The concepts of sustainability and resiliency transcend physical scales—from a community-scaled electric grid to detailed design of equipment.

SUSTAINABILITY AND RESILIENCY

STRATEGIES FROM COMMUNITY TO EQUIPMENT

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Credit: Urban78

With increasing energy demand and natural/human-induced disasters in recent years, the two key concepts—sustainability and resiliency—are crucial for engineers and architects in the current design and construction industry. Careful applications of these two key concepts can resolve many challenges facing the current new construction and existing facilities management landscape.

Sustainability

Sustainability is a priority interest for many organizations, and this is especially true in ASHRAE. Sustainability is defined as "providing for the needs of the present without detracting from the ability to fulfill the needs of the future" in the *ASHRAE GreenGuide*.[1] Another definition from ASHRAE is that sustainability is "the concept of maximizing the effectiveness of resource use while minimizing the impact of that use on the environment."[2] Sustainability is important because buildings and facilities fundamentally impact people's lives and the health of the planet. Driven by sustainability goals, many states, cities, districts, campuses, and building owners set reasonable sustainability goals to achieve. For example, New York State Executive Order 88 mandates improving statewide energy efficiency (building source energy use intensity) by 20% by the year 2020 compared to the baseline year of 2010.

Measurement. With energy being one of the most important measurements of sustainability, there are other components to measure sustainability. Leadership in Energy and Environmental Design (LEED) by the U.S. Green Building Council (USGBC), as one of the most widely acceptable sustainability measurement tools, focuses on the following nine categories: location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, regional priority, and integrative process. Other sustainability rating systems include ASHRAE Building Energy Quotient (bEQ), US Environmental Protection Agency (EPA) Energy Star, and Green Globes.

Resiliency

Since the United Nations Brundtland Commission in 1987, sustainability has been a hot topic for decades. Resiliency has only become popular recently, and most engineers and architects are still not very familiar with the concept. Drawing upon the work of the National Research Council, resiliency is defined as "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" defined by America's design and construction industry.[3] Another common definition of resiliency is "the capacity to adapt to changing conditions and to maintain or regain functionality and vitality in the face of stress or disturbance."[4]

Four key components to understand resiliency are as follows:

1. A livable condition or acceptable functionality is to be maintained or adapted to during or after the adverse events. For example, the living spaces in a residential building should remain in acceptable temperature range after an earthquake.

2. The adverse event can be a sudden catastrophe or a long-term trend. For example, the 2017 Atlantic hurricane season was one of the most destructive hurricane seasons in U.S. history, hurricanes Harvey, Irma, Maria, and Nate have devastated U.S. coastal cities and islands; while the Camp Fire is still burning in California at the time of this writing, it has already been documented as the deadliest wildfire in California history. Although hurricanes and wildfires are natural disasters, the 9/11 attacks in the U.S. are probably the worst human-made disasters in the U.S. since the end of World War II.

3. The adverse event can be a sudden catastrophe or a long term trend. While we are familiar with sudden catastrophes such as hurricanes and earthquakes, long term trends such as climate change may not be as obvious but can cause devastating impacts without proper preparation. That's why ASHRAE—acknowledging the escalated worldwide concern for global climate changes as scientific evidence has become more definitive—is committed to a leadership role in reducing climate change contributed by building systems.[5]

4. The impacts of the event can be a short or extended period. For example, utility companies can restore a minor power outage within hours, but it took nearly a year—according to the Puerto Rico Electric Power Authority—to fully restore the power grid in Puerto Rico after Category 5 Hurricane Maria swept the island in September 2017, ending the longest continuous blackout in U.S. history.

Measurement. While sustainability rating systems are, relatively speaking, well-established, rating systems or measurements of resiliency are far from established. Just as it is described by the Resilient Design Institute, "Resiliency is not any single solution, concept or perspective. Resiliency is a multifaceted lens which balances proactivity and reactivity to inform solutions to disruptions." Therefore, examples of measurement of resiliency includes system redundancy, adaptation, diversity, durability, life safety, renewable systems, natural resources, and social equity. As resiliency seems to have different meanings to different entities in different contexts, building owner's preference is still the most dominant measurement component of resiliency to engineers and architects.

In general, the measurement of resiliency is summarized in the following three categories.

1. Accept measures: to acknowledge and accept the consequences from the adverse events. For example, cities built on flood plains require flood insurance against

Sustainability: maximizing the effectiveness of resource use while minimizing the impact of that use on the environment.

Resiliency: the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events.

property loss or damage—a large portion of New Orleans was built at or below local mean sea level; campuses purchase interruptible natural gas or water supplies with insurance coverage.

2. Prepare measures: to actively prepare and plan for the adverse events. For example, emergency generators are required to be installed, tested and maintained in certain facilities in accordance with National Fire Protection Association (NFPA) standards.

3. Adapt measures: to reduce or absorb the adverse events by adapting the use of the measures. For example, PV panels with battery storage on campuses are used to reduce/offset energy use during normal operation and to generate/store electricity during hurricanes or earthquakes.

The concepts of these resiliency measures are also discussed in the following examples with different physical scales.

In summary, sustainability reduces the energy and environmental impact of systems, buildings, campuses, or communities during design, construction, and operation, while improving the health and comfort of occupants and users during normal operation. Resiliency enables systems, buildings, campuses, or communities to meet desired functionality goals during defined extraordinary conditions that usually include disruptions to normal infrastructure supply chain.

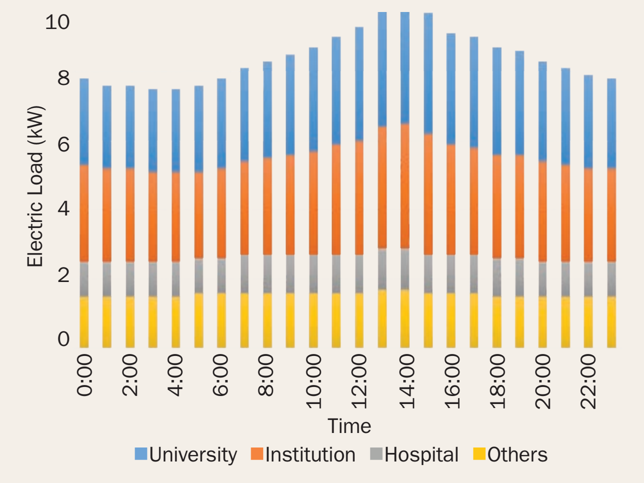
Community Level Strategies

A community can be a district, a village, a town, or a city where a group of people live and share common infrastructure. An example of community energy assessment is presented to support the community-level energy efficiency initiatives through the concepts of sustainability and resiliency. The objective of the example project is to assess the feasibility of a community microgrid to enhance the resiliency of the buildings and facilities that provide critical public safety, health, and security support upon loss of the electric grid for an extended period (for example 72 hours) due to natural or human-made disasters.

Microgrid

Microgrid is defined as "a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid" by Department of Energy. Another definition, by New York's Microgrid Study Team, is that microgrid is "a group of interconnected loads and distributed energy resources that form a single controllable entity capable of operating continuously in both grid-connected and islanded mode." Therefore, a microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.

Figure 1 ELECTRIC LOAD PROFILE OF THE PROPOSED MICROGRID IN A PEAK-LOAD SUMMER DAY.



Example Community

In this example, the community is located in ASHRAE Climate Zone 5A and the total installed electricity generation is about 20 megawatts (MW). The major electricity users to be considered on the microgrid include a university campus, an institutional campus, and a hospital. The other critical buildings and facilities that provide public safety, health, and security support upon loss of the electric grid include police department, nursing homes, water treatment plant, fire department, fire rescue, town hall, jail, telecommunications, and switching station.

Just like most of the existing electric grid in U.S., the community has an existing overhead power system. The example proposed community microgrid includes the following features:

1. It is an underground electric microgrid to improve community-level power resiliency compared to traditional overhead power systems.

2. The microgrid generation is comprised of natural gas electric generators and distributed energy resources (DER), such as diesel generation, solar power, hydropower, wind power, or biomass.

3. The microgrid can connect or disconnect from the grid to enable it to operate in both grid-connected or island mode.

Energy Assessment

An energy assessment for the three major electricity users (university, institution, and hospital) was performed to support the sizing and evaluation of the proposed community resilient microgrid.

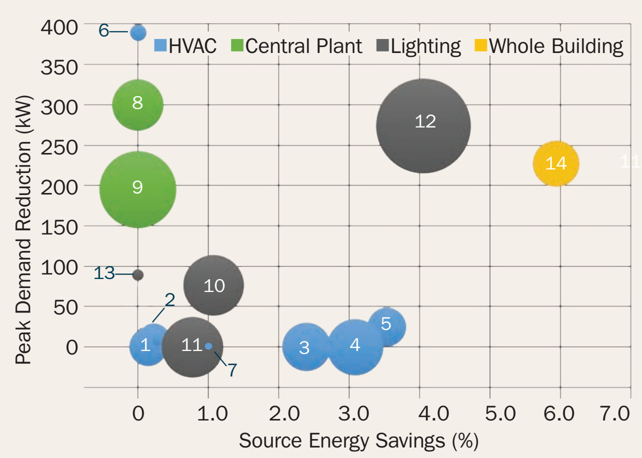
Electric Load. Based on the available electric utility bills from the campuses/buildings on the microgrid for the past several years, the electric peak-load profile of the proposed microgrid in a typical year is presented in *Figure 1*. It includes an "other" load of the critical buildings and facilities that provide public safety, health, and security support upon loss of the electric grid.

Measures. Preliminary Energy-Use Analysis (PEA) and ASHRAE Level 1 Walk-Through Analysis for the three major electricity users (the university campus, the institutional campus, and the hospital) were performed to evaluate the potential impact on the microgrid sizing from energy conservation measures (ECMs) and demand response (DR) measures. The walk-through surveys in the three campuses were not intended to be comprehensive, but rather to focus on major electric loads that would impact the microgrid sizing from ECMs and DRs.

Figures 2, 3, and *4* show the ECMs and DRs at the university, institution, and hospital. The x-axis represents the percentage of source energy savings, which is a key measurement for sustainability. The y-axis represents the peak demand reduction in kilowatts (kW), which is the key measurement for sizing the proposed resilient microgrid. The bubble size represents relative project cost associated with each ECM or DR; the relative project costs are not shown in *Tables 1*, *2,* and *3*, rather the simple paybacks are presented to evaluate the effectiveness of all the measures. The details of all the ECMs and DRs in HVAC, central plant, lighting, and whole building are listed in *Tables 1, 2,* and *3*.

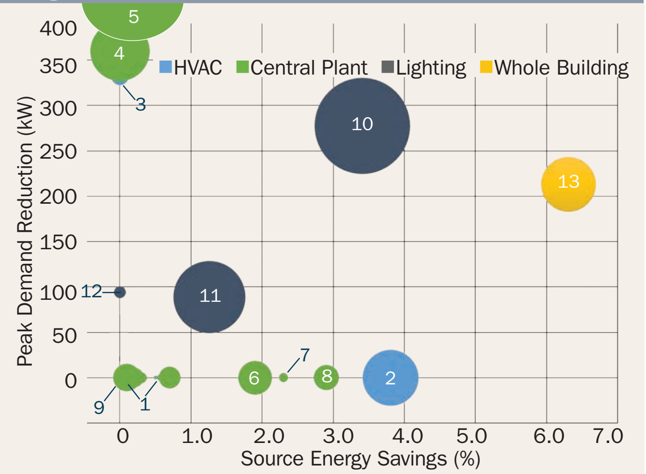
Community microgrid. *Figure 5* shows the peak demand reduction for the community resilient microgrid. First, the three major electricity users and the other critical buildings and facilities are selected to be on the microgrid; this reduces the electric peak demand from 20 MW to 13.4 MW. Second, the identified ECMs and DRs from the three major electricity users reduce the microgrid peak demand to 10.9 MW. Finally, only critical loads (depending on each facility) from the buildings and facilities are selected to be on the microgrid upon loss of the electric grid; this eventually reduces the microgrid peak demand to 4.4 MW. The assessment was intended to support the sizing of the proposed microgrid from

Figure 2 ECMS AND DRS AT THE UNIVERSITY.



The bubble size represents the relative project cost. Not all bubbles can be seen due to size or overlap.

Figure 3 ECMS AND DRS AT THE INSTITUTION.



The bubble size represents the relative project cost. Not all bubbles can be seen due to size or overlap.

Table 1 ECMS AND DRS AT THE UNIVERSITY CAMPUS (SEE FIGURE 2 ABOVE).

ECM/DR	**ECM/DR Details**	**Demand Reduction (kW)**	**Source Energy Savings (%)**	**Simple Payback (yrs)**
HVAC				
1. Electronic Controls	Pneumatic to electronic controls with integration to BAS	0	0.1%	128.9
2. Lab Hood Upgrade	Renovation to exhaust hoods in science buildings & labs	10	0.2%	59.0
2. Duct Static Pressure Reset	Duct static pressure reset in VAV air-handling systems	0	0.4%	2.5
2. Pump Differential Pressure Reset	Variable flow hot water and chilled water pump systems	0	0.2%	1.0
2. Balancing Valves	Open valves, balance with pump VFDs	0	0.1%	0.9
2. Coil Pump Controls	BAS enables upon heating/cooling call—no simultaneous heating/cooling	0	0.4%	0.4
2. VAV and FT Controls	Adjust control sequence; no simultaneous heating/cooling	0	0.2%	0.8
2. Insulation	Insulate HW & CW piping and valves, insulate supply air ductwork	10	0.3%	6.7
3. Demand Control Ventilation (DCV)	DCV in classrooms, lecture halls, meeting rooms, etc.	0	2.4%	10.5
4. Install HVAC Occupancy Sensor Controls	In about 50% of spaces in all non-residential buildings	0	3.1%	11.1
5. Fan VFD Retrofit	Renovations in science buildings & labs	25	3.5%	5.3
6. Space Temperature Setback	Space temperature setback in non-residential spaces with BAS controls	389	0.0%	–
7. Economizer Controls	Add to the AHUs not equipped with economizer controls fixed dry-bulb economizer controls.	0	1.0%	9.6
Central Plant				
8. Ice Storage Chillers	Update existing centrifugal chillers to ice storage chillers	300	0.0%	–
9. Combined Heat and Power (CHP)	Operate existing microturbine and absorption chiller system to follow thermal load, rather than electric load	195	0.0%	–
Lighting				
10. Lighting Occupancy Sensors	Install occupancy sensors in all LED lighting fixtures in non-residential spaces	76	1.1%	42.9
11. Exterior Lighting	Replace non-LED High Intensity Discharge parking lot and exterior lighting with LED with photocell controls or timers	0	0.8%	60.5
12. Interior Lighting Retrofit	Install LED fixtures throughout 75% of floor area in non-residential buildings	274	4.1%	28.0
13. Reduce Lighting Power by 30%	Lighting fixtures with new controls	89	0.0%	–
Whole Building				
14. Existing Building Commissioning	For non-residential buildings except for new buildings	227	5.9%	3.9
	Total	1,595	23.8%	

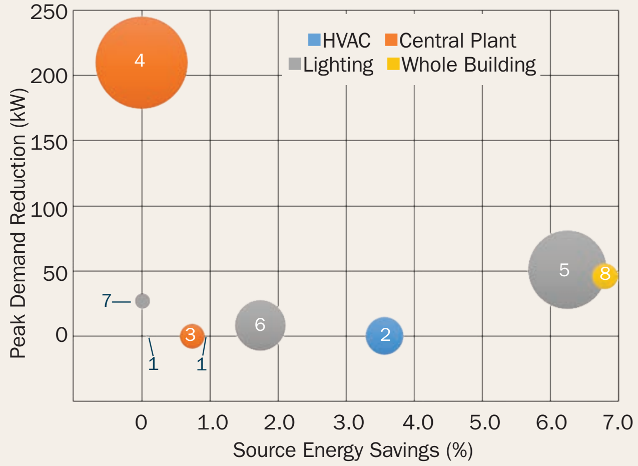
Table 2 ECMS AND DRS AT THE INSTITUTIONAL CAMPUS (SEE FIGURE 3 ON PREVIOUS PAGE).

ECM/DR	ECM/DR Details	Demand Reduction (kW)	Source Energy Savings (%)	Simple Payback (yrs)
HVAC				
1. Duct Static Pressure Reset	In VAV air handling systems	0	0.6%	1.1
1. Pump Differential Pressure Reset	In variable flow HW and CW pump systems	0	0.0%	1.7
2. Install HVAC Occupancy Sensor Controls	In about 50% of spaces in all non-residential buildings	0	3.8%	8.7
3. Space Temperature Setback	Space temperature setback in non-residential spaces with BAS controls	332	0.0%	-
Central Plant				
4. Ice Storage Chillers	Consider replacing the existing chiller and the absorption chiller with a new air-cooled VFD chiller with partial ice storage system. Eliminate the existing cooling towers and associated condenser water system.	360	0.0%	–
5. Combined Heat and Power (CHP)	Use the CHP and absorption chiller system to shave electricity peak and to meet thermal load.	2800	0.0%	–
6. Waterside Economizer	Waterside economizer for chiller bypass via a plate-and-frame heat exchanger	0	1.9%	74.2
7. Steam Trap Monitoring and Maintenance Program	Implement steam trap monitoring and maintenance program.	0	2.3%	945.4
8. Summer Boiler	Consider installing a high-efficiency small steam boiler for shoulder seasons and summer.	0	2.9%	–
9. Replace Chiller with new VFD Chiller	Replace existing chiller with a new VFD chiller, control CW supply temp based on cooling load.	0	0.1%	991.6
9. Reset CW Supply Temperature	Implement CW temp reset for the existing chillers based on cooling load.	0	0.2%	10.6
9. Install VFDs on Existing Cooling Tower Fans	Install VFDs on the existing cooling tower fans and control fan speed based on heat rejection variation.	0	0.0%	441.4
9. Rebalance Balancing Valves	Rebalance balancing valves to fully open or minimally closed for system balancing and use VFD to achieve proper flow.	0	0.0%	0.8
9. Rebalance CW Distribution Loop	Rebalance balancing valves. Install two-way control valves. Control secondary pumps based on valve positions. Install bypass with a two-way control valve. Identify "rogue" zones. Modify piping or terminal units, install tertiary pumps to eliminate "rogue" buildings on campus distribution loop.	0	0.2%	15.0
9. Primary-Secondary Piping Bridge	Verify & modify the primary-secondary piping bridge per design details.	0	0.0%	92.7
9. Chiller Control Sequence Optimization and Surge Protection	Optimize the control sequence for the two centrifugal chillers and the absorption chiller. Monitor centrifugal chiller refrigerant differential pressure.	0	0.2%	39.7
9. Combustion Air Preheater	Consider installing combustion air preheaters for the two NG steam boilers.	0	0.2%	–
9. Flue Gas Economizer	Consider installing flue gas economizers to preheat incoming feedwater for the two NG steam boilers.	0	0.7%	–
9. Adjust Steam Pressure	Evaluate and adjust steam pressure requirements for generation and distribution. Control PRV to minimize unnecessary steam pressure reduction.	0	0.5%	875.4
9. Blow-down Heat Recovery	Install boiler blow-down heat recovery.	0	0.3%	–
Lighting				
10. Interior Lighting Retrofit	Install LED fixtures in about 75% of non-residential floor area	278	3.4%	32.7
11. Lighting Occupancy Sensors	In all LED lighting fixtures in non-residential spaces	89	1.3%	50.1
12. Reduce Lighting Power by 30%	Lighting fixtures with new controls	94	0.0%	–
Whole Building				
13. Existing Building Commissioning	For non-residential buildings except for new buildings	213	6.3%	5.1
	Total:	4,166	24.9%	

Table 3 ECMS AND DRS AT THE HOSPITAL CAMPUS (SEE FIGURE 4 BELOW).

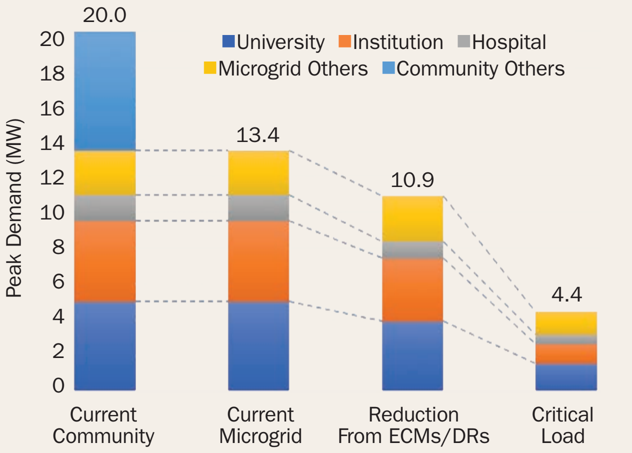
ECM/DR	ECM/DR Details	Demand Reduction (kW)	Source Energy Savings (%)	Simple Payback (yrs)
HVAC				
1. Duct Static Pressure Reset	In VAV air-handling systems	0	0.8%	0.7
1. Pump Differential Pressure Reset	In variable flow hot water and chilled water pump systems	0	0.1%	2.4
2. Install HVAC Occupancy Sensor Controls	In about 50% of spaces in all non-residential buildings	0	3.6%	10.2
Central Plant				
3. Chilled Water Pump VFD Retrofit	Install VFDs on the existing chilled water pumps.	0	0.7%	20.7
4. Ice Storage Chillers	Consider replacing the existing centrifugal chillers with a new air-cooled VFD chiller with ice storage system.	210	0.0%	–
Lighting				
5. Interior Lighting Retrofit	Install LED fixtures throughout 75% of floor area	51	6.3%	24
6. Lighting Occupancy Sensors	LED lighting fixtures in common spaces	8	1.7%	38
7. Reduce Lighting Power by 30%	Lighting fixtures with new controls	26	0.0%	–
Whole Building				
8. Existing Building Commissioning	Entire hospital	46	6.8%	2
	Total:	342	20.0%	

Figure 4 ECMS AND DRS AT THE HOSPITAL.



The bubble size represents the relative project cost. Not all bubbles can be seen due to size or overlap.

Figure 5 PEAK DEMAND REDUCTION FOR COMMUNITY MICROGRID SIZING.



energy perspective, the power factors were not calculated in this phase of the project.

To provide critical public safety, health, and security support for this community upon loss of the electric grid for 72 hours due to natural or human-made disasters, the total power for the microgrid is 316 megawatt hours (MWh), which can be provided by the proper sized natural gas generators and DERs in the community. Based on the energy assessments, the community resilient microgrid can be further designed and constructed for future implementation.

Campus Level Strategies

An example of campus-wide energy assessment (energy master plan) is presented to support the campus-level energy-efficiency initiatives through the concepts of sustainability and resiliency. The objective of the example energy master plan is to provide a roadmap for

Table 4 ECMS AT THE UNIVERSITY CAMPUS (SEE FIGURE 6 BELOW).

HVAC	Central Plant	Lighting	Whole Building	Building Envelope
1. VAV Dual Duct Retrofit in Science	6. District Cooling Evaluation	9. Upgrade Site Lighting	12. Existing Building Cx in Life Science	13. Replace Attic Insulation in Multiple Bldgs.
2. VAV system retrofit in Lecture Center	7. Controls Upgrade/ Integration	10. Upgrade Lighting Fixtures, Controls in Gym	12. Existing Building Cx in Multiple Buildings	14. Replace Single-Pane Windows in Multiple Bldgs.
3. Lab Hoods with AHU VFD Upgrade	7. Update Pump Seal Water Cooling	10. Upgrade Lighting in Lecture Center		
4. Lab Hood Retrofit	7. Distribution Loop Modification	10. Upgrade Lighting in Fine Arts		
5. Lab DCV	7. Distribution Loop Control Valve Station Modification	10. Upgrade Campus-Wide Corridor and Stairway Lighting		
5. AHU VFD Upgrade in Social Science	7. Distribution Monitoring Through BAS	10. Upgrade Lighting Controls in Library		
5. AHU VFD upgrade in Physical Education	8. Distribution loop Monitoring and Controls Through BAS	10. Upgrade Interior Lighting in Offices, Corridors Multiple Bldgs.		
5. Lab Exhaust Heat Recovery		10. Upgrade Interior Lighting in Res. Bldgs.		
5. HVAC/Control Update in Residential Tower		11. Upgrade Lighting Fixtures in Multiple Bldgs.		
5. Pool Ventilation Heat Recovery in Physical Education				

the university campus to improve energy efficiency, reduce energy use, and decrease operating costs to meet the goals and mandate of New York State Executive Order 88 (improving statewide energy efficiency by 20% by the year 2020 compared to the baseline year of 2010).

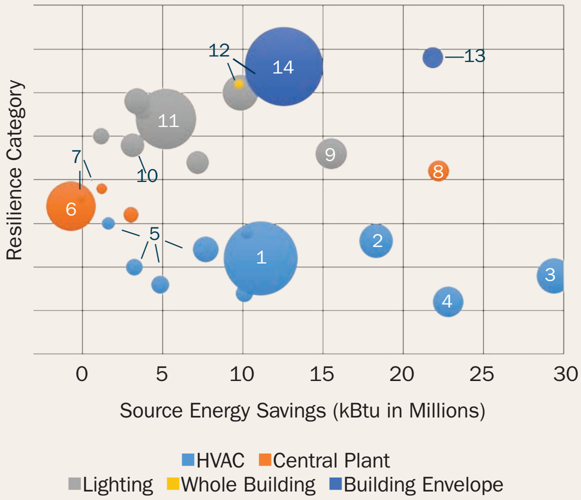
Energy Assessment

An energy assessment for majority of the academic buildings and residential buildings on campus was performed to develop a roadmap for campus-wide energy efficiency projects and actions.

ECMs. Preliminary Energy-Use Analysis (PEA), ASHRAE Level 1 Walk-Through Analysis and Level 2 Energy Survey and Engineering Analysis for the majority of the campus buildings are performed as part of the energy master plan.

Figure 6 shows the ECMs at the university campus. The x-axis represents the source energy savings in kilo Btu (kBtu), which is a key measurement for sustainability. The y-axis does not represent any measurement quantitatively, rather it is used to separate different ECMs. The bubble size represents relative project cost associated with each ECM.

Figure 6 ECMS AT THE UNIVERSITY CAMPUS.



The Y-axis does not represent any measurement quantitatively. The bubble size represents the relative project cost. Not all bubbles can be seen due to size or overlap.

Table 4 shows all the ECMs at the university campus, with the following ECMs highlighted based on simple payback period:

1. HVAC: HVAC and control upgrade in the Residential Tower with about 3.2 years of simple payback.
2. Central Plant: Distribution loop control valve station modification with about 1.4 years of simple payback.

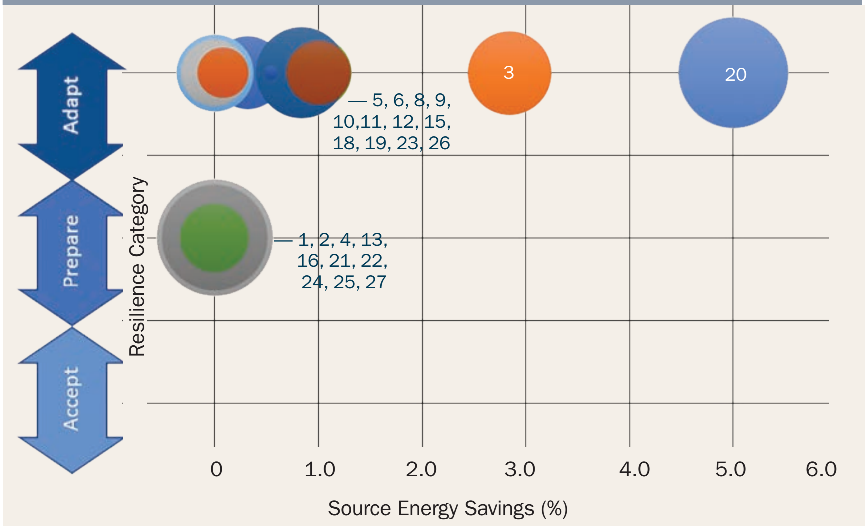
3. Lighting: Upgrade lighting controls in the library with about 1.3 years of simple payback.

4. Whole building: both existing building commissioning (EBCx) measures result about 2 years of simple payback.

5. Building Envelope: Replace attic insulation in multiple buildings with about 4.7 years of simple payback.

Resiliency measures. While the ECMs at the university campus presented above are identified for energy and cost savings during the energy audits (i.e., they can be considered as acceptable resiliency measures), the following measures are identified for consideration for campus resiliency initiatives.

Figure 7 RESILIENT DESIGN STRATEGIES IN A HOSPITAL. COLORS IN TABLE 5 CORRESPOND TO THE CIRCLES BELOW.



The bubble size represents the relative project cost. Not all bubbles can be seen due to size or overlap.

1. Prepare measures: to actively prepare and plan for the adverse events (e.g., hurricane, earthquake, and flooding).

a. Raise critical equipment and backup systems in mechanical penthouses.

b. Provide a backup electric feeder and a natural gas supply line from utilities.

c. Provide backup power generators for the buildings on campus without them.

d. Safeguard toxic materials in research labs.

e. Reduce electric demand through campus control integration and load shedding programs.

2. Adapt measures: to adapt the use of the measure to reduce or absorb the adverse events (to reduce/offset campus energy use during normal operation and to generate/store electric and/or thermal energy during adverse events).

a. Solar Photovoltaics (PV): propose about 1.5 MW solar PV array on the roof of an academic building (reduce campus energy use during normal operation and potentially generate electricity during adverse events).

b. Geothermal heat pumps: propose for several residential buildings on campus.

c. Combined Heat and Power (CHP): propose a 5 MW gas combustion turbine CHP to offset campus electric and thermal loads.

Building Level Strategies

Buildings are the fundamental components for campuses and communities. From the perspective of sustainability and resiliency, buildings are like trees and communities are like forests – they provide a comfortable environment for the society while protecting us from adverse events.

As fundamental building blocks for our communities, most of the buildings are regulated by codes and standards. Most notably, the International Building Code is in use or adopted in all 50 U.S. states, as well as many countries worldwide. One of the key contributions from ASHRAE to International Building Code is ASHRAE/IES Standard 90.1, which is adopted by the International Energy Conservation Code. Standard 90.1 (then Standard 90-75) was first developed in the aftermath of the global energy crisis in the early 1970s. It covers building systems that contribute to energy consumption, including Building Envelope (Chapter 5), HVAC (Chapter 6), Service Water Heating (Chapter 7), Power (Chapter 8), Lighting (Chapter 9), and Other Equipment (Chapter 10).

While many building codes, standards, guidelines and rating systems were written for the ultimate goal of sustainability, measures for building resiliency are only minimally mandated in certain codes and standards (e.g., emergency generators and building wind load design).

Resilient Design Strategies

Based on the resilient design strategies in a hospital building located in the Midwest provided in a study,[6] the following assessment was performed to assess these strategies from both sustainability (e.g., energy savings) and resiliency (e.g., prepare or adapt measures) perspectives.

Figure 7 shows the resiliency design strategies in the hospital. The x-axis represents the percentage of

Table 5 RESILIENT DESIGN STRATEGIES IN A HOSPITAL (SEE FIGURE 7 PREVIOUS PAGE).

Resilient Design Strategy[6]	Hazard[6]	Resiliency Category	Source Energy Savings (%)	Added Cost ($)[6]
🟫 1. Above 500-year Flood Plain	Flooding	Prepare	0.0%	$0
🟦 2. Backup Power (96 hours)	Hazard Preparedness	Prepare	0.0%	$260,000
🟧 3. De-couple Systems (DOAS)	Air Quality + CO_2 Emissions	Adapt	2.8%	$682,000
⬜ 4. Envelope Strengthening	Tornadoes, High Winds, Hail	Prepare	0.0%	$1,320,000
🟨 5. Exterior Shading	Hazard Preparedness	Adapt	0.2%	$100,000
🟩 6. Form for Daylighting (Floor with Daylight Sensors)	Air Quality + CO_2 Emissions	Adapt	1.0%	$489,000
7. Graywater treatment (Not Included)	Drought	Adapt	Not Included	Not Included
🟦 8. Green roofs	High Temperatures	Adapt	0.3%	$510,000
🟦 9. Heat recovery (Ventilation)	Air Quality + CO_2 Emissions	Adapt	0.8%	$800,000
🟥 10. High Performance Envelope	Hazard Preparedness	Adapt	1.0%	$394,000
⬛ 11. Increased Ventilation	Air Quality + CO_2 Emissions	Adapt	0.0%	$292,500
🟦 12. Low-emitting VOC Materials	Air Quality + CO_2 Emissions	Adapt	0.0%	$0
🟩 13. Material Specification (High Winds)	Tornadoes, High Winds, Hail	Prepare	0.0%	$0
14. Passive Cooling (Shading, Operable Windows, Green Roof)	Hazard Preparedness	Adapt	Included in others	Included in others
🟦 15. Permeable or Pervious Paving	Flooding	Adapt	0.0%	$578,000
🟧 16. Raise Critical Equipment	Flooding	Prepare	0.0%	$400,000
17. Rainwater Catchment (Storage Tanks)	Drought	Adapt	Not Included	Not Included
⬜ 18. Reduce Water Use, Indoor	Drought	Adapt	0.0%	$424,000
🟨 19. Reduce Water Use, Landscape	Drought	Adapt	0.0%	$0
🟦 20. Renewable Energy (PV Panels)	Air Quality + CO_2 Emissions	Adapt	5.0%	$1,186,500
🟩 21. Safeguard Toxic Materials	Flooding	Prepare	0.0%	$0
🟦 22. Sewage Backflow Valve	Flooding	Prepare	0.0%	$5,000
🟧 23. Trees and Vegetation	High Temperatures	Adapt	0.1%	$249,500
⬛ 24. Tornado Safe Room	Tornadoes, High Winds, Hail	Prepare	0.0%	$1,075,500
🟨 25. On-site Storage (Food and Supplies)	Hazard Preparedness	Prepare	0.0%	$0
🟦 26. Operable Windows	Hazard Preparedness	Adapt	0.5%	$18,000
🟩 27. Water and Power Outages (Storage Tank)	Hazard Preparedness	Prepare	0.0%	$450,000
		Total:	11.9%	$9,234,000

source energy savings, which is a key measurement for sustainability. The y-axis represents different resiliency categories or prepare and adapt measures (they do not represent any measurement quantitatively). The bubble size represents added project cost.[6] The resiliency design measures, hazards, resiliency categories, as well as source energy savings and added costs are detailed in *Table 5.*

As fundamental building blocks for campuses and communities, large-scale sustainability and resiliency goals, in general, can only be achieved when individual building becomes sustainable and resilient (e.g. in building design, energy assessment, and commissioning).

Equipment Level Strategies

A big part of the design and construction industry is equipment manufacturing for all trades, from architectural wall panels and large steam-powered turbo generators to a bathroom exhaust fan and an LED light bulb.

Equipment manufacturing is essential in the building industry, and it provides the fundamental infrastructures for engineers and architects to apply the concepts of sustainability and resiliency.

Similarly, when applying the concepts of sustainability and resiliency to equipment in design and construction industry, many codes, standards and guidelines cover a wide range of areas, such as life safety, durability and environmental impact. Among them, energy efficiency is one of the most recognized benchmarks, which broadly applies to equipment in most trades. For example, Energy Star (a voluntary energy program developed by U.S. Environmental Protection Agency) helps businesses and individuals save money and protect the environment through the adoption of energy-efficient products. Standard 90.1 provides three compliance paths: prescriptive, energy cost budget, and performance rating method. It still enforces the prescriptive requirements when applying to mandatory provisions for minimum equipment efficiencies. In addition to guiding engineers and architects for more energy-efficient building designs, these mandatory requirements have also been positively leading the equipment manufacturers in our industry to a more sustainable future.

Equipment Considerations

From a consulting engineer's perspective, an example of an air-handling unit (AHU) is briefly discussed to support the application of sustainability and resiliency concepts when specifying building equipment.

For an AHU with heating, cooling and ventilating capacities, several examples of sustainability considerations are as follows:

1. Energy efficiencies for cooling/heating equipment and fans;
2. Other energy-saving features, such as economizer controls and energy recovery systems;
3. Indoor air quality through the filters;
4. Low leakage construction;
5. Environmentally low impact materials; and
6. Minimum maintenance ore replacement requirements.

Several examples of resiliency considerations to prepare for the adverse events are as follows:

1. Available resources (e.g., air-cooled instead of water-cooled);
2. Redundancy of critical components (e.g., fan array for ventilation);
3. Explosion proof or corrosion resistance for certain facilities (e.g., in water treatment plants);
4. Roof curb and supporting systems in hurricane-prone areas (e.g., in Miami-Dade County, Florida); and
5. Raise critical equipment (e.g., in a mechanical penthouse).

Similar to buildings and its systems, the concepts of sustainability and resiliency can be applied to individual equipment in manufacturing design as well as building detail design and commissioning.

Conclusion

With increasing energy demand and natural/human-induced disasters in the recent years, the two key concepts—sustainability and resiliency—are crucial for engineers and architects in the current design and construction industry. The concepts of sustainability and resiliency transcends physical scales—from community scale electric grid to detail design of equipment. Careful applications of these two key concepts can resolve many challenges facing the current new construction and existing facilities management landscape.

Note

The examples presented in this paper do not reflect the results of any specific projects, rather they are based on the author's experience and presented to support community-level and campus-level energy efficiency initiatives through the concepts of sustainability and resiliency.

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