interoperability or (iii) to use a single controls platform that has the versatility to meet the control requirements for the different systems. Separate energy information systems (EIS), which may link data from control systems and energy metering systems, and provide archiving, visualization and analysis capabilities add further complexity and increase the attractiveness of integration platforms, although some HVAC controls vendors provide EIS functionality in add-on software products.

Commissioning can substantially improve the performance of poorly installed control systems. It typically consists of two stages: pre-commissioning and functional testing. Pre-commissioning involves checking the wiring from controllers to sensors and actuators and verifying that the behavior of the sensors and actuators is as specified. Functional testing involves changing set-points or overriding control signals to actuators and verifying that the response of the system or components is as expected. It also involves testing start-up and shut-down sequences and verifying the system behaves safely in the event of malfunctions. Commissioning is valuable in that it it uses systematic testing to reveal faults and other operation problems at or before the start of occupancy; if commissioning is not performed, faults appear in an ad hoc fashion over time, when they are more difficult to diagnose or remedy.

Building control systems typically only include the sensors required by the sequence of operations. Monitoring of performance - energy or indoor environmental quality - requires additional instrumentation, archiving and visualization to analyze performance and detect and diagnose problems, even manually. Installation of electricity sub-meters on key circuits or enabling power read-outs from variable frequency drives and complex equipment, such as chillers, provides valuable information that allows performance to be assessed. ASHRAE Guideline 13 Specifying Building Automation Systems includes an addendum on instrumentation for performance monitoring and ASHRAE Guideline *22 Instrumentation for Monitoring Central Chilled Water Plant Efficiency* also includes analysis procedures for characterizing system performance.

More advanced control technologies are starting to be developed in response to the emerging use of thermal storage systems and weather forecasting. Thermal storage systems include tanks of hot water, chilled water or ice and thermally active building systems (TABS), such as radiant slabs. The desire to optimize the operation of such systems has created a need for predictive control; one option is model predictive control (MPC) (*Ma et* al 2012). MPC uses a simplified model of a building or a central plant, together with weather and utility price forecasts, where available, to determine an optimum control strategy for a period of a few days. The strategy is continuously updated in response to the actual performance of the building or plant and updates to the forecasts. This process minimizes energy costs by reducing under- or over-charging of thermal storage. The motivation to adopt MPC will increase as buildings are incentivized to adapt to increasing volatility on the electric grid caused by an increasing fraction of generation from renewable sources. However, the limiting factor is likely to be the skill level of designers and

facilities staff. Reliable performance can only be obtained if the operating staff can attain, and maintain, sufficient understanding of the systems and their controls.

Campuses, particularly those belonging to organizations with technically-based management and decision-making, offer the most favorable circumstances for the successful adoption of new technologies, including advanced control systems. The scale of campuses justifies the employment and training of the specialists required to enable the evaluation and adoption of new technologies.

One obstacle to the implementation of high-quality sequences of operation for one-off buildings is a lack of controls design analysis tools adapted to HVAC, particularly for use in schematic design and in early design development, before the controls vendor has been selected. Generic tools such as MATLAB (MATLAB n/d) have not found favor in the HVAC industry and are rarely used. The controls modeling capabilities of whole building energy simulation tools such as eQUEST (eQUEST n/d) and EnergyPlus (EnergyPlus n/d) are largely limited to simple supervisory strategies and do not address local loop control. Similarly lacking are the capabilities to address integrated control of HVAC, facades and lighting. One approach is to use more modular simulation tools, such as TRNSYS (TRNSYS n/d) or emerging tools based on the Modelica modeling language (e.g. Wetter *et al.* 2014), though, as with MATLAB, these tools do not scale easily to the whole building level and require skills not often found in the buildings industry.

In addition to the lack of a control strategy design tool for buildings, the current process for implementing control strategies is largely manual and suffers from a number of problems that result in buildings failing to perform to their technical potential unless remedial measures are implemented as part of a commissioning process. The multiple disconnects in the current process can be overcome by the automated tool chain illustrated in Figure 1, which is still in the concept stage for buildings but is based on methods that are already firmly established in the semiconductor and automotive industries (Sangiovanni-Vincentelli and Ricorsi 2010; Di Natale and Sangiovanni-Vincentelli 2010). The key is to represent the sequence of operations produced using the design tool in a machine-manipulable form, with the format defined by an open standard. Hardware selection, network design, and generation of functional tests are performed automatically and the distributed control program is then generated, uploaded and tested automatically. The main benefit, particularly for more innovative designs, is that it is possible to proactively guarantee that the sequence of operations produced by the designers is correctly implemented in the actual control system, which is often not the case in the current process. Once developed, this process could be implemented both by the established controls vendors and by new entrants to the controls market.

Tool Chain: Design to Operation

Control Strategy Design   Hardware Configuration   Code Generation   Tuning & Testing
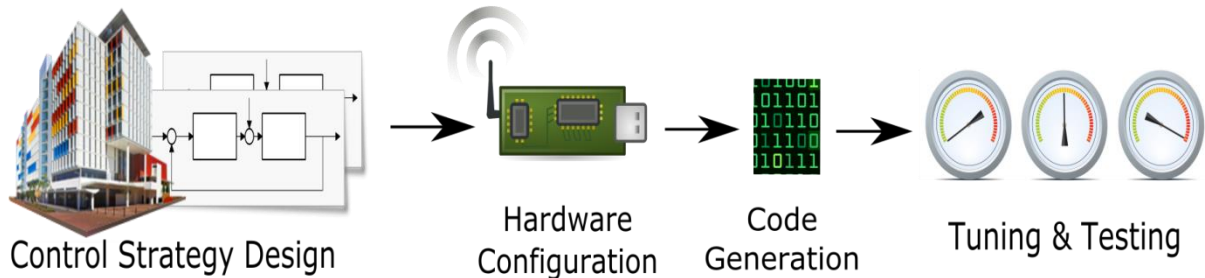
Figure 1. *Future tool chain for automated design and implementation of building controls*

A number of research organizations are investigating new, open architectures to support a wide range of operational functions in buildings and beyond, including integrated control, automated diagnostics and grid transactions. If, and when, any of these efforts come to fruition, they will enable a number of the limitations discussed above to be overcome much more easily and efficiently, potentially transforming not just the operation of individual buildings but the role of buildings in relation to the enterprise and the grid.

Economics

Control systems are enabling technologies in the sense that the cost of the mechanical equipment and active facade components that they control typically exceeds the cost of the control system and so it is difficult to consider the cost of the control system in isolation. Installation costs generally exceed the cost of the control hardware and a major component of the installation costs is the wiring of sensors and actuators to the local controllers. Robust wireless communications could reduce these costs significantly but existing wireless technologies have failed to displace hard-wiring. Sensors and actuators with digital interfaces connected by wired networks could also potentially reduce installation costs but have also failed to have a substantial impact on the HVAC market, in part because there are multiple standards. Proactively commissioning control systems is significantly more cost-effective (and less disruptive to occupants) than piecemeal reactive troubleshooting and repair.

Institutional requirements & capacity

Cyber-security has become an important issue for building control systems, particularly since a recent security lapse at Target Corporation was attributed by several commentators to the lack of segregation of the financial systems from the HVAC controls network, though not to the HVAC control system per se.

As noted above, the relative lack of special control engineering and related skills among designers, contractors and operators is expected to limit the adoption of more advanced control techniques and systems. Organizations that have invested in the recruitment, training, and retention of staff will be better placed to exploit emerging advances in controls technology. Commissioning providers can be looked to as one source of training. More generally, close

attention to specifications is particularly important for control systems and use of tools such as ASHRAE Guideline 13 *Specifying Building Automation Systems* can be part of to a quality assurance process that can help prevent the control system being the Achilles heel of commercial building performance.

8 Indoor Environmental Quality

By Rengie Chan and William Fisk

Indoor environmental quality (IEQ) can affect occupant comfort, health, and productivity, often with significant financial implications because the costs of salaries and health benefits far exceed the costs of energy, maintenance, and annualized construction costs or rent (Fisk et al., 2011; Figure 1). The key components of IEQ are indoor air quality (IAQ), thermal comfort, lighting, and acoustics. Some of the key strategies describe below that can improve IEQ also have the potential to save energy and support sustainability.
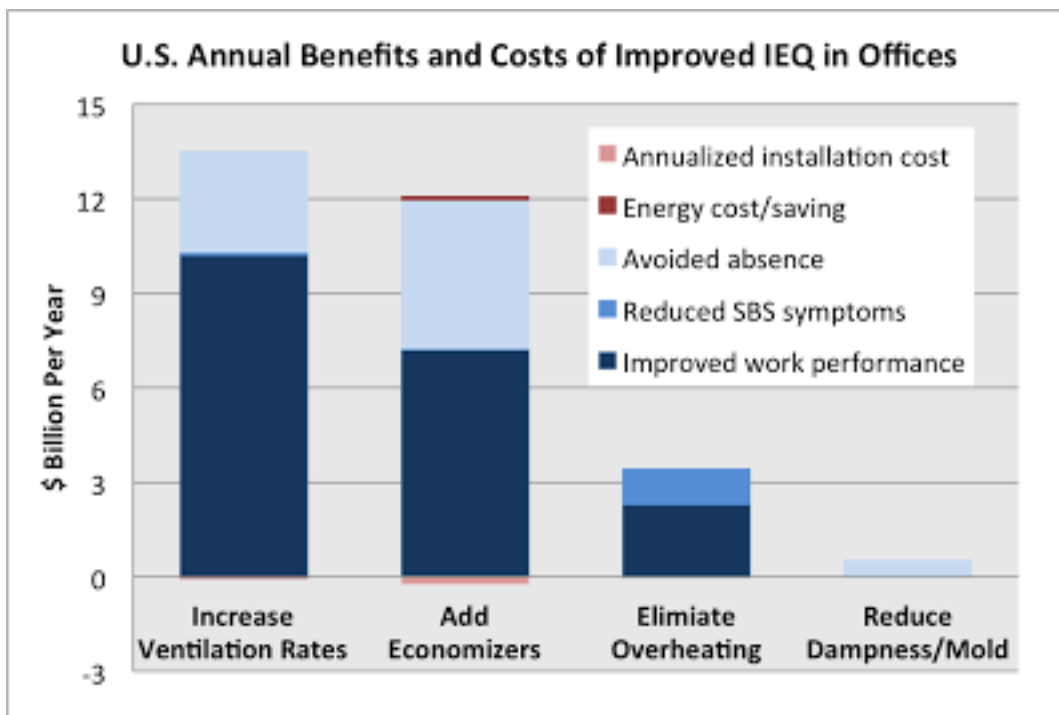
Figure 1. Estimates of the annual benefits and costs of selected strategies to improve IEQ in U.S. offices (Fisk et al., 2011). The combined net benefits from improved work performance, reduced sick building syndrome (SBS) symptoms, and avoided illness absence from a set of non-overlapping scenarios is approximately $20 billion annually.

Applications

Indoor Air Quality

Contaminant source control, such as use of low-emitting building materials, can substantially reduce indoor air contaminant concentrations without increasing energy or equipment costs. Source control is implemented by many large organizations and is an element of green building rating and certification systems. Working with various existing building material labeling systems, this movement is compelling material manufacturers and suppliers to make information more accessible (Figure 2). But source control goes beyond just building materials, furniture, and office equipment, equally important are the pollutant sources that are brought into buildings by occupants and their activities (e.g., use of green cleaning products by Adobe). Proper capture and venting of cooking fumes is also important in spaces with cooking.

Figure 2. Examples of some recent efforts to develop a common tool to share data on green materials and products.

Particle filtration, using more efficient filters than commonly employed, can be highly effective at reducing occupants' exposures to particles from outdoor air and emitted from indoor sources (Fisk, 2013). Using high efficiency air filters that have low pressure drop (e.g., filters with deep

pleating; Figure 3) is an effective strategy that adds little additional cost relative to the projected value of health benefits. A study from Europe estimated that the annual operating cost of filtration using high efficiency air filters (MERV 13) is $2.6 per person (Beko et al., 2008). Efficient particle filtration is especially important where the outdoor air has a high concentration of particles due to regionally poor air quality (e.g., large cities in China) or local particle sources such as wood smoke (e.g. Pacific Northwest in winter time).
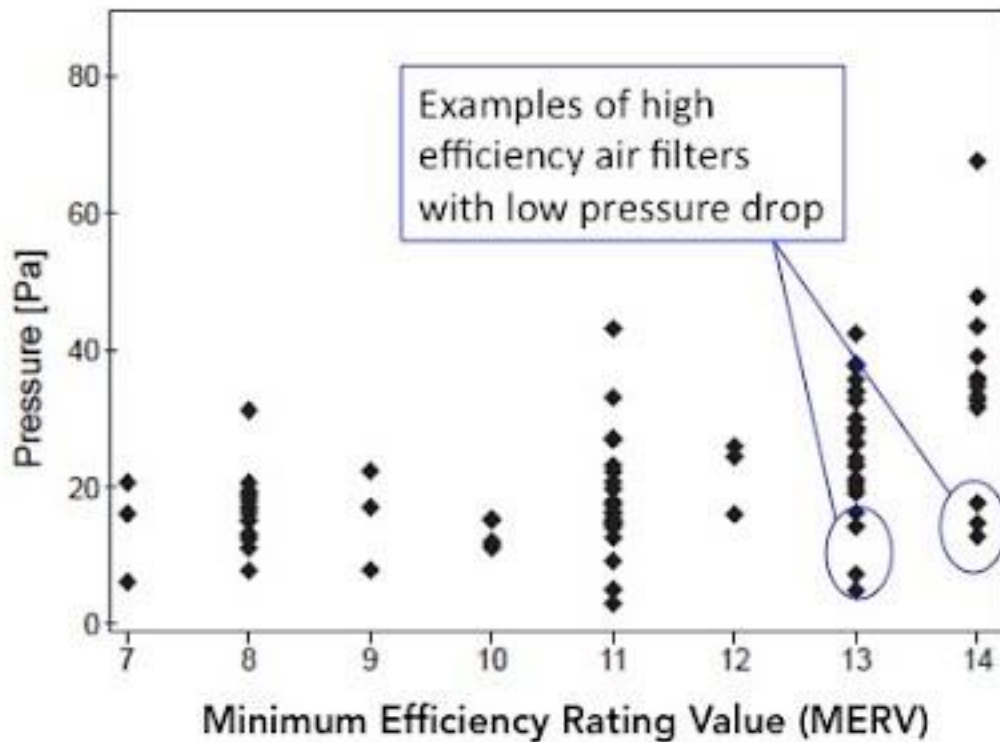
Figure 3. *Calculated filter pressure drop of 90 filters with different efficiency ratings at a given flow rate (Zaatari et al., 2014). This data shows a wide variety of pressure drops owning to differences in filter design.*

Ventilation control systems that deliver adequate ventilation to building occupants are important both to IAQ and energy use. Outdoor air economizers and nighttime pre-cooling with outdoor air, both are simple strategies to implement, will reduce indoor concentrations of contaminants emitted from indoor sources and also save energy. Higher ventilation rates above ASHRAE Standards 62.1 (2013) are associated with reductions in acute SBS (sick building syndrome) health symptoms and improvements in aspects of work performance (Fisk et al., 2011). On the other hand, a dedicated outdoor air system (DOAS) that is often used with radiant systems may result in lower ventilation by eliminating the outdoor air economizer. DOAS may also result in poorer IAQ because the particle filtration of recirculated indoor air is eliminated.

Dampness and mold problems that can result from water leaks and poor relative humidity control can have a large impacts of occupants' health. Some building designs or mechanical systems that increase ventilation rates (e.g., evaporative cooling systems) will require careful attention to dampness and mold control, because such systems can also be sources of microbial contaminants and increase indoor air humidity.

Lighting

People associate daylight in offices with better comfort and health (Galasiu and Veitch, 2006). The strong preference for daylight, in addition to the energy saving potential, is driving designs that increase daylight. But in daylit offices, sun glare, direct sun and heat gain, are concerns that need to be addressed. Advanced lighting controls must be responsive to the different lighting level preferences of people, and their different responses to glare. Design strategies to incorporate daylight need also to consider that the preference for daylight may be strongly tied to a preference for a view to the outdoors. integrated building envelope, daylighting, and lighting for more throughout discussions of technologies and economics.

Thermal Comfort

Avoiding over-cooling in summer, which is very common, and overheating in winter can improve occupant thermal comfort and cut energy costs. At the same time, work performance will often be improved (Seppanen and Fisk, 2006). Avoiding elevated temperatures can also improve satisfaction with air quality and reduce sick building symptoms. Large thermal zones controlled by a single thermostat are one common source of poor thermal control. Ceiling fans can enhance thermal comfort in warm environments (de Dear et al., 2013) at low energy cost (Figure 4). There is potential for radiant systems to improve thermal comfort by allowing finer zonal control, where the local gains and losses (e.g., hot or cold interior surfaces because of glazing) can be more easily balanced by surface temperature control.
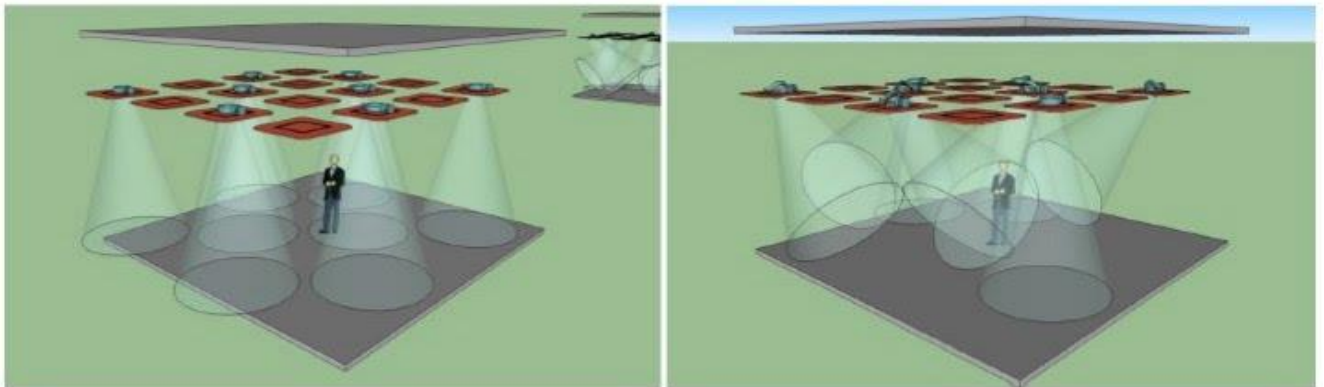
Figure 4. Project by Center for the Built Environment (CBE) to develop efficient prototypes of an integrated ceiling system that has ceiling fans, induction units, and nozzles. This work is conducted in collaboration with Armstrong World Industries (Arens and Brager, 2012).

Acoustics

A survey of 101 California buildings (including offices, public buildings, educational buildings, hospital, etc.) found the lowest satisfaction ratings for noise level (37% dissatisfied) and sound privacy (60% dissatisfied) (Moezzi et al., 2014), indicating that acoustic conditions are very important for occupant satisfaction. There are many complex relationships affecting privacy and acoustic quality (e.g., organizational culture, nature of work, management structure, and worker psychology) that should be considered when designing the office layout. For example, a study of fifteen LEED-certified office buildings found that among the three open-plan office types, occupants in bullpen configurations were more satisfied with acoustic quality than those in cubicles (Lee, 2010). This suggests that better understanding of occupant psychology (e.g., bullpen type offices allow workers to adjust work etiquettes in response to their neighboring coworkers) may be more important than having partitions.

Emerging technologies and strategies

Below are several examples of new technologies that have the potential to improve IEQ in innovative ways.

- **Sensor technologies:** While lighting and occupancy sensors are already common in buildings, as well as thermostat and CO2 sensors used for HVAC (heating, ventilating, and air-conditioning) control, new technologies are emerging that take into account multiple indoor environmental attributes to enable more advanced control. Sensor technologies may become available that can manage multiple aspects of IEQ in 5 to 10 years. For example, personalized preferences can be better satisfied by integrating people-counting and recognition technologies into control systems. Smartphones allow more ways for users to control lighting levels and room temperature. Low cost indoor air quality sensors being developed have the potential to detect specific air pollutants of health concern and send signals to control systems (e.g., particles and specific volatile organic compounds). Ventilation control can also make use of outdoor air quality data in its control algorithm, and outdoor air intake velocity sensor to improve system performance.

- **Building materials as passive air cleaners:** Building materials that can remove air pollutants are potential alternatives to conventional air cleaners that can be energy costly to operate. Studies in a laboratory setting show that activated carbon mat and and perlite-based ceiling tile can remove ozone in buildings without generating undesirable by-products (Cros et al., 2012). New wallboard and coating systems are being introduced that claim to remove formaldehyde from indoor air. Formaldehyde increases the risks of cancer and may increase allergy and asthma health outcomes. Long term performance data are needed. Commercial products with data to show their efficiencies may take 10 or more years to become available on the market.

- **Indoor microbial environments on health and productivity:** Very little is known about the airborne microbial communities in built environments. Some of the factors that can affect their presences may include human occupancy, outdoor air, ventilation strategies, humidity, space cleaning, and other aspects of building design. Allergens and airborne infectious agents have clear and important health consequences to building occupants. Ventilation and filtration strategies that can reduce allergies, asthma symptoms, and disease transmission will have substantial health and productivity benefits. There are existing HVAC technologies that aim to provide antimicrobial

protection (e.g., UV lights, antimicrobial coatings), but more research that focus on asthma and disease transmission reduction is needed.

- **Photobiology:** The link between lighting and health and well-being goes beyond visibility. Insufficient or inappropriate light exposure can disrupt standard human rhythms, which may result in adverse consequences for performance, safety, and health (Bellia et al., 2011). Lighting designs that consider both the visual and non-visual effects on human physiology and behavior (e.g. circadian rhythms and metabolic activities that can in turn affect disease prevalence) may bring great benefits to building occupants. A shift from lumens to circadian efficiency as LED technologies become more common is likely to change future designs of lighting intensity, spectrum, and timing of exposure.

- **Thermal comfort controlled by occupants:** Occupant's ability to control their environment is a strong determinant for occupant satisfaction. Technologies such as personal environmental control systems (PECS; Figure 5) has the potential of achieving high satisfaction at low energy costs. In mixed-mode buildings, buildings can perform well when the system is designed with high degrees of direct user control, such as operable windows (de Dear et al., 2013). The ways occupants interact with the building introduce new opportunities and challenges in maintaining comfort in thermal non-uniform and non-steady state environments. More reliance on personal environmental control and natural ventilation may be the trend in the next 5 to 10 years in effort to reduce HVAC energy use.

Conventional		dead band	
Adaptive	radiant	free-running	ceiling fans
PECS	personal environmental control systems		

16 18 20 22 24 26 28 30
Temperature (°C)
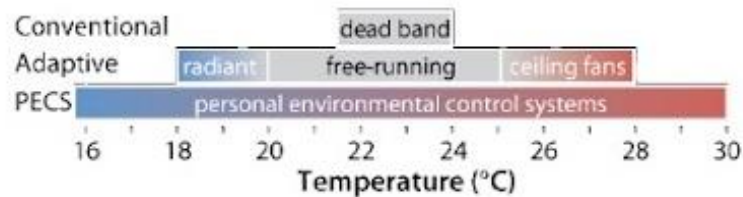
Figure 5. Personal environmental control systems (PECS) can provide comfort in naturally ventilated or radiantly cooled buildings, where the air temperature is less-controlled and likely to be slowly-responding relative to conventional HVAC systems (Arens and Brager, 2012).

Other Considerations

Beside good designs, IEQ also depends on good maintenance practices and the way occupants interact with the indoor spaces. The commissioning process can include IEQ to identify opportunities to make improvements. For campus-scale adoption, it is important to recognize good IEQ as part of the concept of "healthy buildings", that can also include issues affecting the well-being of employees and the larger community such as walkability, linkage between work and home environment, and environmental justice, are some extensions to the "healthy buildings" concept. Finally, the resilience of our built environment is becoming an increasing concern as we face climate change. Building designs may include features that can maintain IEQ during heat waves, power outages, and nearby wildfires, and can reduce risks of dampness and mold problems after severe storms and floods.

Institutional Requirements & Capacity

There are many aspects of IEQ that require a wide range of expertise from the design team, who needed to be educated on issues related to indoor air quality, lighting, thermal comfort, and acoustics. The design team will need inputs from the users (may include facilities, building managers, employees, and other stakeholders) so that their needs for IEQ are met. While simple IEQ checklists (e.g. LEED) are helpful, they are likely inadequate to ensure comfort, health, or productivity on their own. The Center for Built Environment (CBE) has an Occupant IEQ Satisfaction Survey that can be used to gather information for post-occupancy or post-retrofit evaluation (Figure 6). The effects of IEQ on health and productivity will require more specific tools to assess. Even though it is not the common practice, maintaining good IEQ will require long-term environmental monitoring as well as periodic evaluations from occupants. Thermal and visual comfort have been rigorously brought together in a Genentech case study building.
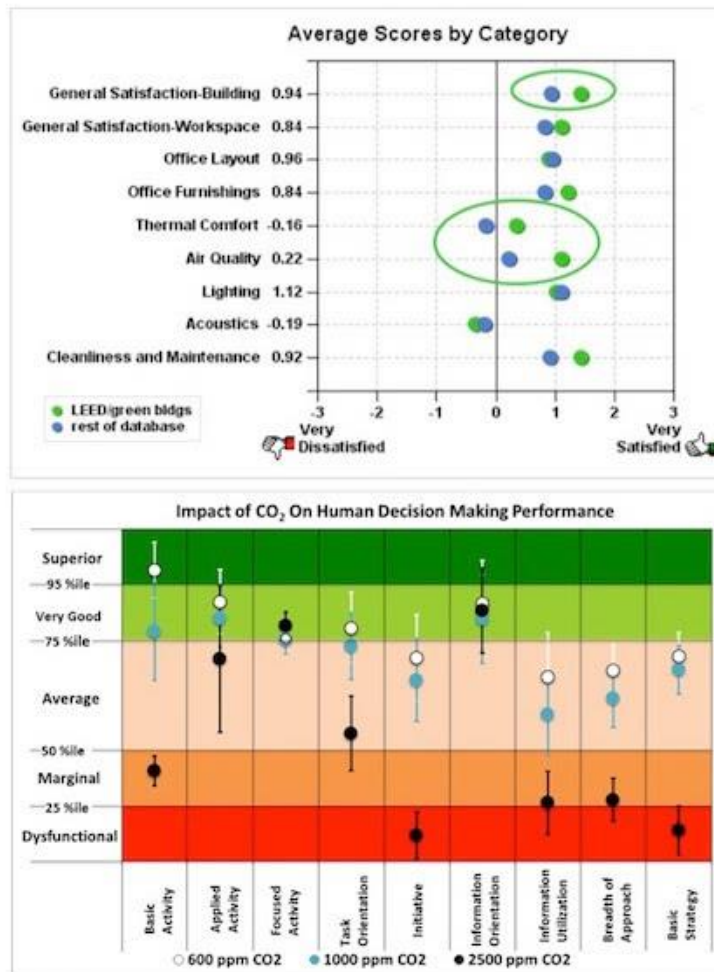
Figure 6. Example results of CBE's Occupant IEQ Satisfaction Survey (top) and performance evaluation tool to assess the effects of CO2 on decision making (bottom, Satish et al., 2012).

B Applications at multi-building and urban scales

1 Demand Response & Electric Vehicles
By Mary Ann Piette

Demand response (DR) programs are developed and executed between electricity providers and customers to help change electric load shapes in response to economic or reliability issues with the electric grid. This is a topic of interest to large building owners because there are a growing array of programs available for owners to save money on electricity costs.

There are growing DR programs around the US and around the world. Figure 1 shows the DR capacity for commercial and industrial customers from a study to explore these developing markets. There is a large existing and technical potential for DR in 11 western states. These data are from the FERC National Assessment of DR with extensions from LBNL. The existing DR capabilities range from about 1% to nearly 11% of peak demand, with technical potential reaching 16%.

Chart 1.1   C&I DR Capacity by Region, World Markets: 2014-2023

(Source: Navigant Research)

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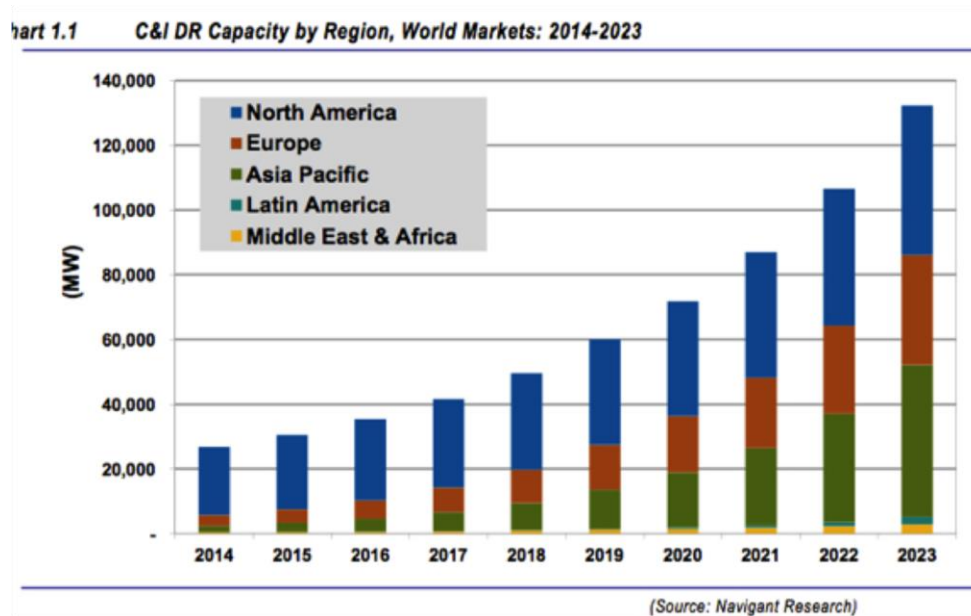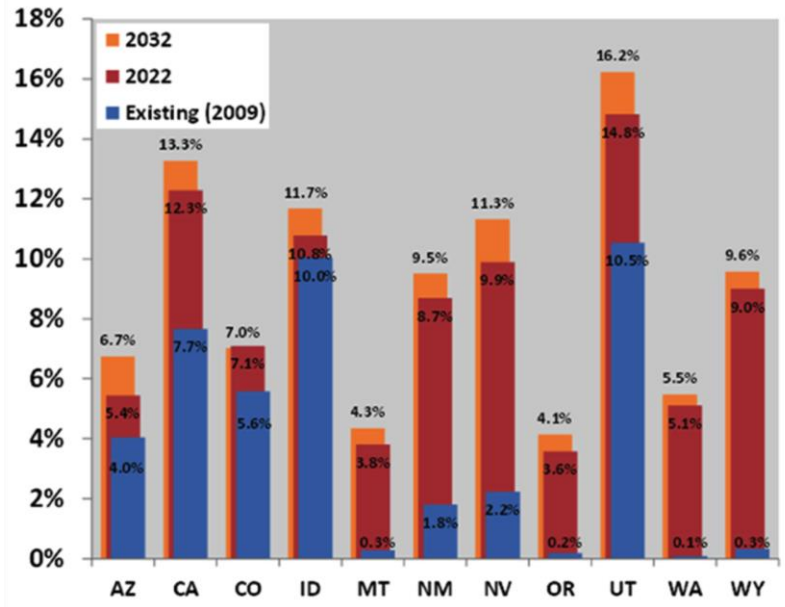
Figure 1. (a) Growing array of DR programs in the US, Europe, and in Asia and (b) a large savings potential in the Western US.

Applications

Historically DR has been targeted towards reducing customer demand during times of seasonal grid stress (typically hot summer afternoons or cold winter mornings or afternoons). Demand response strategies can be manual, semi-automated, or fully automated. Manual techniques require that a person actively participate in a DR event and change control systems for a given period of time, then restore them to normal. Semi-automated DR is a "man in the middle" configuration where there may be a set of automated responses programmed into a sequence of operations, with the trigger requiring a person to confirm or execute the command. Fully automated DR involves the electricity providers or DR program aggregator using an automated signaling system and the facility receiving signals. These signals are linked with pre-programmed control sequences in lighting or HVAC controls to automatically execute a change in the electric load shape.

The most common end-uses for demand response in commercial buildings are HVAC systems. There are a variety of strategies that can change the electric load shape depending on factors such as built-up or package unit systems or variable air volume or constant volume systems (Motegi et al, 2007; Piette et al, 2007.) Buildings with high thermal mass are good candidates for DR because the mass can be used to shift cooling loads and pre-cooling can be effective as part of a DR strategy. Many lighting systems can also provide demand response depending on how centralized the controls are. Dimming systems are capable of providing a fast and predictable load change.

Two key trends are motivating new DR program designs. One is that with improved automation and telemetry systems, building loads can provide fast ancillary services that are cleaner and potentially lower cost than conventional generators. Examples of the grid products that are

developing into new markets are shown in Table 1. These products require DR systems that respond more often at different times of the day. Grid operators are looking for loads that can be reduced as well as increased. The second trend is that with the desire to provide greater levels of electricity from renewable sources such as wind and solar, the need for these advanced DR products are increasing. Developing an electric grid with more variable renewable supply is requiring the need for more flexible demand.

Products		Physical Requirements			
Product Type	General Description	How fast to respond	Length of response	Time to fully respond	How often called
Regulation	Response to random unscheduled deviations in scheduled net load (bidirectional)	30 seconds	Energy neutral in 15 minutes	5 minutes	Continuous within specified bid period
Flexibility	Additional load-following reserve for large un-forecasted wind/solar ramps (bidirectional)	5 minutes	1 hour	20 minutes	Continuous within specified bid period
Contingency	Rapid and immediate response to a loss in supply	1 minute	≤ 30 minutes	≤ 10 minutes	≤ Once per day
Energy	Shed or shift energy consumption over time	5 minutes	≥ 1 hour	10 minutes	1-2 times per day with 4-8 hour notification
Capacity	Ability to serve as an alternative to generation	Top 20 hours coincident with balancing authority area system peak			

Table 1. Summary of new grid products for ancillary services (Kiliccote, et al. 2015).

An important technology trend in is the use of open standards for DR communication. All of the large California electric utilities are using Open Automated Demand Response (OpenADR) version 2.0 which is supported by the OpenADR Alliance. OpenADR 2.0 is also adopted by the Bonneville Power Administration. It is used in more than 8 countries around the world and in a growing number of utility programs across the US. In California the new building codes require that lighting and HVAC systems have the capability to receive and respond to a DR signal. This is a trend likely to continue in other parts of the US and around the world, and it is worth noting that all of the major building control companies are members of the OpenADR Alliance, offering many commercial products that are OpenADR 'ready'.

Figure 2 shows the client server architecture that is the core of OpenADR. Utility or grid operators provide signals to facilities using XML-based clients. There is a new language of DR signals in OpenADR that represent information such as integer electricity prices or grid signal modes.
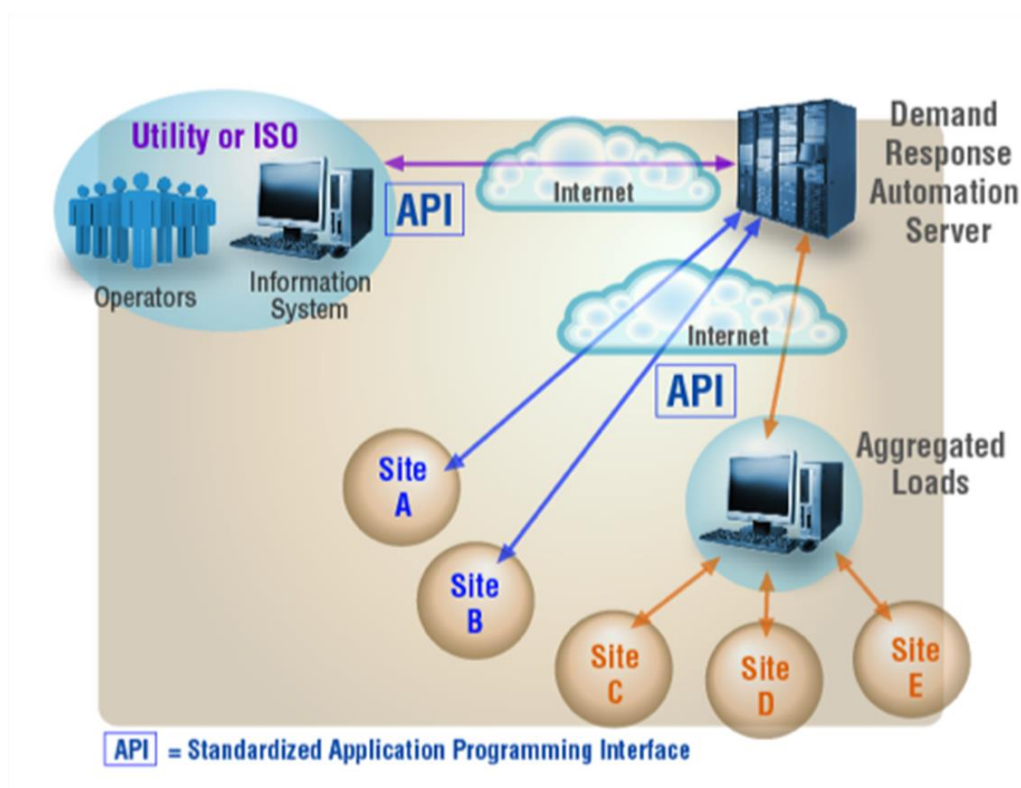
Figure 2. *OpenADR is a client server signals system where utility or grid operator's servers send signals to clients who are aggregators, campuses, buildings, or end-use system controls.*

As DR programs evolve, dynamic pricing is key factor in DR and also a distinct issue in facility design and operations. The design of building, facility and systems needs to consider the electricity pricing available from the local electricity providers. There are many tariff designs around the US and around the world. There is a growing trend toward dynamic pricing. Most large campuses have to respond to time-of-use pricing and may have peak demand charges. Some regions have critical peak pricing that may include particularly high prices for 50 to 100 hours per year. The new advanced heating and cooling storage plant at Stanford University will be subject to day-ahead hourly prices. They will use a 7-day model predictive control to minimize energy costs (see discussions in District-level Energy Services and Diagnostics sections).

Another key factor in DR is energy storage. Large campus systems can often use storage systems to manage and flatten electric loads to minimize energy prices. Storage systems may consist of ice or chilled water, hot water, or electric batteries. The design and operation of these systems can reduce operating costs.

Another trend that facility managers need to plan for is the introduction of electric vehicles (EVs). These vehicles may include a local fleet that the campus manages and dispatches as well as EVs owned by the employees and visitors. EVs are a growing electric load that is plugged into the building or campus in the morning when employees arrive, and comes off the system when they

depart. There may also be on-site electric fleets. The most important issue is the coordination of charging to ensure that electric loads are flattened and distributed.

Some innovative campuses are evaluating whether a fleet of electric vehicles can provide two-way, vehicle to grid storage. (Marnay et. al 2013, Juul Frederick et. al 2015)

Economics

The economics of demand response and storage systems is highly variable and related to the electricity pricing structures, incentives from utilities, and structure of DR program incentives. Some past customers have saved about 2% of annual utility costs by participating in DR programs. The first cost for enabling DR systems depend on whether the effort is manual, semi-automated or fully automated. Electric utilities in California are providing incentives of about $200/kW to $400/kW to pay for OpenADR.

With the growing EV loads at campuses and facilities the energy management staff needs to determine if charging will be free or if there is a recharge mechanism. There are a variety of techniques to manage charging infrastructures and commercial offerings.

Other considerations

A key co-benefit of demand response is energy efficiency. Many facilities managers find that when they participate in DR events there is an important feedback to basic energy management. For example, a common DR strategy is to set up zone temperatures for 4 hours. Many facility managers identify zones that are over cooling and may end up resetting normal operating conditions. Another example is duct static reset. A DR strategy that changes the duct static pressure for a short time can result changing normal set points. Another co-benefit of DR is load shape analysis and price response. Many facilities pay high peak demand charges, which can represent up to half of electric utility costs. Participating in DR events can provide information about how to modify electric load shapes to reduce utility bills.

A final area of co-benefits of DR is the consideration of the capability of the system to run in low-power modes. Future electric systems will have more distributed generation, storage, and features common to emerging micro-grids. Having distributed DR capabilities allows a local system to run in low-power mode during emergencies and grid outages. A DR capable system has the ability to run on reduce power mode for sustained periods. An advanced DR system may be able to reduce lighting, HVAC data center, and plug loads.

The development of the ability to reduce electric loads for transactions with the electric grid is an important capability that is emerging in energy management. The need and nature of these transactions will continue to evolve over the next decade as we have more distributed generation and lower cost control automation. These capabilities have synergistic benefits with daily energy management and are valuable as electric prices become more dynamic and time differentiated.

Institutional requirements & capacity

There are training needs associated with demand response since it is a new area of operations. Facility managers need to understand the economics of participating in a program as well as the control strategies the facility plans to execute. In addition, commissioning practices will need to be modernized to address DR systems and protocols.

Similarly there are new electrical system requirements for EV charging stations. Facility managers need to evaluate the location and use of these stations to provide new services to the growing number of EVs at their sites. Some facilities instigate recharge systems to the local staff or visitors.

As more EVs are located on a facility's electric meter, the dynamic charging system can use the EV load as part of a DR strategy and defer the charging for a few hours, or cycle the cars to manage the peak demand. The basic concept is to require that when a car is plugged into the charging system, the requirements for how fast it has to be charged are recorded and the charging is managed as part of the total load management activity. If charging is no needed to be completed until the end of the work day, the charging load can be flattened and managed as part of the flexible load for cost minimization.

2 District-level Energy Services
By Gerald Robinson

Best practice with district energy systems is quickly changing and evolving well past what was commonly thought of as an underground system of hot and chilled water lines feeding campus buildings from a centrally located plant of pumps, chillers and boilers. Goals of high reliability, resilience after major disasters, managing energy price volatility, "decarbonizing" energy supplies, reducing capital and operating costs, and high levels of energy and water efficiency are pushing the district energy system to new levels of performance and functionality. It is the district energy system that provides the integration platform and allows planners great flexibility in thinking holistically which make possible the achievement of these multifaceted enterprise goals in a campus setting. Often undervalued and overlooked, it is district energy systems that liberates the architectural design and planning process to achieve ground breaking visions as the often highly constraining (and costly) challenges around siting utilities at each building are resolved.

Applications

The new Stanford University district energy system (under construction) provides an excellent large-scale example of how multiple benefits can be achieved by exploiting the synergies between interrelated systems (Figure 1). The strategy for reducing greenhouse-gas emissions was to move from natural gas to electricity generated by 25% to 33% renewable energy. The green oval in Figure 1 highlights two scenarios (one with 25% and the other with 33% renewable energy) that achieve the simultaneous benefits of reduced emissions, increased efficiency, low

life cycle cost, reasonable capital and operating costs and very low water use. This new plant has many of the features depicted in Figure 2, such as ground source heat pumps, onsite renewable energy, and high levels of waste heat capture.
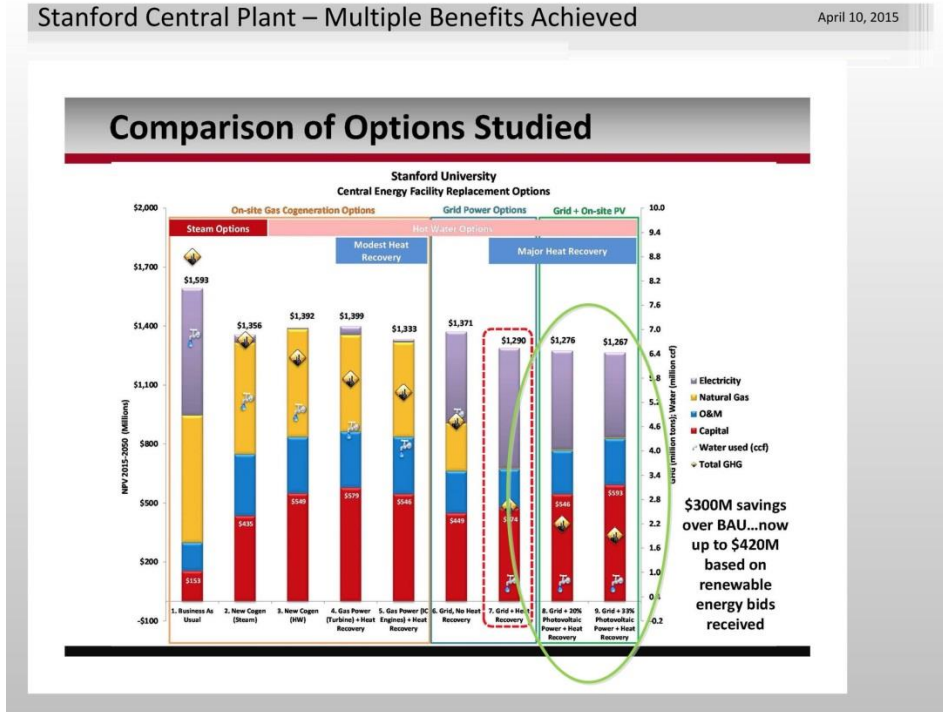
Figure 1. Stanford Energy Systems Innovation - March 2015 Presentation "Systems Overview" (source: Joseph Stagner)

In addition to reducing the capital costs of new construction projects, district energy infrastructure allows for flexibility in long-range planning and operations. District energy systems provide the flexibility in site planning needed to attain architectural and space planning objectives as each building no longer needs a cooling and heating plant and can be located remotely from energy sources needed. The infrastructure allows sources of energy (electricity, gas, waste heat) to be remote from the loads thereby allowing great flexibility in planning building locations and managing site environmental, noise and sight-line factors. District systems can be established as a campus-wide system or in a grouping of a smaller clusters of buildings which provides for flexibility in investing in the infrastructure.

Harnessing waste heat and capturing the full benefits of heat pumps (in this case used to raise the temperature of waste heat) are examples of strategies enabled by district systems. Waste heat recovered from combined heat and power systems, chillers, food service equipment and data centers offsets the use of hydrocarbons, eliminates water use in cooling towers (and associated chemicals and O&M costs), while increasing reliability and energy efficiency.

The ability to utilize sources such as biogas and reclaimed water located outside the property boundary becomes possible as the district system provides convenient points where sources can be injected into the system. This is important in interfacing with the region's electrical, natural gas, and waste water systems.
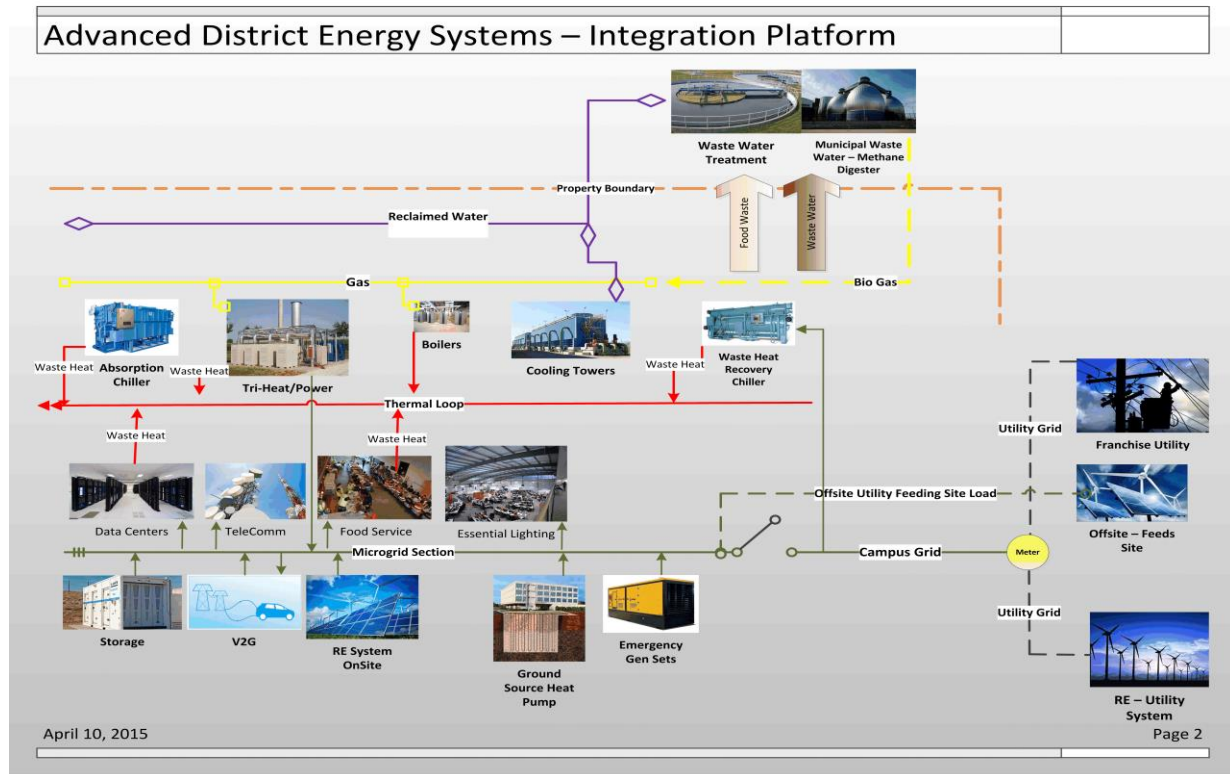
Figure 2. Depicting Interrelated Benefits in an Advanced District Energy System.

"Quick payback" present-day technologies

Designing low-temperature (less than 170F) and low-head pressure systems with advanced controls that enable setbacks on temperatures according to loads required to meet space conditioning needs is a very effective investment. Such systems minimize the use of expensive control valves with variable speed pumps placed strategically to ensure a balanced energy delivery to all locations where the supply is closely matched to the need/demand.

Such systems allow for the use of materials (piping and insulation) that are much more durable and less expensive than traditionally used copper, steel and iron piping. Examples of lower cost yet durable piping materials are polyethylene cross-linked (PEX), high density polyethylene (HDPE) and fiber piping. These new piping materials are flexible allowing for high survivability during earthquakes and are used with trenchless installations that have proven to be very valuable when running services through environmentally sensitive areas and or where existing buildings and hardscape make traditional digging, disruptive and expensive.

Lifecycle-Cost-Effective technology

Establishing an advanced microgrid as part of a district energy system provides high value of reduced downtime, disaster resilience along with savings from demand response, efficiency and onsite/adjacent renewable systems. A microgrid should be viewed as an essential element. From an operational and broader societal perspective, a large customer that can clearly demonstrate the value of an advanced microgrid.

Use of energy storage as a means to enable arbitrage between on- and off-peak rates and provide valuable flexibility in load management; compensating for intermittent renewables and demand response (DR) programs. Thermal storage can act in a manner analogous to electrical batteries; charging with excess or low cost power and discharging to offset expensive or scarce electricity. Thermal storage can be used to relieve the timing constraints associated with combined heat and power systems around electrical and waste heat production and use.

Emerging technologies and practices

While still in the early- to mid-development phases, vehicle to grid infrastructure (V2G) is a very germane and exciting technology (Tomic et al., 2007; Wang et al., 2014). The V2G technology value come from enhanced resiliency (a source of backup power in disasters) and from grid services such as micro-second load smoothing of large onsite solar PV systems and other power quality services (voltage, VAR and power factor). V2G technologies can also offer DR value in the form of curtailing charging. However, using vehicles as storage sources for the utility or microgrids is complicated by battery life considerations.

A growing portion of buildings loads can be classified as "natively direct current" meaning the end use components operate on direct current (DC) Lighting, data centers, desktop computers, monitors, telecom equipment and networks are all native DC appliances. Given that onsite renewable and storage systems produce and store DC power, at least a hybrid AC/DC microgrid is important to consider as power supplies can be eliminated (or simplified) thereby saving energy, eliminating most power quality issues, reducing points of failure. and lowering first costs. The move towards power over Ethernet (POE) and over new USB standards is illustrative of this trend towards DC power sources proliferating in buildings to meet DC loads. A main DC electrical bus may also be an ideal integrating (simple, low cost, robust) for onsite renewables, battery storage and native DC loads.

Economics

A financial analysis of district system investments should take into account the avoided cost savings accrued from not installing heating and chilling plants in each building and from the reduction in floor space dedicated to multiple utility rooms. Square footage and infrastructure (boilers, chillers, pumps, controls, fire life safety systems shop space) all represent very large first costs that can be saved altogether. In the presence of a district system, a building can "plug and play" with minimal investment in utility systems. With life-cycle cost analysis, two factors increase the financial attractiveness as these systems as efficiency improves with square footage

served. System losses are spread out and greater diversity in loads increases the ability to operate equipment at peak efficiency.

Other considerations

With low- or no-cost design features built into district systems, the distribution of thermal and electrical energy can be attained with very high levels of reliability. For example, with "looped" distribution systems, repairs can be performed without the loss of services to individual buildings.

The need for redundant fire/life safety issues are reduced as generator sets and fuel storage, combustion appliances and fuel, pressure vessels, chillers, cooling towers and water treatment chemicals are located centrally verses at each building. This reduces the need for specialized fire suppression systems and alarms and exhaust systems to manage refrigeration leaks. The number of remote locations where facility engineers must work in is greatly reduced, decreasing labor costs and the opportunity for workplace accidents.

Building occupant comfort is improved as there is a reduction downtime, in noise and unsightly utility equipment located at each building. Compatibility with radiant heating and cooling within the building envelope is also aligned with enhanced comfort.

Institutional requirements & capacity

The costs to maintain the utility infrastructure are greatly reduced. Proactive and intensive preventative maintenance program are also easier to sustain when equipment is located centrally. Cost savings come from several sources. The number of trips taken by facilities engineers with the associated fleet vehicles (plus fuel and wear and tear) is greatly reduced as the majority of maintenance work shifts to central utility buildings.   The costs and administrative effort to maintain repair parts and supplies inventories results in real savings with district systems. Each large building with its own heat, cooling and power plants represent a large commitment in man power, specialized service contractors and repair parts inventories.

3 Waste Heat Recovery
By Gerald Robinson

In a campus setting with many sources of waste heat, a large percentage of the heating load normally carried by conventional heating equipment can be directly offset. Waste heat recovery should be implemented as part of a comprehensive and integrated campus energy and water plan. Waste heat capture schemes directly offset hydrocarbon use, reduce water consumption (cooling tower use) and increase energy efficiency, reliability and service life of compressor-based equipment (chillers, food service equipment) and data center servers. Waste heat recovery technologies, ground source heat pumps (or air source heat pumps) and district energy systems are often highly complimenting and interdependent technologies.

Applications

District heating loops are critical in making the link between waste heat (sources) and end uses (loads) physically separated in disparate buildings (Figure 1). Examples of sources are shown in Table 1. Thermal storage is important in breaking through the limitation of timing waste heat source generation with when it is needed by end uses. District heat loops can be established between a smaller cluster of facilities or campus-wide depending on density of buildings and the sources and uses for waste heat. Through the use of hot water heating loops and or thermal storage, waste heat system are highly flexible in meeting space heating and domestic hot water needs.

"Quick payback" present-day technology

Data centers using water-cooled CPUs represent an existing cooling technology that captures higher temperature waste heat (up to 80C) that can be directly injected into heating loops to provide very cost effective space and domestic hot water (Coles et al., 2014). Water cooled servers not only make use of a high quality waste heat source but also increase reliability as the critical componentry is kept well below manufacturer's recommended operating temperatures. There are other data center cooling schemes in use today that capture large volumes of lower temperature waste heat that can also be very valuable (see Google case study for an example).

Boiler stack retrofit recuperators and heat recovery ventilators are two very cost effective heat recovery technologies for retrofit of existing equipment. These technologies when applied correctly do not interfere with normal operations of the host equipment. Heat recovery ventilators, which exchange thermal energy from exhaust and outside air are particularly effective in facilities (labs and clean rooms) that must have a very high percentage of exhaust and outside air with several full building air exchanges per hour. Boiler stack recuperators are applied to non-condensing equipment as a means of using stack waste heat.

Lifecycle-cost-effective

Heat recovery chillers can be installed when the infrastructure (low temperature heating loop) is in place to capture and transport that heat to end uses. This type of chiller is designed to develop higher temperatures on the condenser side of the machine and are often cost effective when electricity prices are low. Instead of a single condenser bundle connected to a cooling tower, a heat recovery chiller has a second bundle for capturing waste heat - waste heat is taken first and then what remains is dissipated by a conventional cooling tower. A small amount of additional space is needed for the extra pumps and piping to make the connection to a district heating loop (Trane 2015).

Designing a low temperature hot water loop is not only important for efficiency but also for effective waste heat capture and for keeping the capital and operating expenses low with the associated equipment. Designing the hot loop operating temperature low enough so that waste heat can be taken directly off a heat recovery chiller is ideal as the capital and operating expense of installing and using a heat pump to raise the temperature is avoided altogether. If the hot water loop design temperature is too high, a heat pump will be needed to raise the temperature of the

waste heat. McQuay is one manufacturer that offers an appliance designed specifically for this purpose (McQuay 2015).
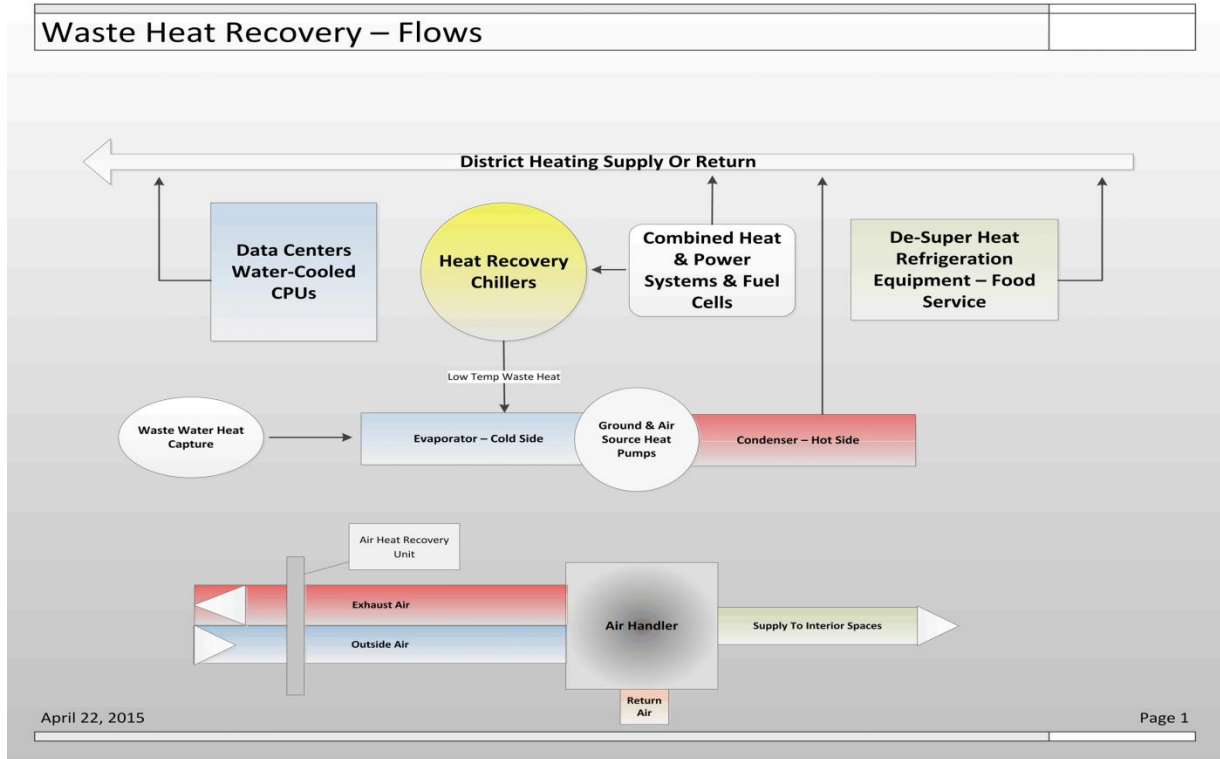
Figure 1. *Common Waste Heat Opportunities - Commercial Sector (Gerald Robinson LBNL 2015)*

Table 1. *Waste Heat Sources Availability and Hardware Needed. (Gerald Robinson, LBNL 2015)*

Emerging technologies and practices

Using double-walled brazed heat exchangers to move heat between dissimilar substances such as refrigerants and water or hot gases under pressure and water has proven to be a very effective technology in industrial settings and could easily be adapted in commercial buildings. This is an available but highly underutilized technology that can very cost effectively (simply, safely and by code) bridge between waste heat sources that in the past could not be associated such as hot refrigerant gases under pressure and domestic hot water.

Extracting heat from waste water streams should be considered where there are large outflows. The City of Vancouver is extracting heat from waste water for injection into a rapidly grown hot water district plant. Large waste water outflows should be examined for the potential for waste heat capture (Bula 2014).

Campus-scale and other considerations

Low temperature hot water district energy loops with thermal energy storage is needed to allow for substantial waste heat capture and to associate sources and uses that are rarely co-located. With the underlying infrastructure in place, the campus design team is freed from the constraints of co-locating sources and uses of waste heat which in turn allows important architectural and planning features to be realized.

Waste heat capture technologies in a commercial setting represent an improvement in safety and noise pollution from a reduction in the use of combustion appliances and cooling towers. It also can reasonably be assumed that waste heat capture would also likely improve the service life of compressor-based equipment as the work load is greatly reduced.

4 Renewable Energy
By Gerald Robinson

Large private enterprises can play a significant role in deploying renewable energy technologies at scale while advancing their own financial and sustainability goals. A well-planned and executed strategy, backed by senior management, will achieve multiple benefits. Among these are utility cost reduction, "decarbonized" energy supply, disaster resilience, grid interoperability, employee-commuter cost savings, high levels of energy efficiency, water conservation, and reduced business risks associated with energy price volatility. Obtaining these benefits requires that renewable energy acquisitions be planned so as to exploit synergies with interrelated on-site infrastructure as well as Federal, state and region's energy, water and waste management conditions. Emerging technologies and practices offer opportunities for novel applications for power, heat, and gaseous fuels.

Applications

The following sections group renewable energy technologies and strategies into progressively cutting-edge categories.

Mainstream Technology

Solar PV – Today's prices for solar photovoltaic systems demonstrate strong economies of scale making aggregated purchases across multiple sites attractive financially. Prices for large, >1 MW rooftop and ground mounted systems are at or below the $3.50/watt which equates to $0.09 - $0.11/kWh. Purchased Power Agreements for multi-megawatt offsite projects can offer significantly lower prices ($/kWh). Economies of scale are mostly achieved in customer acquisition and legal costs (Barbose, Weaver and Darghouth 2014; Honeyman et al. 2015). Sites with very low utility costs can be made viable through an aggregated procurement by leveraging economies of scale benefits.

Solar thermal (air and liquid) - Evacuated tube solar thermal technologies offer the ability to capture heat during sub-optimal weather conditions and can generate higher water temperatures than do flat plate collectors. This technology is also less orientation-sensitive and therefore easier to integrate into building facades. Solar walls and roofs are an effective technology for pre-heating ventilation air as well as night cooling, and are nearly maintenance free (Figure 1).
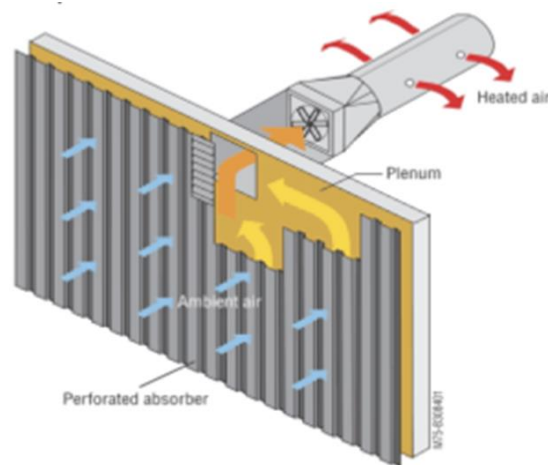
Figure 1. Solar thermal wall (Source: www.solarwall.com)

Wind - While it is often impractical to site wind projects onsite, power contract prices for large offsite wind contracts have fallen to below that of power from natural gas plants (Wiser et al. 2013). While small, building-mounted turbines have achieved some visibility and serve to make a certain "green statement", given their size and siting constraints their contribution to overall energy needs is small.

Lifecycle-cost-effective

Ground source heat pump (GSHP) technologies exchange thermal energy with ground water or soil and provide an effective means of reducing purchased energy and water while providing an efficient, flexible, and low-cost means of capturing waste heat. GSHP systems require no cooling towers, saving on capital costs and space requirements, associated high water consumption and chemical treatment systems, as well as maintenance. They can serve a single facility but are most effective as part of a district energy system where waste heat can be easily utilized and where

simultaneous heating and cooling is needed. High efficiency is achieved independent of climatic conditions, yielding five-to six-times more useful thermal energy than electric resistance heating.

Alternative fuels for fleet, vendor and employee vehicles are part of any comprehensive strategy. Establishing, for example, renewably-based vehicle chargers with one of the emerging vehicle-to-grid (V2G) approaches provides a means of enhancing resiliency, grid services (voltage support, power factor correction, VAR support), and reducing vehicle-related emissions and costs. Solar-PV-shaded carport structures are ideal locations for electric vehicle (EV) charging and or the implementation of V2G strategies allowing EV batteries and or plug-in electric vehicles batteries and engine/generators to provide load management services to nearby buildings and backup power capability during grid disruptions.

Emerging technologies and financing mechanisms

Building integrated solar PV (façade and window) or building integrated solar thermal technology (beyond thermal walls) developments represent an area of renewable energy of high potential currently receiving little industry attention. Intense market pressures to date have focused nearly all R&D investments on conventional roof, ground and carport systems.

Large energy users also have an opportunity to become active members of the project finance community, and to develop new and widely replicable financing mechanisms. One example is innovative power contracts such as the "synthetic power purchase agreements" (PPAs) used to a limited extent with wind and solar PV projects (Figure 2). Synthetic PPAs result in new-renewable generation being added to the regions' transmission/distribution system without the constraints of gaining an interconnection agreement from merchant utilities. The generated power is not delivered to end-user; rather the customer pays a hedge price to the developer in exchange for the market price. This allows the developer to have a guaranteed price for power (the hedge price) and shares market risks with end use customer, which can see either income or an expense depending on the market price relative to the hedge price.
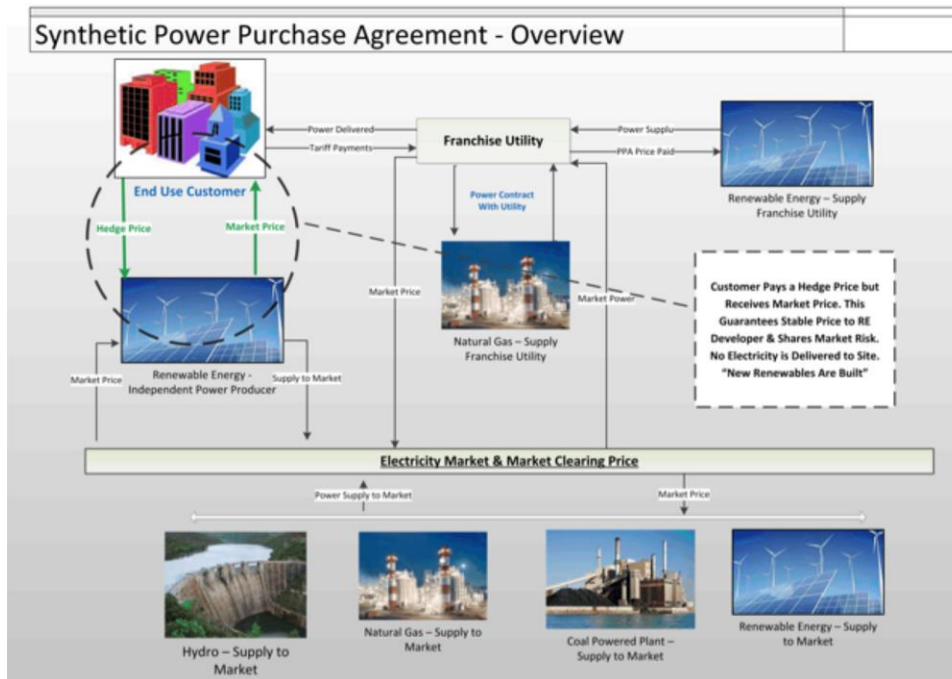
Figure 2. *Synthetic power purchase agreements in context with the broader market and more traditional approaches*.

Customers can also partner with regional utilities and regulators on pilot initiatives. There is potential for adding new features to offsite renewable power contracts such as "dispatchability" standards that require industry to find ways of managing the problems of intermittent supplies. Several technology companies, including Adobe, Cisco, Ebay, EMC2, Facebook, HP, and Intel participate in a 25-company initiative championed by the World Wildlife Fund and World Resources Institute to promote Corporate Renewable Energy Buyer's Principles, setting aggressive renewable energy goals, addressing barriers, and collaborating to drive change in policy.

Enterprises are integrated parts of the region's utility markets and waste management systems. Analyzing the capacity and technology limitations of these systems can reveal opportunities. One example is to generate biogas either onsite or at an offsite waste-management plant, in turn alleviating stresses on existing public infrastructure. Water conservation (reclaimed water for landscape) and reduction of excess nitrogen levels from wastewater releases could also be achieved [see Apple example].

Institutional Considerations

Consumers can source renewable energy from onsite systems as well as through partnerships with investor utilities and independent power producers (Figure 3). Onsite technologies should be selected and sized based on resiliency considerations as a first priority and then, if conditions allow, specified to attain greater contributions to overall energy needs. Onsite production opportunities will most often be insufficient for achieving the "net zero" energy goals. Offsite contracts help extend the renewable power fraction.

Comparing Locations of Renewable Power Systems & Benefits Achieved					
Siting Option	Serves Site Loads	Benefits	Limitations	Contract Methods	Operations Responsibilities
On-Site	Yes	Resiliency, Cost Savings, Visibility	Smaller sized systems	Self-Funded, Power Purchases or Utility Funded	Self or Contract Operations or Utility Operated
Adjacent Property	Yes	Larger, Higher Savings, Reduced Price Volatility Manage Noise & Sightline Issues	Potentially Larger Systems	Power Purchases or Utility Funded	Power developer
Offsite Through Franchise Utility or Independent Power Producer	Yes	Larger, Manage Noise & Sightline Issues Locate where renewable resources are better Meet Net Zero Goals	May need Interconnection Agreement	Power Purchases or Utility Funded	Utility
Offsite Through Independent Power Producer	No	Very Large System Sizes Reduced Price Volatility Locate where renewable resources are better Meet Net Zero Goals	Price Risk	Synthetic Power Purchase	Power Developer

Figure 3. Renewable power system siting options and implications.

The setting of renewable energy targets is an important part of the planning process. Organizations should establish financial metrics (e.g., levelized cost of energy internal rate of return, return on equity, simple payback period), minimum thresholds for each that factor in the value of co-benefits (water savings, resiliency, etc.), and targets for energy-related emissions reductions for both onsite and offsite systems. This requires development of associated guidelines for risk tolerance, use of debt and equity and for renewable power system purchases versus contracts for the purchase of renewable energy from third parties.

From a broader community perspective, renewable power contracts should induce the construction of "new renewable sources" that either feed site load directly or equally offset power usage through the region's power market. For customers interested in pushing the cutting edge, participation in a wider array of off-site generation types can be considered, including emerging strategies such ocean energy. The purchase of generic renewable energy credits (RECs) unbundled from the power source have no affect on the market for new renewables and do not spawn the construction of new sources. The cost of generic RECs is very low and thus provide no financial incentive to developers of renewable projects. With limited exception, generic RECs should not be used.

Renewable energy systems can enhance resilience and support business continuity plans in the event of external utility service disruptions. This can be achieved in conjunction with advanced micro-grids (a modern component of district energy systems) which also bring many other benefits to the enterprise in terms of demand response (DR) capability and other grid responsiveness features in the form of power quality benefits.

Minimizing obstacles to future implementation of renewable systems

All new and major construction projects should embrace a high degree of flexibility in design in order to accommodate future additions to renewable power systems onsite by embracing the principals of "solar" "microgrid" and "EV charger" ready.

Either in phases or in large efforts, investing in district energy distribution infrastructure (electrical, thermal, gas) will make future investment in renewable energy sources technically and financially viable while providing for greater levels of energy and water efficiency.

Signing long-term power contracts with third party independent power producers and or offering hedges (as with synthetic leases) can make new projects attractive to investors – minimizing barriers for developers and investors is critical.

C Flagship Projects

1 Adobe

By Paul Mathew

	Fact box
	Global number of employees: **11,847** Locations globally: **86** Square feet of occupied space: **3,213,120** LEED-certified Buildings: **70% of total floor area** EnergyStar Buildings: **5**

Corporate Initiatives & Goals

Adobe's 2013 Corporate Responsibility report states that: "Every year we strive to outdo ourselves in operating sustainably. We aim to make our sites as green as possible, offsetting our carbon emissions and generating our own energy at key locations. Additionally, our products allow our customers to live greener through products like EchoSign and Creative Cloud."

Adobe has a Sustainability Policy Statement that includes goals for energy, water, waste, materials, products, education.

Their Corporate Sustainability Report (CSR) brief from 2012 states that they have three high level goals:
- Achieve Net Zero energy consumption by 2015 in owned facilities in the United States

- Reduce the amount of product packaging used per unit by 40 percent by 2012, and 80 percent by 2014
- Expand the employee-led Green Team to all of our 12 major sites globally by 2015

Adobe clearly has aggressive and multi-year sustained enterprise-wide efforts for sustainability. In *Newsweek's* 2014 Green Rankings, Adobe was named the second greenest company in the United States and third greenest in the world, after Vivendi and Allergan. In the category of IT companies, Adobe tops the list both in the U.S. and globally. It has a CDP (Carbon Disclosure Project) score of 99. Adobe was the first company to earn LEED-EB Platinum Certification in June 2006 and has continued certification resulting in over 70% of its entire workspaces being LEED certified. In terms of carbon emissions reductions, Adobe has directly reduced and/or avoided its Scope 1 and Scope 2 carbon emissions through sustainability initiatives for its owned and managed buildings in the United States by 51%, and through purchase of RECs and VERs (Verified Energy Reductions), they have offset their total Scope 1 and 2 emissions by 100%.

Since 2002, Adobe's nine owned North American facilities we've completed more than 180 energy efficiency projects that have reduced electricity usage by 50 percent, natural gas usage by 30 percent, domestic water usage by 79 percent, and irrigation water usage by 71 percent. They have developed and implemented a monitoring and energy analytics system that captures energy and critical operations data based on thousands of data points, from electricity, water, and natural gas usage to the power usage effectiveness (PUE) of all Adobe data centers. In their San Jose, California, headquarters they collect energy usage and critical operations information for more than 30,000 data points. Many end uses are sub-metered, including data centers, HVAC, lighting, kitchen loads. They worked closely with their Energy Information System (EIS) vendor to develop and configure the EIS to meet their requirements.

Beyond energy-related sustainability efforts, Adobe employs an aggressive waste diversion policy in all of its owned and controlled buildings. Currently, this initiative has resulted in Adobe facilities diverting 97% of its waste overall within the US. It actively collaborates in USGBC's Building Health Initiative, Net Zero buildings and BSR's Future of Internet Power (BSR-FOIP). Adobe also participates in a 25-company initiative championed by the World WIldlife Fund and World Resources Institute to promote Corporate Renewable Energy Buyer's Principles, setting aggressive renewable energy goals, addressing barriers, and collaborating to drive change in policy.

Flagship Project: Adobe Corporate Headquarters

- Project type: retrofit
- Address: 345 Park Avenue San Jose, CA 95110-2704 [Map]
- Number of buildings: 3
- Floor area: 939,358 square feet of office space; 938,473 square feet of semi-enclosed parking garage
- Occupants: 2,300 employees, including consultants and temporary workers
- Site: N/a acres

- Walk Score: 86/100*

Extensive improvements to this existing Headquarters facility achieved LEED-EB platinum certification in 2006 (Figure 1). In working towards LEED certification, Adobe implemented over 64 energy and energy-related conservation projects at a cost of $1.4 million with an annual cost savings of $1.2 million – equating to an ROI of 121 percent and an average payback per project of 9.5 months. Adobe's LEED-EB Platinum certification efforts, specifically, have had a net ROI of 148 percent while the costs of certification are just 10 percent of one year's savings. In its most recent Portfolio Manager update (2013), the building scored 82 (ranging from 75 to 100 over the years).

As a result, they achieved the following resource-use reductions:

- electricity use: 35%
- natural gas: 41%
- domestic water use: 22%
- irrigation water use: 76%

Figure 1: The Adobe Corporate headquarters consists of three buildings in San Jose, California, all of which are ENERGY STAR certified.

Selected measures include:

- Occupancy control of HVAC for 201 conference and meeting rooms. Occupancy controlled stairwell lighting.
- Retrofitting variable frequency drives for main supply fans in the West Tower resulted in annual savings of approximately $47,000.
- Installing variable frequency drives (VFD) on the primary chiller in Adobe's West Tower resulted in savings totaling approximately $39,000.
- Labor to reduce operating times on garage supply fans cost a total of just $100. This modification in the fans' programming resulted in savings of approximately $67,000 per year – with no compromise to air quality.
- Real-time, digital electric meters and enhanced graphic data analysis software closely monitor electricity use and measure savings realized from the various electricity-conserving projects undertaken by Adobe. This monitoring system has allowed Adobe to

identify and correct programming errors and other inefficiencies that might otherwise have gone undiscovered, resulting in annual savings of approximately $96,000.

- Adobe has also installed 12 100 kW Fuel Cells by Bloom Energy on its 5th floor parking garage (Figure 2). The fuel cells deliver about 30% of the electricity used at Adobe's headquarters. Adobe purchases RECs (Renewable Energy Certificates) to balance the CO_2 generated by the fuel cells and achieve carbon neutrality.
- 20 vertical axis wind turbines (called "Windspires") on the 6th floor patio generate clean energy from the natural wind tunnel configuration of the towers (Figure 3).
- Adobe provides free Cal Train passes to its employees and monthly vouchers for other transit systems. Bicycle commuting is encouraged by providing weather-sheltered bicycle racks, with gear lockers and showers at each building. Electric vehicle charging stations are available for guests and employees free of cost. As a result of these measures, 24% of the total Adobe population commutes on public transit (compared to 4% average for the surrounding county of Santa Clara).
- Adobe diverts up to 95 percent of its waste from landfill projects. Computer equipment, batteries, printer toner, fluorescent lamps and ballasts are among office waste items recycled; kitchen grease and cafeteria waste are composted.
- All janitorial products satisfy the American Society for Testing and Materials (ASTM) Cleaning Stewardship for Community Building Standards and meet the Green Seal Cleaning Products Standards.
- Water use has been reduced by 30 percent overall, and by 76 percent in landscaping. Run times of outdoor fountains have been reduced from 119 to 60 hours a week. Adobe was the first company in Santa Clara County to obtain a permit for installing waterless urinals. Landscape plants were specifically selected for the local climate zone; they are low-maintenance and drought-tolerant. Watering is by subsurface drip irrigation, turned on and off by eT-controllers which automatically adjust watering rates according to air temperature, precipitation, wind and humidity – factors all transmitted by wireless technology from local weather stations.

Figure 2: Adobe has installed 12 100 kW Fuel Cells by Bloom Energy on its 5th floor parking garage.
The fuel cells deliver about 30% of the electricity used at Adobe's headquarters.

Figure 3: There are 20 vertical axis wind turbines on the 6th floor patio.

2 Apple

By Richard Diamond

Factbox

Global number of employees: **98,000**
Locations globally: **453 Retail Stores around the world**
Square feet of occupied space: **n/a**
LEED-certified Buildings: **23**
EnergyStar Buildings: **0**

Corporate Goals & Initiatives

Apple's sustainability goal is:

> "to power all Apple corporate offices, retail stores, and data centers entirely with energy
> from renewable sources — solar, wind, micro hydro, and geothermal, which uses heat

right from the earth. We're designing new buildings and updating existing ones to use as little electricity as possible. We're investing in our own Apple onsite energy production as well as establishing relationships with third party energy suppliers to source renewable energy." (Apple 2015).

As of 2014, 100 percent of Apple's U.S. operations and 87 percent of their operations worldwide were powered by renewable energy, including their current headquarters (Figure 1) (Apple 2015). Apple and First Solar announced in early 2015 that Apple was paying $848 million for 25 years of the output of a 130 MW block of First Solar's California Flats project in southeast Monterrey County. Economists speculate that the deal may have been influenced by the company's corporate commitment to sustainability, Google's recent solar investments, and by involved favorable tax credits (Wolfram 2015). Focusing on its supply chain (energy and paper) and overseas operations, Apple is building a 20MW photovoltaics system in China and partnering with the World Wildlife fund to safeguard 1 million acres of forests from unsustainable logging practices (Gallucci 2015). The company's ultimate goal is to power 100% of its supply chain with renewables (Phillips 2015).

Figure 1. Apple headquarters, Cupertino, California

Apple's commitment to sustainability is company wide, including headquarters, retail stores, data centers, and their manufacturing sites. As noted, Apple's main campus in Cupertino, CA runs on 100 percent purchased renewable energy, and energy efficiency is a high priority. In 2012, they completed a major energy overhaul of their six buildings at the Infinite Loop location, achieving a combined electric and natural gas savings of more than 30 percent at a time when occupancy increased by more than 12 percent.

Apple's electricity use has been increasing due to the growth in data centers, but has stayed flat in corporate and retail sectors despite increases in area and people due to the investments in efficiency (Figures 2a-b).
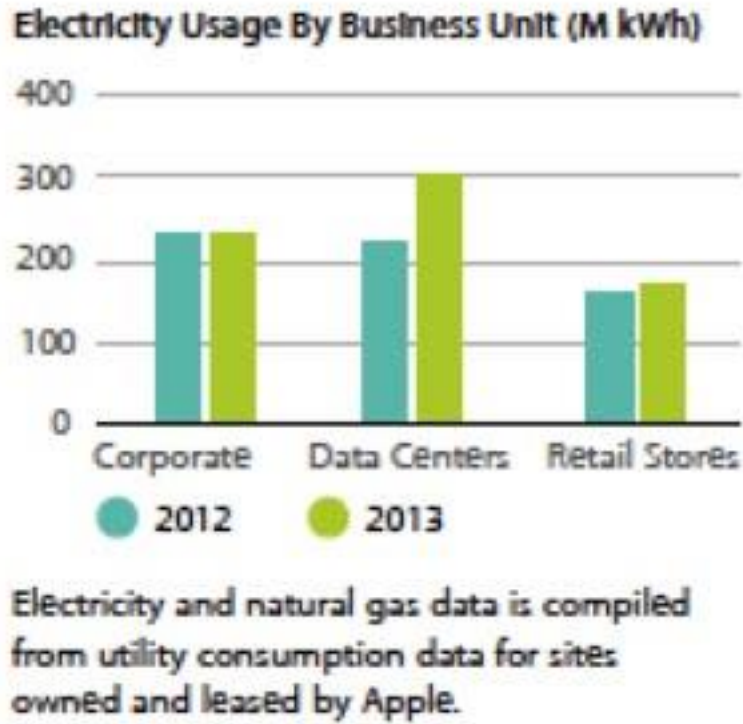
Figure 2a. *Apple's Electricity Use for Corporate, Data Centers, and Retail Stores, 2012 and 2013   Source: Apple 2014*
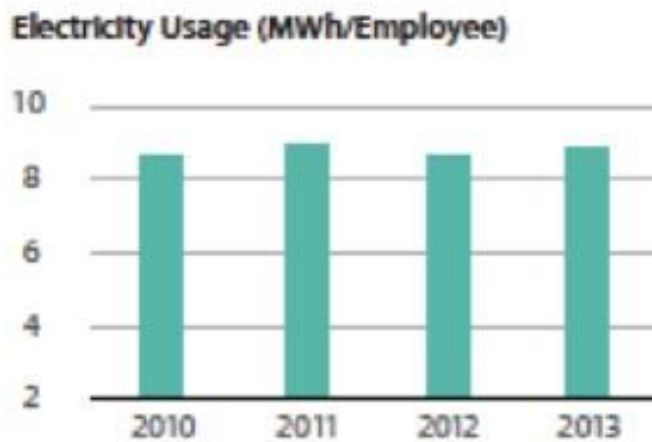
Figure 2b. *Apple's Electricity Use per Capita 2010 and 2013 Source: Apple 2014*

By applying energy-equipment upgrades and control system improvements across the more than 100 buildings they occupy in Cupertino and the area, Apple has saved 28.5 million kWh of electricity and 751,000 therms of natural gas over the past three years. Their Cupertino buildings are supplied by 100 percent clean, renewable energy. An onsite directed biogas fuel cell currently produces approximately 4 million kWh of electricity annually, and rooftop solar systems on the Vallco Parkway and Homestead facilities collectively produce 1.1 million kWh annually. To meet the rest of their load, Apple purchases clean power through California's direct access program and use the Green-e Energy program to certify that it is truly renewable (Apple 2014). Twenty biodiesel buses already transport employees within a large surrounding radius.

Flagship Project: Apple Campus 2 (under construction)

- Project type: new construction
- Address: 19111 Pruneridge Avenue, Cupertino, CA 95014 [Map]
- Number of buildings: 1
- Floor area: 2,800,000
- Occupants: 13,000
- Site: 176 acres
- Walk Score: 44/100*

Figure 3. Apple Campus 2

Steve Jobs presented his vision to the Cupertino City Council in 2011 (video here). Energy was not discussed per se, but considerable emphasis was given to other environmental dimensions of the project and implications for the broader community. One aim is to consolidate a workforce of approximately 12,000 people, currently spread among many sites in the region, and, in the process reduce transportation dependency for some. Another overarching goal is to provide a smaller aggregate built footprint by removing many buildings and constructing a single far larger one, while increasing the accompanying vegetated space. Some of the targets are:

- Increase landscaped portion of the 150 acre site from 20% to 80% (while increasing interior space by 20%)
- Reduce surface parking by 90% (parking underground)
- Reduce site-wide building footprint by 30%
- Increase vegetation cover by 60% (from 3,700 to 6,000 trees)

Apple is committed to using 100% renewable energy throughout Apple Campus 2 (Figure 3), including the sites east and west of North Tantau Avenue. The Main Building will incorporate a variety of technologies that help to achieve Apple's net zero energy goal. Initiatives include radiant conditioning systems, LED electric lighting, natural ventilation, and green information and communication technologies. The building will use 30% less energy than typical R&D office buildings (Apple 2015).

Other energy initiatives at Campus 2 include:

- 300 electrical vehicle-charging stations will be provided, with built-in capacity to expand.
- Buildings will be designed to allow for passive heating and cooling and high performance building systems.
- The majority of energy use be generated on-site through the use of photovoltaics and fuel cells with directed biogas. These will be supplemented by grid purchased renewable energy if needed during periods of peak demand.
- Approximately 8MW of photovoltaics will be installed on the Main Building and parking structure roofs.

In addition to their buildings-related energy goals, Apple has plans for transportation energy reduction, based on their current programs. These new plans include:

> "Getting to and from the new campus will be greener, too. We're expanding our existing commute alternatives program by 20 percent. This means that over a third of our nearly 15,000 employees in Cupertino can commute to the new campus using our biofuel buses, public transit, bicycles, carpools, and their own two feet. And for drivers, we'll have over 300 electric vehicle charging stations."

Water use is also targeted for conservation, both at headquarters and in manufacturing centers. In 2013, Apple made a number of water improvements at their Cupertino headquarters. Apple converted over six acres of landscaping to climate adapted, drought tolerant plants and retrofitted the irrigation system to optimize water savings. They replaced over 36,000 square feet of turf with drought tolerant plants, which is expected to save over 3 million gallons of water each year. In 2015, Apple agreed to co-fund one-third of a $17M recycled water infrastructure project that will serve the community in which Campus 2 is located (Love 2015). Apple will itself use only three percent of the pipeline's capacity.

3 Ebay
by Evan Mills

Factbox

Global number of employees: **33,000**
Locations globally: **185**
Square feet of occupied space: **n/a**
LEED-certified buildings: **2**
EnergyStar Buildings: **7**

Corporate Goals & Initiatives

Social Innovation is one of the four top-level categories messaged on Ebay's corporate website, and the company organizes its corporate social responsibility into 11 major areas, three of which -- obtain 8% of electricity use from green energy sources, reduce carbon emissions per transaction by 10%, and green shipping-- focus on energy and environment. The first two of these pertain directly to energy use in facilities.

Ebay estimates that about 26% of its carbon footprint is attributable to its office buildings, and 50% to its data centers, and 16% to warehouses. A number of buildings have been constructed to LEED standards, including one in Bangalore India. Energy use in facilities, receives only brief discussion in the latest (2013) sustainability report, with most attention given to community activities, waste management, and charity. The company constructed its first building in 2008, which received a LEED Gold rating, and states that every subsequent building has also achieved LEED Gold (CDP 2014 report). The building included what was at the time the largest rooftop solar array in the city of San Jose, CA. Most of Ebay's efforts on energy management appear to be focused on data centers.

Ebay participates in a 25-company initiative championed by the World Wildlife Fund and World Resources Institute to promote Corporate Renewable Energy Buyer's Principles, setting aggressive renewable energy goals, addressing barriers, and collaborating to drive change in policy.

According to its 2014 CDP report, the company identifies 16 sustainability criterion that it uses in citing its data centers:

1. Available free air cooling
2. Ability to provide key metrics on facility and subleased space on energy use, water use, waste, etc., as well as KPIs such as facility PUE, CUE, WUE, etc.
3. Incentive programs (tax, federal, state and local) to offset costs of sustainable measures
4. Current grid energy fuel mix (fossil/renewable)
5. Cost and permissive co-generation opportunities
6. Regional carbon capacities
7. Anticipated/future grid energy fuel mix (fossil/renewable)
8. Available solar energy capacity at or near the site
9. Available wind energy capacity at or near the site
10. Alternative water sources
11. Grey water reuse opportunities
12. Redevelopment and adaptive use opportunities
13. Ability of site to add scoring of LEED, BREAM or comparable system
14. Ability of site to contribute to net zero opportunities
15. Brownfield opportunities
16. Opportunity to locate in a rural area or diminished market

Ebay also notes that "historically, particularly for our low carbon energy investments, we have used alternative (as compared with standard business-as-usual) criteria for investment, including a longer payback period and lower ROI specification."

Flagship Project: Draper Customer Service Center

- Project type: retrofit
- Location: 583 West EBay Way, Draper, UT 84020, USA [Map]
- Number of Buildings: **2 (1: offices, 37 conference rooms, 1: reception, gift shop, food service and 300-seat dining area, training/fitness, and 480-seat auditorium)**
- Floor area: **237,181 square feet**
- Occupants: **1,800**
- Site: **36 acres**
- Walkscore: **20/100***

LEED Facts

for LEED BD+C: New Construction
(v2009)

Certification awarded May 2013

Gold	62
Sustainable sites	14/26
Water efficiency	5/10
Energy & atmosphere	16/35
Material & resources	7/14
Indoor environmental quality	13/15
Innovation	6/6
Regional priority credits	1/4

Figure 1. EBay facility in Draper, UT

A good work environment was cited as a key design objective for this building (Figure 1). Extensive attention to appears to have been paid to indoor environmental quality (13 of 15 possible LEED points earned). Company information states that heavy use was made of daylighting, although no related points were awarded under LEED (Figure 2). No post-occupancy evaluation has been reported.

Minimizing HVAC energy use was pursued on several fronts. A direct-indirect evaporative cooling system was employed, coupled with under-floor thermal distribution with a degree of personal control. The curtain wall glazing treatment is 0.25 SHGC low-e. A cool roofing system was used to minimize space-cooling needs. Company information states that 30% HVAC savings were achieved compared to typical practice, but no specific data were located. Extensive commissioning was performed.

The project received an Illuminating Engineering Society award for the lighting design, with mention of the lighting controls that included wireless daylight harvesting. LED parking lighting was used with peer-to-peer controls, reducing light pollution and meeting Dark-Sky Society standard. Green power is outsourced for all electricity needs. Preferential parking is given to electric and low-emission vehicles.

1000022564, Draper, UT

EBay Draper Campus
LEED BD+C: New Construction (v2009)

GOLD, AWARDED MAY 2013

SUSTAINABLE SITES		AWARDED: 14 / 26
SSc1	Site selection	1 / 1
SSc2	Development density and community connectivity	0 / 5
SSc3	Brownfield redevelopment	0 / 1
SSc4.1	Alternative transportation - public transportation access	6 / 6
SSc4.2	Alternative transportation - bicycle storage and changing rooms	1 / 1
SSc4.3	Alternative transportation - low-emitting and fuel-efficient vehicles	3 / 3
SSc4.4	Alternative transportation - parking capacity	0 / 2
SSc5.1	Site development - protect or restore habitat	0 / 1
SSc5.2	Site development - maximize open space	1 / 1
SSc6.1	Stormwater design - quantity control	0 / 1
SSc6.2	Stormwater design - quality control	0 / 1
SSc7.1	Heat island effect - nonroof	0 / 1
SSc7.2	Heat island effect - roof	1 / 1
SSc8	Light pollution reduction	1 / 1

WATER EFFICIENCY		AWARDED: 5 / 10
WEc1	Water efficient landscaping	2 / 4
WEc2	Innovative wastewater technologies	0 / 2
WEc3	Water use reduction	3 / 4

ENERGY & ATMOSPHERE		AWARDED: 16 / 35
EAc1	Optimize energy performance	10 / 19
EAc2	On-site renewable energy	0 / 7
EAc3	Enhanced commissioning	2 / 2
EAc4	Enhanced refrigerant Mgmt	2 / 2
EAc5	Measurement and verification	0 / 3
EAc6	Green power	2 / 2

MATERIAL & RESOURCES		AWARDED: 7 / 14
MRc1.1	Building reuse - maintain existing walls, floors and roof	0 / 3
MRc1.2	Building reuse - maintain interior nonstructural elements	0 / 1
MRc2	Construction waste Mgmt	2 / 2
MRc3	Materials reuse	0 / 2
MRc4	Recycled content	2 / 2
MRc5	Regional materials	2 / 2

MATERIAL & RESOURCES		CONTINUED
MRc6	Rapidly renewable materials	0 / 1
MRc7	Certified wood	1 / 1

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 13 / 15
EQc1	Outdoor air delivery monitoring	1 / 1
EQc2	Increased ventilation	1 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	1 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	1 / 1
EQc5	Indoor chemical and pollutant source control	1 / 1
EQc6.1	Controllability of systems - lighting	1 / 1
EQc6.2	Controllability of systems - thermal comfort	1 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	1 / 1
EQc8.1	Daylight and views - daylight	0 / 1
EQc8.2	Daylight and views - views	0 / 1

INNOVATION		AWARDED: 6 / 6
IDc1	Innovation in design	5 / 5
IDc2	LEED Accredited Professional	1 / 1

REGIONAL PRIORITY		AWARDED: 1 / 4
EAc1	Optimize energy performance	0 / 1
EQc8.1	Daylight and views - daylight	0 / 1
SSc4.1	Alternative transportation - public transportation access	1 / 1
WEc1	Water efficient landscaping	0 / 1

TOTAL	62 / 110

40-49 Points	50-59 Points	60-79 Points	80+ Points
CERTIFIED	SILVER	GOLD	PLATINUM

Figure 2. LEED Scorecard for Ebay Draper, UT facility

4 Facebook
By Paul Mathew

Factbox

Global number of employees: 9,200
Locations globally: 52
Square feet of occupied space: N/A
LEED-certified Buildings: at least 8
EnergyStar Buildings: 5

Corporate Goals & Initiatives

In a departure from most of the other companies we have studied, Facebook does not have a publicly available Corporate Social Responsibility policy, and does not respond to the annual Carbon Disclosure Project surveys. However, Facebook's sustainable activity appears to be broad-based, although they do not seem to publicize it as much as organizations such as Adobe. Their "Green on Facebook" facebook page has information on their enterprise wide initiatives. Most notably they provide real-time data on the energy and water efficiency of their data centers, which comprises the majority of their energy footprint (96% of their total energy use in 2013). The real-time energy information appears to be an element of their Open Compute Project. A 2012 article in The Guardian noted that Facebook revealed the carbon footprint of its operations, and that it was much lower than Google's. For datacenters, they had a fleet-wide PUE of 1.09 in 2013. Facebook also hosts sustainability-related events such as their Sustainability @scale conferences. They received the Silicon Valley Business Journal 2014 Structures Awards for Best Innovative/Sustainable Design for Facebook's new West Campus. Facebook participates in a 25-company initiative championed by the World Wildlife Fund and World Resources Institute to promote Corporate Renewable Energy Buyer's Principles, setting aggressive renewable energy goals, addressing barriers, and collaborating to drive change in policy.

Flagship Project: Facebook Headquarters

- Project type: retrofit
- Address: 1601 Willow Road, Menlo Park, US [Map]
- Number of buildings: 8
- Floor area: 1.1 Million sf
- Occupants: n/a
- Site: 57 acres
- Walk Score: 21/100*

Facebook moved into a campus previously occupied by Sun Microsystems and renovated it, achieving LEED-CI (commercial interiors) Gold certification. The project profiles on the USGBC

website indicate that the buildings obtained high points in lighting power, lighting controls, HVAC, equipment and appliance, commissioning, and green power (Figure 1). An application for an Environmental award from City of Menlo Park indicates the following measures were implemented:

- 15 to 20% reduction in energy use via energy efficient lighting and ballasts (LEDs and T-8s), occupancy sensors, windows films, HVAC controls, commissioning, BMS.
- Over 50% reduction in indoor water use through low flow fixtures/aerators, efficient cafeteria dishwashing, and low-volume toilets.
- 60% reduction in outdoor water use through Bay-friendly landscaping, lawn removal, and weather-based irrigation.
- 208 kW DC PV system (Figure 2).
- 34,714 kWh of thermal and electric energy saved through a solar PV and thermal co-generation system (Figure 3).
- 80% campus wide waste diversion.
- Over 40% alternative commuting (shuttles, vanpools, bicycling) - not clear in source docs whether this is number of employees, person-miles, or some other metric.
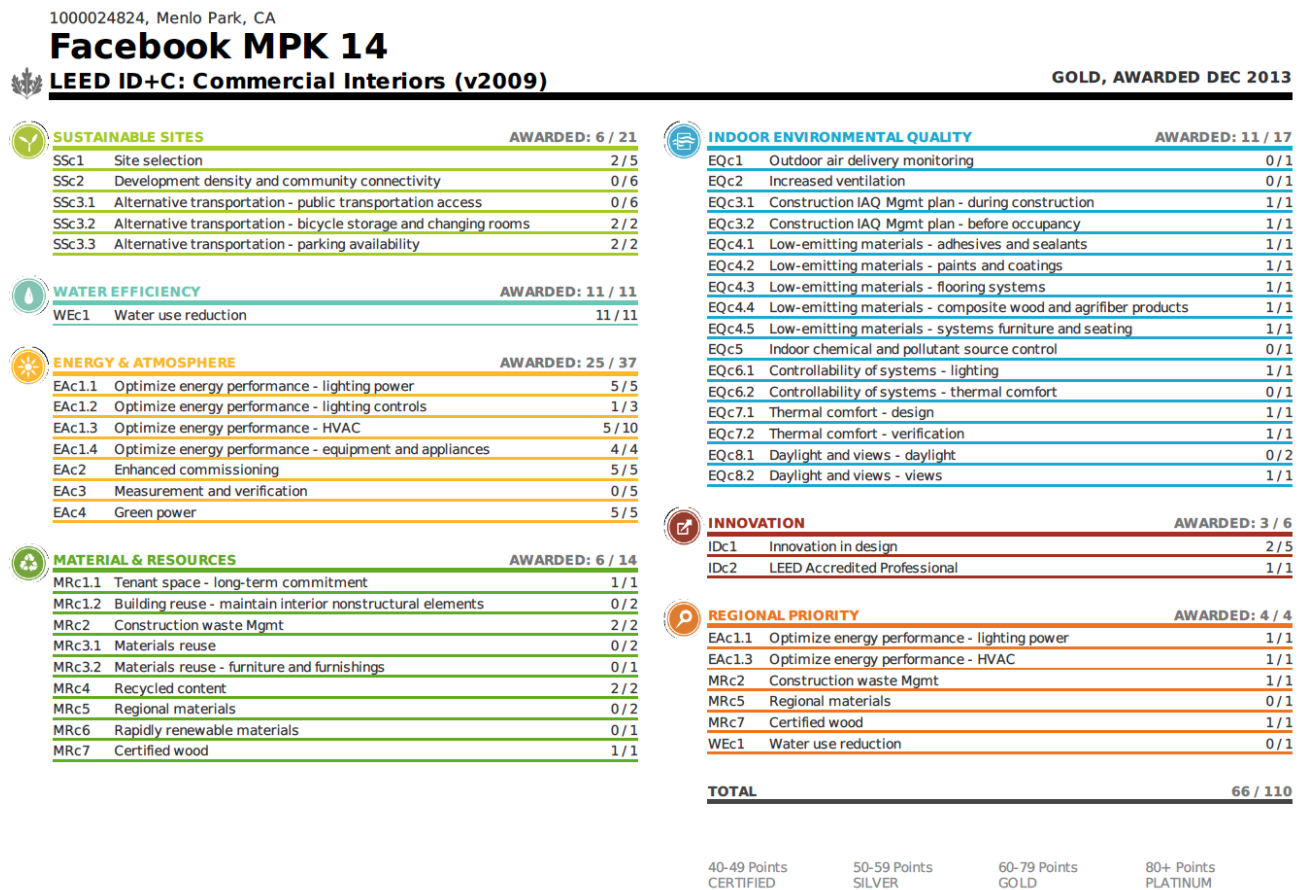- 25 electric vehicle charging stations (Figure 4).

1000024824, Menlo Park, CA

Facebook MPK 14

LEED ID+C: Commercial Interiors (v2009)

GOLD, AWARDED DEC 2013

SUSTAINABLE SITES		AWARDED: 6 / 21
SSc1	Site selection	2 / 5
SSc2	Development density and community connectivity	0 / 6
SSc3.1	Alternative transportation - public transportation access	0 / 6
SSc3.2	Alternative transportation - bicycle storage and changing rooms	2 / 2
SSc3.3	Alternative transportation - parking availability	2 / 2

WATER EFFICIENCY		AWARDED: 11 / 11
WEc1	Water use reduction	11 / 11

ENERGY & ATMOSPHERE		AWARDED: 25 / 37
EAc1.1	Optimize energy performance - lighting power	5 / 5
EAc1.2	Optimize energy performance - lighting controls	1 / 3
EAc1.3	Optimize energy performance - HVAC	5 / 10
EAc1.4	Optimize energy performance - equipment and appliances	4 / 4
EAc2	Enhanced commissioning	5 / 5
EAc3	Measurement and verification	0 / 5
EAc4	Green power	5 / 5

MATERIAL & RESOURCES		AWARDED: 6 / 14
MRc1.1	Tenant space - long-term commitment	1 / 1
MRc1.2	Building reuse - maintain interior nonstructural elements	0 / 2
MRc2	Construction waste Mgmt	2 / 2
MRc3.1	Materials reuse	0 / 2
MRc3.2	Materials reuse - furniture and furnishings	0 / 1
MRc4	Recycled content	2 / 2
MRc5	Regional materials	0 / 2
MRc6	Rapidly renewable materials	0 / 1
MRc7	Certified wood	1 / 1

INDOOR ENVIRONMENTAL QUALITY		AWARDED: 11 / 17
EQc1	Outdoor air delivery monitoring	0 / 1
EQc2	Increased ventilation	0 / 1
EQc3.1	Construction IAQ Mgmt plan - during construction	1 / 1
EQc3.2	Construction IAQ Mgmt plan - before occupancy	1 / 1
EQc4.1	Low-emitting materials - adhesives and sealants	1 / 1
EQc4.2	Low-emitting materials - paints and coatings	1 / 1
EQc4.3	Low-emitting materials - flooring systems	1 / 1
EQc4.4	Low-emitting materials - composite wood and agrifiber products	1 / 1
EQc4.5	Low-emitting materials - systems furniture and seating	1 / 1
EQc5	Indoor chemical and pollutant source control	0 / 1
EQc6.1	Controllability of systems - lighting	1 / 1
EQc6.2	Controllability of systems - thermal comfort	0 / 1
EQc7.1	Thermal comfort - design	1 / 1
EQc7.2	Thermal comfort - verification	1 / 1
EQc8.1	Daylight and views - daylight	0 / 2
EQc8.2	Daylight and views - views	1 / 1

INNOVATION		AWARDED: 3 / 6
IDc1	Innovation in design	2 / 5
IDc2	LEED Accredited Professional	1 / 1

REGIONAL PRIORITY		AWARDED: 4 / 4
EAc1.1	Optimize energy performance - lighting power	1 / 1
EAc1.3	Optimize energy performance - HVAC	1 / 1
MRc2	Construction waste Mgmt	1 / 1
MRc5	Regional materials	0 / 1
MRc7	Certified wood	1 / 1
WEc1	Water use reduction	0 / 1

TOTAL	66 / 110

40-49 Points	50-59 Points	60-79 Points	80+ Points
CERTIFIED	SILVER	GOLD	PLATINUM

Figure 1. LEED Scorecard for Facebook Menlo Park Building 14.

Figure 2. *Facebook headquarters with 208 kW DC solar system.*

Figure 3. *44-module solar cogeneration system on the roof of one of the cafes. The system has a capacity of 106 kW thermal and 20 kW   electrical and will substantially offset the energy required to produce hot water for the cafe.*

Figure 4. *One of 25 electric vehicle charging stations.*

Facebook is committed to providing electric vehicle charging for employees, and recently joined 15 other companies in the Department of Energy's Workplace Charging Challenge. The campus currently offers employees all available options, including DC fast charging, Level 2 charging, and Level 1 (trickle) charging.

5 Genentech

By Stephen Selkowitz

Corporate Goals & Initiatives

Genentech, founded in 1976, is a biotech/pharmaceutical company, subsidiary of Roche Pharmaceuticals with U.S. business headquarters in South San Francisco and three other smaller U.S. sites. The corporate headquarters site comprises buildings totaling 3.5 million square feet and housing ~12,900 employees. The space provides support for office, lab, and administrative functions and is growing with the addition of new office and lab space. Genentech had 2014 revenues of $16.3B and ranks #6 on the Fortune "100 Best Companies to Work For".

As a subsidiary of the European-based company Roche, Genentech inherits some of its building energy and sustainability performance themes and goals from its Swiss corporate parent but with a U.S. business practice overlay. Roche tracks a wide range of Key Performance Indicators, KPIs, which include many related to energy use, emissions, waste generation and water use. (Roche 2014) These are tracked over time and reported 1) in absolute terms, 2) with reference to number of employees, and 3) with reference to corporate sales. Genentech tracks a more limited set of Corporate sustainability parameters for its US operations, and for each of its four sites. They follow site energy use, site emissions, business travel emissions, fleet energy use, water use, waste generation, etc. as part of a 10 year master plan (Genentech 2014).

As a global biotech company faced with recruiting and ongoing staff retentions and productivity challenges, Genentech facilities objectives include:

1) Providing an attractive and supportive work environment in a competitive industry;

2) Optimizing energy efficient operation of the building while providing a comfortable and responsive workspace;

3) Providing a workspace that is amenable to ever-changing corporate needs; and

4) Broadly supporting corporate sustainability goals.

Genentech has undertaken an aggressive program on its South San Francisco site to upgrade existing buildings and to ensure that all new buildings push the state of the art. This supports the broader site goals to reduce energy use and carbon emissions. The South San Francisco (SSF) site is responsible for 62% of Genentech's total onsite energy use and they achieved a 4% reduction in total energy use between 2013 and 2014 despite doubling production output and an increase of 5% in headcount. Natural gas use was reduced by 9% in that time period due to to more steam production in production operations and ongoing work to optimize HVAC operation campus wide. Genentech participates in the USGBC Best Buildings Challenge with a goal of 20% reductions in energy, water and waste. The SSF site reduced energy use across 5 buildings by 33% per employee in two years and between 2009 and 2014, reduced onsite energy use per employee by 24%, exceeding its goal of 15%, from 153 GJ/person to 130 GJ/person in 2014. Onsite energy use data are externally audited by PricewaterhouseCoopers as part of the annual Roche Group sustainability data verification process.

Flagship Project: Genentech HTA Building

- Project type: new construction
- Project Name: Hilltop A, Bldg 35
- Address: 1475 Grandview Drive, South San Francisco, CA
- Number of buildings: 1
- Floor area: 260,000 sf
- Occupants: 1200
- Site: 173 acres

The most recent new building at the South San Francisco site is the "Hilltop A" HTA/Bldg 35, a 7-story, 260,000-sf general office use building, completed in early 2015 and to be occupied by September 2015. The new building is contributes to their strategy to reduce emissions at this site.

Genentech engaged Perkins and Will for the architectural design, with engineering design by Arup. The building is important not just as the newest on their site but because it incorporated a series of novel design studies intended not only to enhance this building but to provide a basis for enhanced design of future construction as well.

The design included two office wings connected by a large atrium. The longer axis of the building is oriented 22 degrees to the west of south. The primary office space is conditioned with a VAV system that makes use of outside for conditioning when possible and draws cooling water from a site wide central system when needed. The atrium space is conditioned with a radiant slab (see related Key Strategy). The envelope has relatively large glazed areas (glass type and area varies with orientation) with exterior fixed shading that varies with orientation and double, spectrally selective low-E glazing and dynamic interior roller shades linked to responsive daylight dimmable LED light fixtures (see related Key Strategy). Webcor was retained as the contractor with the challenge of making these complex design solutions deliver on their promise. Webcor had previously worked on other bay area buildings that also specified dynamic shading and dimmable lighting and noted that since these were not standard practice and routinely specified, that there were challenges getting the design and operational details to work effectively.   Webcor posed the following challenge to Genentech: "For a new building design, can we answer these questions in the affirmative?:

1. Do we understand how actual energy performance will correlate to predicted performance?

2. Will we be providing a consistently comfortable work environment for all employees at all times?

3. Is the space plan optimal; e.g. are we effectively using office space near windows and controlling lighting to service all work areas?

4. Will the facility management team know how to operate all controls and systems so as to deliver consistent and reliable performance?"

The owner/contractor team agreed that the answer was generally "not always", so they embarked on a rapid turnaround project to answer these questions for their new building that had been designed, with construction just underway. Although the primary building design had been completed, they had not yet specified the final lighting systems or lighting controls (LED, indirect fixtures with up and down independent sources, all sources dimmable, variable color temperature control); interior automated shading systems (automation sequences, control setpoints, roller shade optical properties, shade interior appearance, override capabilities); and office furniture systems (system type, location relative to window wall). Genentech engaged Lawrence Berkeley National Laboratory (LBNL) to assist in optimizing interior features that are critical to energy use and occupant acceptance; e.g. lighting, lighting controls, automated shading, and related space planning features that impact thermal and visual comfort. These tests were conducted in LBNL's FLEXLAB (Facility for Low Energy Experiments in Buildings) and test results were used to make final design decisions for the building. Their plan is to compare these results to performance in the occupied building and use these findings to influence future building designs. (Genentech 2014 video)

The contractor proposed and the owner agreed to conduct a series of studies to address key unresolved design issues while the primary building was under construction. This imposed tough time constraints, as final design decisions had to be made and orders placed so as not to delay final occupancy. Since the building had fixed external shading that differed by orientation, a 20' wide by 30' deep space in the rotating testbed in FLEXLAB was used. This allowed sequential testing of three primary orientations for solar control, glare and daylight (E, S, W) with weekly reconfigurations of the space after rotation by 90 degrees (fixed external shading was relocated as appropriate for each orientation and lighting fixtures were realigned internally). Iterative testing was conducted over a 6-month period with changing solar angles, under both clear, partly cloudy and overcast days built a database and experiential base on which final choices could be made. Interior measurements were made on light level distribution throughout the space, glare conditions at multiple task locations, thermal comfort measurements near the glazed façade, and lighting power measurements of each fixture. Control of the lighting was a particular challenge due to challenges of sensor placement and calibration with both the independent uplight and downlight components. Measured data was used to recalibrate lighting sensors to provide light levels that most consistently met targets under all sun and sky conditions. Different shade fabrics, interior shade finishes, control setpoints and shade positions were all explored to optimize visual and thermal comfort and still provide daylight savings. Initial testing under the spring season found 60% lighting energy savings in open plan office areas were achieved by tuning the lighting controls beyond the default daylight dimming baseline commissioned by the lighting control vendor.

Detailed iterative analysis of data from these design alternatives led to design recommendations for each of these topics. These were documented in a technical report and supplemented by onsite visits by Genentech staff who were able to work in the mockup to experience the operational issues, which allowed confirmation of reported findings. A key finding was the measurement of thermal and visual comfort in proximity to the window wall with proper shade and glare control. The study concluded that with reliable thermal and visual comfort near the curtain wall the furniture systems can be placed ~2 feet closer to the window than with conventional solutions,

thus "recapturing" ~2sf of floor area per lineal foot of façade. With a desire to comfortably accommodate as many staff as possible and with construction costs in the range of ~$500/sf, this represents a very large first cost savings that, in principle, pays for the incremental cost of automated shading and related light control features (even before energy savings are counted).

Genentech wants to extend this "performance experiment" further with two additional tasks to close the loop and inform future Genentech building designs. The test findings will first be confirmed during a "burn in" period after the building has been turned over to the owner by the contractor but before occupancy. A series of prototypical spaces will be tested over a one-month period to confirm both design predictions and implementation in the actual building. Note that traditional "Commissioning" is supposed to ensure that each component and system works "as intended" but does not always guarantee that the overall performance results for comfort and savings are achieved. This "burn-in" task extends the scope of traditional start up functions to better ensure that occupancy has fewer unexpected challenges. Feedback from occupants is crucial to continuous refinement of corporate real estate. Approximately six months after occupancy the LBNL team will initiate a post occupancy survey in conjunction with continued data collection to determine if the design "as-operated" meets expectations. This approach is intended not only to optimize the operations of this building but to further inform future Genentech design, construction, and operational efforts. Implementing state of the art controls in a manner that saves real energy and meets occupant comfort needs throughout the year has been an on going challenge in many new buildings. This project intends to break new ground in this area and set new expectations for high performance design that delivers on its promises.

6 Google
by Richard Diamond

	Factbox
	Global number of employees: **53,600**
	Locations globally: **several facilities in Mountain View, CA, plus offices nationally and 70 offices in more than 40 countries**
	Square feet of occupied space: **7,500,000**
	LEED-certified Buildings: **At least 30**
	EnergyStar Buildings: **1**

Corporate Goals & Initiatives

Google describes its commitment to sustainability and healthy environments as follows:

> "Our focus on creating healthy environments doesn't stop with the building materials in our offices. We make every effort to address the factors that impact people's experience of indoor environments, such as thermal comfort, daylight and access to views. We also provide aggressive performance benchmarks for energy and water consumption. We use sophisticated building control technologies to ensure systems are on only when we need them. We've installed solar electric and solar hot water panels on our roofs, treated water on-site for reuse, and used recycled municipal wastewater for other applications (e.g. toilet flushing and landscape watering). We have the aspirational goal of diverting 99% of construction waste from our projects."

Google has also pursued energy and environmental workplace standards, including ISO 140001 (Environmental Management), OHSAS 18001 (Occupational Health and Safety Management Systems) and ISO 50001 (Energy Management Certification) certifications.

Google is taking a three-pronged approach to reach its zero-carbon goal. First, it is making its server farms, office buildings, and commuting habits more energy efficient. Then the company is investing heavily — $915 million to date — in solar and wind producers to make clean energy more available. And finally it is buying enough carbon offsets to make the company carbon neutral — at least on paper — until it can meet its overall goal. In March, 2015, Google announced that it was investing $300 million in a fund created by Solar City. Some economists believe the deal was structured to allow Google to get the tax equity (Wolfram 2015). According to the Washington Post, Google has now committed more than $1.8 billion to renewable energy projects, including wind and solar farms on three continents. The Solar City deal, which may have a return as high as 8 percent, is a sign that technology companies can take advantage of investment formats once reserved only for institutional investors. Google emphasizes that this move is driven in no small part by the value of locking in known energy prices into the distant future, as distinct from reliance on highly volatile fossil fuel prices (Google 2014).

Google has pursued sustainability across its portfolio worldwide.

- **Utilizing waste heat from data centers:** At some of its data centers, Google re-uses waste heat from the servers to provide heat to the office building. Air from the hot aisles in the data center, which would normally be exhausted outside, is instead drawn over an air-to-air heat exchanger, where it is used to heat up incoming fresh air for the office area. In this way, no additional source of heat, such as a natural gas boiler, is required to heat the office building (Google 2014).
- **Reducing energy use in New York City:** They are participating in the Mayor's Carbon Challenge and reduced the carbon footprint of the NYC office by more than 15% in the first year of the challenge. More projects are on the way to further reduce energy usage, including chiller upgrades, lighting controls and wall insulation. They are also currently installing what will be some of the highest thermal-performing windows in the world.

- **Efficient heating and cooling In Zurich, Switzerland:** A chilled beam heating, ventilation, and cooling (HVAC) system uses significantly less energy to regulate building temperature while also occupying less space than conventional equipment.
- **LEED certification of buildings globally:** Google has over 4 million square feet of LEED certified buildings, 1.2 million of which are rated Platinum (highest level possible) and 2.6 million Gold, with more in the works. They also have one Green Star certification (Australia's LEED equivalent). The office in Dublin achieved Ireland's first Platinum certification and the Buenos Aires office achieved the first LEED certification in Argentina.
- **Energy benchmarking:** Google has set goals and benchmarks building performance using industry frameworks such as the US Green Building Council's Leadership in Energy and Environmental Design (LEED) certification program and the Living Building Challenge.

- **Water recycling in Hyderabad, Sydney and New York:** In Hyderabad, roughly 380,000 gallons of wastewater are treated and reused annually in non-potable systems (e.g. flushing toilets and landscaping). Similarly, the Sydney office (recently Green Star certified by the Green Building Council of Australia) treats and recycles waste water for toilet flushing and landscape irrigation. The New York office installed a system to capture and use groundwater that was being pumped into the sewer system since the building opened in 1932, replacing 20% to 60% of potable cooling-tower water.
- **Rainwater harvesting system in Dublin, Ireland:** A rainwater harvesting unit collects, filters, and treats rainwater to be used for toilet flushing for the bathrooms in the building. The system is estimated to gather 157,350 gallons annually (25% of the water demand).
- **Urban agriculture across offices:** Several Google offices, including New York, Pittsburgh and Mountain View, have taken up urban agriculture. Several have small gardens that supply fresh greens to the onsite cafes. Some even allow Googlers to pick their salad straight from the plant to reinforce where the food comes from. New York and Pittsburgh also host beehives that help pollinate the gardens and provide honey for the cafes, not to mention fighting the disappearance of honeybees by maintaining strong, managed hives.

In February 2015, Google unveiled plans for a ground-breaking, 3.4 million-square-foot campus conceived by architecture firms BIG and Heatherwick Studio (Figure 1).

> "Tech really hasn't adopted a particular language for buildings," said David Radcliffe, Google's vice-president of real estate development in a video proposal. "I mean, we've just found old buildings, and we've moved into them, and made do best we could."

Envisioned as both a neighborhood and as a wildlife habitat, the proposed master plan for the new Google campus on the fringes of Mountain View, California, features four clusters of buildings draped in a thin, glass membrane. These buildings, "rather than being made from concrete, will be built from lightweight materials in order to be quickly reconfigured to keep pace with Google's ever-expanding forays into fields such as automotive technology and biotechnology. Radcliffe compared the design to Lincoln Logs" (Wainwright, 2015).

Figure 1. *Artist rendering of the new Google Campus showing the glass canopy and landscaping (Source: Fixsen, 2015)*

Flagship Project: Googleplex (Headquarters)

- Project type: retrofit
- Address: 1600 Amphitheater Parkway, Mountain View, CA 94043 US [Map]
- Number of buildings: 8+ on main campus
- Floor area: 3,100,000
- Occupants: n/a
- Site: 26 acres
- Walk Score: 38/100*

The 3.1-million-square-foot Googleplex facility (Figure 2) implemented a variety of measures spanning energy efficiency, renewable energy, water efficiency, and transportation alternatives for employees (Google 2015; Wikipedia 2015).

Figure 2. *Aerial view of the "Googleplex" Google's Headquarters in Mountain View, CA, showing the photovoltaic panels on the roofs*

Their 1.9 MW solar installation supplies approximately 30% of peak energy consumption on the buildings it covers, and they've implemented a building management system that monitors and controls campus-wide energy use.

When the current California drought started, Google had already been participating with the California Best Building Challenge, targeting 20% reductions on already high-performing buildings in energy, water and waste. They undertook a huge effort to convert their landscape irrigation to recycled municipal water (purple pipe), saving an estimated 24 million gallons of potable water for the year. They've also been replacing water-intensive turf with drought-friendly native landscaping all over campus, as well as replacing shower heads and faucets in favor of low-flow ones. In light of the drought, they've upped the ante to a 30% reduction target. They're also on track for the 20% reductions in waste and energy.

Google has built a green transportation system that includes biodiesel shuttles and the largest corporate electric vehicle charging infrastructure in the country. Every day, Google shuttles keep thousands of Googlers out of the driver's seat and reduce their impact on the environment. And GFleet—their car-sharing program for Googlers on campus—includes the newest generation of plug-in vehicles. Google estimates that their shuttles and GFleet result in net annual savings of more than 29,000 metric tons of CO_2. Color-branded bicycles are also provided for on-site use (Figure 3).

Figure 3. *Google provides bicycles for on-site travel*

Google has created an internal program known as "Sustainable Pursuit"--based on the popular trivia pursuit game and the LEED framework--to measure and improve how they operate their buildings. When not racing down play slides (Figure 3), teams at Google offices around the world compete for points depending on their site's sustainable initiatives. Through this program, the Google Real Estate & Workplace Services Green Team works closely with facility managers at Google offices worldwide to implement innovative, locally-appropriate strategies to reduce waste, save energy and water, and improve indoor environmental quality. Google also makes it a priority to document and share team innovations so that organizational knowledge is spread across all Google teams (Google, 2015).

Figure 4. *The famous slides in the Google offices (source: Saleem, 2014)*

No specific references to buildings energy efficiency measures at Googleplex were identified, but the company's Carbon Disclosure Report flags measures used in Google buildings more broadly, as summarized in Table 1, which shows carbon savings, costs, and simple payback times by measure.

Table 1. *Examples of Google's recent energy efficiency upgrades*

Source: Investor CDP 2014 Information Request

Description of Activity	Annual Emissions Savings (CO2e tonnes/yr)	Annual Savings ($)	Investment ($)	Payback (Years)
Parking lot & exterior induction lighting in northern California offices	104	118,000	303,000	1-3 years
Cafe exhaust control retrofits in northern California offices	205	113,000	289,000	4-10 years
Retro-commissioning activities at northern California offices	461	101,100	259,000	1-3 years
HVAC retrofits	88	45,000	590,000	11-15 years
Data center lighting controls	49	7,700	1,000	<1 year
Reuse data center waste heat in offices	134	6,400	27,700	4-10 years

7 Infosys
By Philip Haves

Factbox

Global number of employees: **165,000**
Locations globally: **11 (India)**
Square feet of occupied space: **37 million**
LEED-certified Buildings: **13 Platinum**
EnergyStar Buildings: **n/a**

Corporate Goals and Initiatives

Key sustainability-related corporate goals are reduction in per capita carbon intensity and reduction in per capita fresh water consumption. Progress is evaluated on a semi-annual basis and the performance on these goals has a direct influence on the variable component of the remuneration of the Head of Infrastructure and Facilities.

The Green Initiatives team is responsible for environmental sustainability at Infosys. The performance indicators for the green initiative team are:

1. Reducing the per capita energy consumption (goal: 5% per year)
2. Reducing the per capita water consumption (goal: 5% per year)
3. Increasing renewable electricity
4. Increasing the recycling percentage of organic waste
5. Number of trees planted annually

Progress toward these goals has a direct impact on the individual performance ratings of the Green Initiatives team lead, which are evaluated semi-annually and have a direct influence on the variable component of his compensation and his annual increment. Per-employee energy use has been reduced by 44% in 2014 compared to 2008.

Infosys currently meets 30% of its electricity requirements from renewables. It has made a public commitment to meet 100% from renewables by 2018 and will be investing in about 175 MW of solar PV. This is a key part of its public commitment, made in 2012, to become carbon neutral by 2018.

Infosys's commitment to carbon neutrality by 2018 and to LEED Platinum standard for new construction applies to all 11 Infosys campuses in India. The current Energy Use Intensity (EUI) target is 24 kBtu/ft2, compared to 80 kBtu/ft2 for earlier buildings. Across all its 11 campuses in India, Infosys has cut electricity consumption per employee by 44% since 2008 and has reduced greenhouse emissions per employee by 61%, with a cumulative utility bill savings of $80M. All new buildings are designed to meet LEED Platinum standards, a total of 13 thus far.

Infosys has a three year simple payback requirement for retrofits. However, it has a number of chiller replacement projects for which the projected payback periods are in the range four to six years. It has a number of projects with projected payback periods of one to three years and less than one year.

Flagship Project: Infosys campus in Pocharam SEZ, Hyderabad, SDB1 Office Building

- Project type: new construction
- Address: Hyderabad, India [Map]
- Number of buildings: 8
- Floor area: ~2.4 Msf
- Occupants: ~16,000
- Site: 457 acres

A key institutional innovation strategy is that the performance of each new building should be a significant improvement on that of its immediate predecessor - a process of learning from each new building. One example is the SDB1 office building, shown in Figure 1, in which the east wing has radiant slab cooling and the west wing has a variable-air-volume (VAV) system. There is very little east- and west-facing glazing, so the two halves are effectively thermally identical. The VAV system uses approximately half the energy for cooling and ventilating used by the earlier building but, for several years, the radiant slab system has used 1/3 less energy than the VAV system (Figure 2) (Sastry and Rumsey 2014). Occupant satisfaction with the working environment was assessed using an on-line survey developed by the UC Berkeley Center for the Built Environment, which showed significantly greater satisfaction with the radiant system than the VAV system. These energy and occupant satisfaction differences have led Infosys to standardize on radiant cooling for its future buildings.

Figure 1. The Pocharam SEZ Campus, Hyderabad. One half has a VAV cooling system and the other half has a radiant slab cooling system, which consistently uses 1/3 less energy than the VAV system (Sastry and Rumsey 2014).
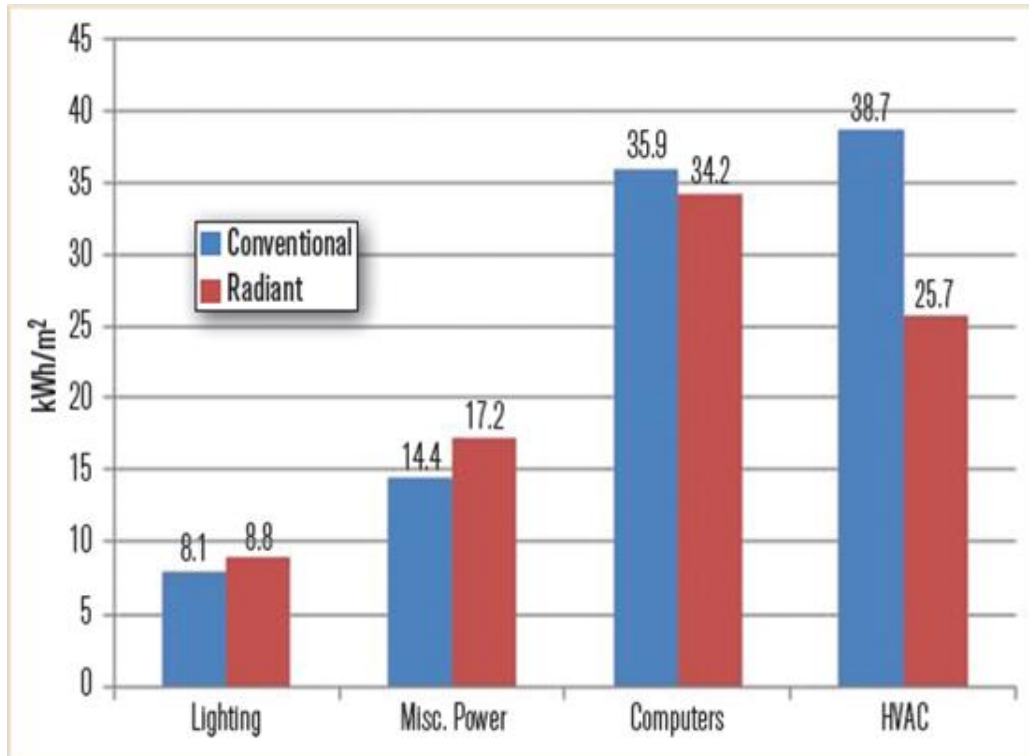
Figure 2. Comparison of the energy use in the two halves of the SDB1 office building. In spite of the internal gains being slightly higher, the cooling energy used by the radiant cooling system is 1/3 less than that used by the conventional VAV system (Sastry and Rumsey 2014).

Infosys assigns significant importance to thermal comfort, and efforts along those lines have manifested in improved outcomes in the SDB1 project (Figure 3). In addition to the benefits of hydronic cooling, task lighting and ceiling fans provide improved control to individual workers.
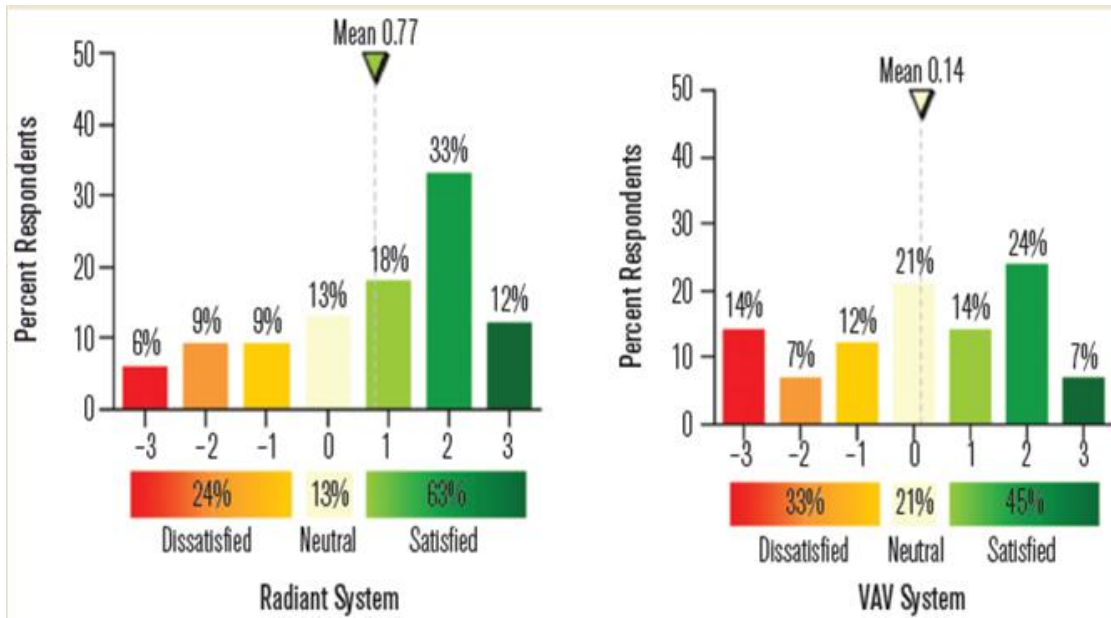
Figure 3. Results of an occupant comfort survey of the SDB1 office building showing significantly greater satisfaction with the radiant system than the VAV system (Sastry and Rumsey 2014).

Infosys has also ensured that there is effective daylighting in its new buildings. The window design shown in Figure 4 results in an operational lighting energy intensity of 0.17 W/ft2 in SDB1 (Greensource 2012). Figure 5 shows a workstation in the same building. Infosys's design policy is for all workstations to be daylit.

Figure 4. Window detail, showing overhang / light shelf and translucent side fins.

Figure 5. *Workstation adjacent to a window of the design shown in Figure 4.*

As part of its policy of installing innovative technologies which have significant energy savings potential, Infosys has installed a chiller with magnetic bearings in its central plant, along with a system that injects sponge balls into the water entering the condenser to reduce fouling of the heat exchanger tubes. Both systems are performing to expectations.

Of the 457 acres of the site, approximately two thirds of has been left undeveloped, apart from earth works that form part of a water management system (Figure 4). The water management system has been implemented as part of Infosys' strategy towards water sustainability. One benefit that has already been observed is an increase in the height of the water table in the surrounding area, which benefits nearby villages by reducing the work required to pump water from wells. The undeveloped area also serves as a nature reserve, with an essentially undisturbed habitat for animal and plant life.

Figure 6. *Earthworks for the water management system under construction.*

In summary, Infosys has established an aggressive energy efficiency and sustainablity policy and is implementing it on a comprehensive scale at its eleven campuses in India. It has received numerous awards as a result, including a prestigious Ashden Award (Ashden 2015).

Table 1. Distillation of Key Strategies considered in the report.

	Established Best Practices	Emerging Opportunities
Discrete technologies		
HVAC	- High-efficiency chillers - Radiant cooling - Direct-expansion (DX) cooling - Underfloor air distribution (UFAD) - Natural ventilation - Heat-recovery chillers - Thermal storage - Ceiling fans for local comfort enhancement - Commissioning	- Hydronic systems, with water-side free cooling and dedicated outside air systems (DOAS) - Rigorous post-occupancy evaluation to determine efficacy of new strategies - Chillers with magnetic bearings - Chillers optimized for low lift - Advanced thermal comfort analysis during design and operation - In-house training and capacity building
Electronics & Networks	- Optimal device specification - Optimal device operation (advanced power strips)	- Energy reporting over network - DC operation
Integrated systems within buildings		

	Established Best Practices	**Emerging Opportunities**
Action-oriented benchmarking	• Energy per unit floor area, at whole-building level • Background for commissioning process	• Special-purpose metrics, depending on business needs • End-use, or equipment-level focus Inference of savings opportunities • "Asset-based" methods, controlling for operations • Higher-quality peer-group data-sets for more granular filtering • Occupancy-based dynamic load-shape benchmarking • Improved user interfaces and dashboards More proactive focus on non-energy issues (e.g., IEQ) • Fuller integration into "corporate culture"
Commissioning	• New construction as well as existing applications • Applied through design review, construction observation, and a performance-focused acceptance testing process. • Dominant focus on HVAC	• Process automation Increased use of measured data (vs visual inspection) • Commissioning for other aspects of green buildings (water, etc.) • Regarded and valued as risk-management strategy • Improved continuity (vs. one-time application) • Adaptations for emerging technologies (vehicle-building interfaces, energy storage systems, wireless controls, and demand-response technologies) • In-house training and capacity building

	Established Best Practices	**Emerging Opportunities**
Diagnostics	• Setting efficiency, demand, and energy consumption *targets* at the whole-building, system, and end-use levels • Continuous fault and energy anomaly detection is applied to hourly or sub-hourly data, as well as operational trend data, at various levels of granularity • Analysis: top-down = whole-building, systems, and end uses; bottom-up = constituent systems and end-uses • Daily and weekly operational assessments to maintain persistent operational efficiency • Sub metering to generate metrics	• Continuous corrective action-based on diagnostics • Virtual sensing: use of measured data to estimate the value of other variables • Hybrid empirical/physical simulation based approaches • Design of electrical distribution systems in which end use loads are disaggregated and thus meterable • Integration of diagnostics with maintenance
Integrated Building Envelope, Daylighting, and Lighting	• Proper siting • Maximize daylighting, within constraints of visual and thermal comfort, and electric lighting controls • Minimized envelope air leakage • Multi-pane, spectrally-selective glazings • Operable windows and skylights • Fixed louvers and exterior shading for glare and thermal control	• Extend usable space even closer to window plane thanks to improved visual and thermal performance and control • Zero-net-energy envelopes (gain as much or more than lost) • Dynamic louvers, interior shading, and glazing materials for glare and thermal control • Motorized systems linked to BMS

	Established Best Practices	**Emerging Opportunities**
		- More advanced daylighting harvesting controls - LED electric lighting, for increased efficiency, longevity, control, and quality - DC power-over-ethernet infrastructure for low-power lighting
HVAC controls	- Standardized sequences of operation - Commissioning - Performance monitoring - Full documentation for all systems and comprehensive training for operators and other facilities staff	- More sophisticated controls (model predictive control) - Augmentation with sensors beyond minimum requirement - Advanced pre-commissioning review and functional testing - More advanced technologies, e.g., for thermal storage and predictive control (e.g. based on models and/or weather forecasts) - Integrated controls addressing integrated HVAC-facade-lighting systems - Grid- and price-aware control - Electric sub-meters on key circuits - Improved modeling and design tools; automated tool chain approach to specification - Training
Indoor	Source control: materials,	Radiant thermal systems

	Established Best Practices	Emerging Opportunities
environmental quality	furniture, office equipment, cleaning products, etc. • Particle filtration • Demand-controlled ventilation • Moisture control • Daylighting • Thermal comfort enhancements	with zonal control • Personalized control of comfort, lighting, etc. • Improved sensor technologies • Building materials as passive air cleaners • New focus on microbial environments • Photobiology-informed lighting systems • More well-informed maintenance practices
Applications at multi-building and urban scales		
Demand response & electric vehicles	• Manual or semi-automated DR • Taking advantage of thermal mass; pre-cooling • Open Automated Demand Response (Open ADR) • Electric utility programs and incentives	• Fully-automated DR and telemetry • DR-specific control sequences • Modes that maximally utilize renewables when available • Energy codes requiring DR-enabled equipment • Response to increasingly specialized tariffs • Integration of electric vehicles (EVs) • Two-way electric<=>grid EV response • Dynamic charging modalities • Low-power modalities for emergency operations

	Established Best Practices	**Emerging Opportunities**
District-level energy services	- Integrating renewable energy - Microgrids - Low-temperature, low-head designs with variable-speed pumping - PEX and HDPE piping instead of steel - Energy storage	- Vehicle-to-Grid applications - Direct current power distribution, or hybrid AC/DC - Biofuels
Waste heat recovery	- Low-temperature hot water loop - Waste heat recovery chillers - Data center waste heat recovery (at CPU as well as facility level) - De-superheat waste heat recovery - Boiler-stack recuperators - Heat-recovery ventilation - Heat-recovery chillers - Thermo-electric technologies	- Double-walled, brazed heat exchangers with two types of working fluid - Waste-water heat recovery
Renewable energy	- Solar PV - Solar thermal (air/liquid) - Wind - Biogas - Ground-source heat pump - Solar PV shaded car structures with charging - On- and off-site production and procurement mechanisms	- Increased-efficiency PV and solar-thermal modules - Building/facade-integrated PV - Vehicle-to-grid systems - Building-mounted wind turbines - Resiliency-drive designs - Innovative procurement mechanisms, e.g., synthetic power purchase agreements

References

Apple Campus 2. (n.d.). Retrieved February 26, 2016, from

      http://www.cupertino.org/index.aspx?page=1107

Arens, E. and G. Brager (2012) Improving Indoor Comfort While Using Less Energy. Center

      for the Built Environment, University of California Berkeley.

      http://uccs.ucdavis.edu/assets/event-assets/event-presentations/arens-brager-

      presentation

ASHRAE Guideline Project Committee 36. (n.d.). Retrieved February 11, 2016, from

      http://gpc36.savemyenergy.com/public-files/

Barbose, G., Weaver, S., & Darghouth, N. (2014). Tracking the Sun VII: An Historical

      Summary of the Installed Price of Photovoltaics in the United States from 1998 to

      2013. Retrieved from http://emp.lbl.gov/projects/solar

Brown, R.E., T. Walter, L.N. Dunn, C.Y. Custodio, and P.A. Mathew. (2014). "Getting Real

      with Energy Data: Using the Buildings Performance Database to Support Data-Driven

      Analyses and Decision-Making." *Proceedings of the ACEEE Summer Study on*

      Energy Efficiency in Buildings, American Council for an Energy Efficient Economy:

      Washington, DC, pp. 11-49 – 11-60. Retrieved from

      http://energy.gov/eere/buildings/building-performance-database

Bula, F., (2014) " Vancouver: Heating the city, one neighborhood at a time" Citiscape

Bailey, T, O'Neill, Z, Shashanka, M, Bhattacharya, P, Haves, P, Pang, X.(2011) Automated

      continuous commissioning of commercial buildings. *Lawrence Berkeley National*

      Laboratory, LBNL Report No. 5734-E.

Bonvini, M, Piette, MA, Wetter, M, Granderson, J, Sohn, M. FDD (2014) Bridging the gap

      between simulation and the real world: An application to FDD. *Proceedings of the*

2014 ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove,

California.

Bellia, L., Bisegna, F., & Spada, G. (2011). Lighting in indoor environments: Visual and non-

visual effects of light sources with different spectral power distributions. *Building and*

Environment, 46(10), 1984-1992.

Center for Built Environment, Occupant Indoor Environmental Quality (IEQ) Survey.

http://www.cbe.berkeley.edu/research/survey.htm.

Corporate Responsibility. (n.d.). Retrieved February 26, 2016, from

http://www.adobe.com/corporate-responsibility/environment.html

Cros, C. J., Morrison, G. C., Siegel, J. A., & Corsi, R. L. (2011). Long-term performance of

passive materials for removal of ozone from indoor air. *Indoor Air, 22*(1), 43-53.

Corporate Responsibility. (n.d.). Retrieved February 26, 2016, from

http://www.adobe.com/corporate-responsibility/sustainability.html

Carmody, J. (2004). *Window systems for high-performance buildings*. New York:

W.W. Norton &.

Center for Global Ecology. Retrieved from https://dge.stanford.edu/about/building/Sus_features.pdf

Cole, H., S. Greenberg 2014. "Direct Liquid Cooling for Electronic Equipment" 22-25pp.

CPUC, California's Energy Efficiency Strategic Plan 2011,

http://www.energy.ca.gov/ab758/documents/CAEnergyEfficiencyStrategicPlan

_Jan2011.pdf

Dear, R. J., Akimoto, T., Arens, E. A., Brager, G., Candido, C., Cheong, K. W., . . . Zhu, Y.
(2013). Progress in thermal comfort research over the last twenty years. *Indoor Air,*
23(6), 442-461.

EnergyPlus Energy Simulation Software. (n.d.). Retrieved February 11, 2016, from
http://www.energyplus.gov/

ENERGY STAR. (n.d.). Retrieved February 26, 2016, from
http://www.energystar.gov/index.cfm?fuseaction=labeled_buildings.showProfile

Energy Efficiency in Buildings, pp. 12.166-12.178. Retrieved from
http://aceee.org/files/proceedings/2012/data/papers/0193-000369.pdf

Energy Commission, Public Interest Energy Research, HPCBS # E5P2.2T1e. LBNL Report
No. 53406. Proceedings of the International Conference for Enhanced Building
Operations.

Energy Efficiency in Buildings, pp. 12.166-12.178. Retrieved from
http://aceee.org/files/proceedings/2012/data/papers/0193-000369.pdf

eQUEST. http://www.doe2.com/equest/

http://www.emergealliance.org/

Fisk, W. J. (2013). Health benefits of particle filtration. *Indoor Air, 23*(5), 357-368.

Fisk, W. J., Black, D., & Brunner, G. (2011). Benefits and costs of improved IEQ in U.S.
offices. *Indoor Air, 21*(5), 357-367.

Facebook Menlo Park. (n.d.). Retrieved February 29, 2016, from
https://www.facebook.com/fbmenlopark

Federal Energy Regulatory Commission (FERC), National Assessment and Action Plan on
Demand Response. 2009. A National Assessment of Demand Response Potential.

Galasiu, A. D., & Veitch, J. A. (2006). Occupant preferences and satisfaction with the

    luminous environment and control systems in daylit offices: A literature review.

    Energy and Buildings, 38(7), 728-742.

Garbesi, K., Vossos, V., Sanstad, A., & Burch, G. (2011). Optimizing Energy Savings from Direct-DC

    in U.S. Residential Buildings.

Green on Facebook. (n.d.). Retrieved February 29, 2016, from

    https://www.facebook.com/green

Green on Facebook. (n.d.). Retrieved February 29, 2016, from

    https://www.facebook.com/green/app_439663542812831

Granderson, J, Piette, MA, Rosenblum, B, Hu, L, et al (2013). Energy information handbook:

    Applications for energy-efficient building operations. CreateSpace, 2013, ISBN

    1480178276 / 9781480178274; LBNL Report No. LBNL 5272E.

Glazer, J. (2006). "Evaluation of Building Energy Performance Rating Protocols." Prepared

    for *ASHRAE Technical Committee* 7.6 – Systems Energy Utilization. December 6,

    255pp.

Greenberg, S., W. Tschudi, and J. Weale. (2006). "Self-Benchmarking Guide for Data Center

    Energy Performance (Version 1.0)

Henderson, P, Waltner, M. (2013) Real-time Energy Management A Case Study of Three

    Large Commercial Buildings in Washington, D.C. *Natural Resources Defense*

    Council, Report Number CS-13-07-A.

Home | HEATISLAND. (n.d.). Retrieved February 11, 2016, from

    https://heatisland.lbl.gov/

High Performance Building Facade Solutions, https://facades.lbl.gov/

Hydeman, M., S. Taylor and B .Eubanks. 2015. "RP-1455 and Guideline 36 control sequences
and controller programming." ASHRAE Journal

Heat Recovery | CenTraVac | Trane Commercial. (2015). Retrieved February 29, 2016, from
http://www.trane.com/commercial/north-america/us/en/products-
systems/equipment/chillers/water-cooled-chiller/centrifugal-liquid-cooled-
chillers/earthwise-centravac/HeatRecovery.html

Jensen, K. and Arens, E. (2005). "Acoustical quality in office workstations, as assessed by
occupant surveys). *Proc. Indoor Air 2005, Beijing, China.*
http://escholarship.org/uc/item/0zm2z3jg

Juul, F., Negrete-Pincetic, M., Macdonald, J., & Callaway, D. (2015). Real-time scheduling of
electric vehicles for ancillary services. *2015 IEEE Power & Energy Society General
Meeting*.

Kiliccote, S., Olsen, D., Sohn, M. D., & Piette, M. A. (2015). Characterization of demand
response in the commercial, industrial, and residential sectors in the United States.
WIREs Energy Environ Wiley Interdisciplinary Reviews: Energy and Environment.

Lee, E. S., Fernandes, L. L., Coffey, B., Mcneil, A., Clear, R., Webster, T., . . . Hoyt, T.
(2013). A Post-Occupancy Monitored Evaluation of the Dimmable Lighting,
Automated Shading, and Underfloor Air Distribution System in The New York Times
Building.

Lee, E. S., et al. 2005. *Daylighting the New York Times headquarters building: Final
report.* LBNL-57602 http://buildings.lbl.gov/sites/all/files/daylighting-
nytimes-final.pdf

EMerge Alliance Home. (n.d.). Retrieved February 11, 2016, from

Lobato C., Pless, S., Sheppy, M., and Paul Torcellini (2011). Reducing Plug and Process
Loads for a Large Scale Low Energy Office Building: NREL's Research Support

Facility. National Renewable Energy Laboratory, February 2011. NREL Report
Number NREL/CP-5500-49002 .

Lubell, Sam.(2012). "High Tech Headquarters" *Greensource Magazine*. Retrieved from
http://greensource.construction.com/features/currents/2012/1207-High-Tech-
Headquarters.as

Lee, Y.S. (2010) Office layout affecting privacy, interaction, and acoustic quality in LEED-
certified buildings. *Building and Environment* 45(7):1594-1600.

Mathieu, J. L., P. N. Price, S. Kiliccote, and M.A. Piette. (2011). "Quantifying Changes in
Building Electricity Use, with Application to Demand Response." *IEEE Transactions
on Smart Grid*, 2(3)507-518. Retrieved from
http://eetd.lbl.gov/publications/quantifying-changes-building-electricity-use-
application-demand-response

Marnay, Chris, Chan TW, DeForest N, Lai J, MacDonald J, Stadler M, Erdmann T, Hoheisel
A, Mueller M, Sabre S, et al.(2013). Los Angeles Air Force Base Vehicle to Grid
Pilot Project. In ECEEE 2013 Summer Study on Energy Efficiency. LBNL Report
LBNL-6154E.

Motegi, NA., M.A. Piette, D.S. Watson, S. Kiliccote, P Xu. (2007). Introduction to
Commercial Building Control Strategies and Techniques for Demand Response.
Report for the California Energy Commission, Lawrence Berkeley National
Laboratory. LBNL-59975.

Motegi, N, Piette, MA, Kinney, S, Dewey, J. (2003). Case Studies of Energy Information
Systems and Related Technology: Operational Practices, Costs, and Benefits. Report
prepared for the *California*

McConahey, E. (2008). Mixed Mode Ventilation Finding the Right Mix - ashrae.org. Retrieved February 29, 2016, from https://www.ashrae.org/File Library/docLib/eNewsletters/McConahey-0908--feature.pdf

McQuay. (2015). Retrieved from http://www.georgia.daikinmcquay.com/Templifier

Metzger, I., Sheppy, M., and D. Cutler (2013). Reducing Office Plug Loads Through Simple and Inexpensive Advanced Power Strips. National Renewable Energies Laboratory, July 2013. NREL Report Number NREL/CP-7A40-57730

Mills, N. and E. Mills. (2015). "Taming the Energy Use of Gaming Computers." *Energy Efficiency* (in press).

Mills, E. and P. Mathew. (2014). "Monitoring-Based Commissioning: Benchmarking Analysis of 24 University Buildings in California," *Energy Engineering* 111(4):7-24.

Mills, E. (2011). "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions in the United States." Energy Efficiency, 4(2):145-173

Mercado, A., and J. Elliott. (2012). "Energy Performance Platform: Revealing and Maintaining Efficiency with a Customized Energy Information System." Proceedings of the 2012 ACEEE Summer Study on

Mills, E., P. Mathew, N. Bourassa, M. Brook, and M.A. Piette. (2008). "Action-Oriented Benchmarking: Concepts and Tools." *Energy Engineering*, 105(4):21-40. LBNL-358E

Mercado, A., and J. Elliott. (2012). "Energy Performance Platform: Revealing and Maintaining Efficiency with a Customized Energy Information System." *Proceedings of the 2012 ACEEE Summer Study on*

Mills, N. and E. Mills. (2015). "Taming the Energy Use of Gaming Computers." In review.

Ma, Y., Borrelli, F., Hencey, B., Coffey, B., Bengea, S., & Haves, P. (2012). Model Predictive Control for the Operation of Building Cooling Systems. *IEEE Transactions on Control Systems Technology IEEE Trans. Contr. Syst. Technol., 20*(3), 796-803.

MATLAB. (n.d.). Retrieved February 11, 2016, from

http://www.mathworks.com/products/matlab/

Moezzi, M., C. Hammer, J. Goins, and A. Meier (2014). Behavior strategies to reduce the gap

between potential and actual savings in commercial buildings. Contract Number:09-

327. Sacramento, California Air Resources Board

Natale, M. D., & Sangiovanni-Vincentelli, A. (2010). Moving From Federated to Integrated

Architectures in Automotive: The Role of Standards, Methods and Tools. *Proceedings*

of the IEEE Proc. IEEE, 98(4), 603-620.

Naval Facilities Engineering Command. 2012. "Naval Techval Program" presentation.

http://www1.eere.energy.gov/femp/pdfs/ntwg_052012_kistler.pdf

Nordman, B., K. Christensen, R. Melfi, B. Rosenblum, and R. Viera.(2014). "Using Existing

Network Infrastructure to Estimate Building Occupancy and Control Plugged-in

Devices in User Workspaces," *International Journal of Communication Networks and*

Distributed Systems, 12(1):4-29.

Nordman, B. (2014) "Energy Reporting". Report to Northwest Energy Efficiency

Alliance, Lawrence Berkeley National Laboratory.

Navigant Research. 2015. Demand Response Enabling Technologies: Metering,

Communications, and Controls Equipment: Global Market Analysis and Forecasts.

OpenADR Alliance web site - http://www.openadr.org/, Control Your Energy Future. (n.d.).

Retrieved February 29, 2016, from http://www.openadr.org/

Piette, M. A., Watson, D., Motegi, N., Kiliccote, S., & Xu, P. (2006). Automated Critical Peak

Pricing Field Tests: Program Descriptionand Results.. *PG&E Emerging Technologies*

Program. LBNL 62218

Power Over Ethernet (n.d.). Retrieved February 11, 2016, from

  http://en.wikipedia.org/wiki/Power_over_Ethernet

Powering Businesses on Renewable Energy. (n.d.). Retrieved February 26, 2016, from

  http://www.worldwildlife.org/pages/powering-businesses-on-renewable-energy

Prineville Data Center. (n.d.). Retrieved February 29, 2016, from

  https://www.facebook.com/PrinevilleDataCenter/app_399244020173259

Powering Businesses on Renewable Energy. (n.d.). Retrieved February 29, 2016, from

  http://www.worldwildlife.org/pages/powering-businesses-on-renewable-energy

  Roberts, C. and Naqvi, A. (2010). ASHRAE Technology Awards: Learning by Doing.

  ASHRAE Journal, vol. 52, no. 5, May 2010. Retrieved from

  bookstore.ashrae.biz/journal/download.php?file=ASHRAE-D...pdf

Robinson, A. et al, 2014, Integrated Daylighting

  Systems, http://www.gsa.gov/portal/content/19333

Sastry, G. and Rumsey, P.(2014). VAV vs. Radiant Side-by-Side Comparison. *ASHRAE*

  Journal 56(5) May. Retrieved from https://www.ashrae.org/resources--

  publications/periodicals/ashrae-journal/features/vav-vs--radiant-side-by-side-

  comparison

Schuetz, N., A. Kovaleva, and J. Koomey. (2013). "eBay, Inc.: A Study of Organizational

  Change Underlying Technical Infrastructure Optimization." Stanford University.

  27pp.

Stein, J., & Taylor, S. T. (2013). Why Join ASHRAE. Retrieved February 26, 2016, from https://www.ashrae.org/resources--publications/periodicals/ashrae-journal/features/vav-reheat-versus-active-chilled-beams--doas

Smothers, Frederic J., and Kristopher L. Kinney. (2002). Benefits of enhanced data quality and visualization in a control system retrofit." *Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings,* Pacific Grove, California.

Sangiovanni-Vincentelli, A. and C. e Ricorsi. 2010. " The EDA Story." *IEEE Solid-State Circuits Magazine*, pp. 6-25, Summer.

Satish, U., M.J. Mendell, K. Shekhar, T. Hotchi, D. Sullivan, S. Streufert, and W.J. Fisk (2012). Is CO2 an indoor pollutant? Direct effects of low-to-moderate CO2 concentrations on human decision making performance. *Environmental Health Perspectives* 120(12):1671-1677.

Seppanen, O., & Fisk, W. (2006). Some Quantitative Relations between Indoor Environmental Quality and Work Performance or Health. *HVAC&R Res. UHVC HVAC&R Research, 12*(4), 957-973.

Tomić, J., & Kempton, W. (2007). Using fleets of electric-drive vehicles for grid support. *Journal of Power Sources, 168*(2), 459-468. Retrieved from http://www.rmi.org/Content/Files/Fleetsforgridsupport.pdf

Top 10 Green Companies in the World. (2014). Retrieved February 26, 2016, from http://www.newsweek.com/green/top-10-green-companies-world

Tour of Adobe's triple Platinum LEED certified HQ - GreenMonk: The blog. (2009).

    Retrieved February 26, 2016, from http://greenmonk.net/2009/03/25/tour-of-adobes-

    triple-platinum-leed-certified-hq/

TRNSYS. (n.d.). Retrieved February 11, 2016, from http://www.trnsys.com/

U.S. Solar Market Insight. (n.d.). Retrieved February 23, 2016, from

    http://www.seia.org/research-resources/us-solar-market-insight

V2G-Sim. (n.d.). Retrieved February 29, 2016, from http://v2gsim.lbl.gov/

Ventilation for Acceptable Indoor Air Quality - ASHRAE. (2013). Indoor Air Quality.

    American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

    Retrieved February 17, 2016, from https://www.ashrae.org/File

    Library/docLib/Public/200418145036_347.pdf

World Wildlife Fund and World Resources Institute, Corporate Renewable Energy Buyers'

    Principles http://www.worldwildlife.org/pages/powering-businesses-on-renewable-

    energy

Wiser, R., & Bolinger, M. (2014). 2013 Wind Technologies Market Report. Retrieved from

    http://emp.lbl.gov/sites/all/files/lbnl-6809e.pdf

Wang, Y., Sheikh, O., Hu, B., Chu, C., & Gadh, R. (2014). Integration of V2H/V2G hybrid

    system for demand response in distribution network. *2014 IEEE International*

    Conference on Smart Grid Communications (SmartGridComm).

Wetter, M., W. Zuo, T. S. Nouidui and X. Pang. Modelica Buildings library. Journal of

    Building Performance Simulation 7(4):253-270, 2014

Wei, J et al, 2012, Responsive Lighting

Solutions, http://www.gsa.gov/portal/mediaId/197379/fileName/GPG_Occupa

nt_Responsive_Lighting_09-2012.action

Wilkins, C.K. and M.H. Hosni.(2011). "Plug Load Design Factors." *ASHRAE Journal*. May,

pp 30-34. Retrieved from

https://www.ashrae.org/File%20Library/docLib/eNewsletters/Wiilkins-052011--

01242013feature.pdf.

Zaatari, M., A. Novoselac, and J. Siegel (2014) The relationship between filter pressure drop,

indoor air quality, and energy consumption in rooftop HVAC units. *Building and

Environment* 73, 151-161.