# Prevalence of Findings from ASHRAE Level 2 Energy Assessments at 13 Colleges

*Michael J. Madigan, P.E., LEED AP*
*Robert M. Neimeier, and Stuart J. Spiegel*

ABSTRACT

To meet a number of objectives, not the least of which is cost savings, colleges and universities of all sizes, public and private, have been exploring opportunities to reduce energy use and costs. In operational or maintenance practices, energy inefficiencies may be present due to the condition of mechanical systems or campus infrastructure, or as a result of behavioral and cultural habits. To derive information for an energy master plan (EMP), and derive, prioritize and implement energy conservation measures, the first step is to obtain a perspective on campus-wide opportunities for an improved energy profile and resultant cost savings. This program of energy assessments has been performed at 13 of the colleges at the City University of New York (CUNY). The assessments identified opportunities in the following 12 categories on a building-specific basis for a total of 169 buildings: building envelope, lighting, HVAC, plumbing, boiler plant, chiller plant, building automation system, utility distribution, electrical, special systems (as appropriate), O&M, and existing building commissioning (EBCx). There were 36 subcategories, which are described for clarity as to the scope of the assessment in these areas. The energy assessments have noted some commonalities among the energy saving opportunities that were observed. Buildings with some common uses (administration, library, science) did not necessarily reflect strong commonalities, possibly given the relatively limited number of buildings with these uses in the database and the relative diversity of building age, historical use and construction.

The results of this article will be useful as a benchmark to stakeholders involved in or planning similar assessments.

## INTRODUCTION

Buildings are a key area of interest for any type of energy reduction policy in the U.S., often noted as accounting for over 40% of national energy use as of 2008 (U.S. Department of Energy 2011) and around the world (United Nations Environment Programme 2014), across the public and private sectors. Institutions of higher education have been taking steps to reduce energy use, energy costs, and greenhouse gas (GHG) emissions. The drivers are varied, but include limited financial resources engendering a need for cost reduction wherever it does not interfere with an institution's basic mission, the necessity to be perceived as having a leadership role in the reduction of GHG emissions and impacts to climate change, and the public relations benefits from the aforementioned activities with respect to the expectations of potential students.

As a useful benchmark, we have recently focused on the higher education sector (colleges and universities), which features buildings representing a wide range of activities found elsewhere in the public and private sectors: offices, lecture facilities, libraries, laboratories, residential centers, athletic facilities (including natatoriums, ice rinks, field houses, fitness areas, stadiums, and support activities), conference centers, greenhouses, research facilities, motor pools and repair shops, and storage facilities. Campuses can encompass a large amount of space (often in the millions of gross square feet per institution) and age (significant capital growth in higher education occurred in the 1950s through the 1970s).

The results of energy assessments of college campuses have been presented in the literature, but typically based on assessments of single campuses (Kozman et al 2011; Pullen 2000), or of specific spaces or systems on a campus or with similar building uses (Pitts and Saleh 2007; Doty 2011; Eberly 2012). Ritter (2012) presented the results of an ASHRAE (American Association of Heating, Refrigerating and Air-Conditioning Engineers) Level 2 energy audit of a senior living facility, which would have some of the same building uses, and possible conformation, as found in some campus buildings (particularly residence and dining halls). Zhou et al. (2013) is the exception, with an analysis of energy uses in more than 50 institutions in China.

Reported here are results from energy assessments on more than 20 million square feet of higher education building systems, and spaces, such as central heating and cooling plants, teaching laboratories, gymnasiums (including natatoriums), classroom buildings, and administrative and office buildings. These energy assessments were performed on behalf of the City University of New York (CUNY) and were funded through the auspices of the Dormitory Authority of the State of New York (DASNY), both of which had very active roles in this program. CUNY is an urban university system consisting of 24 campuses of 4-year and community colleges, and over 500,000 total students located wholly in the five boroughs of New York City. The assessments were carried out through interviews of campus facilities staff, design/drawings reviews, building field surveys (day and night), and of energy procurement records. Together, these activities provided a broad picture of demand-side building energy consumption and GHG emissions, as well as opportunities for improvement. These opportunities were aggregated into four categories: (i) immediate actions, such as behavior and operations & maintenance (O&M) changes; (ii) near-term actions, such as specific energy conservation measures (ECMs) with implementation horizons of up to 5 years; (iii) long-term actions, such as infrastructure renewal (IR) with implementation horizons of up to 15 years; and (iv) new construction and major renovation projects, including the pursuit of highly energy efficient buildings.

This article will discuss the process used and how it helps to prioritize projects for implementation as well as the common findings and some calculated simple payback periods for these ECMs. The importance of the respective systems that were assessed is described from the perspective of energy use. The results presented herein will be of value to stakeholders involved in or planning similar energy assessments in that it provides:

- A road map of the process for those planning energy assessments and are conflicted over how to prioritize limited financial resources with respect to scoping of an assessment.

- Guidelines for those who have completed an energy audit or assessment, given the number of campuses and buildings included in the database.

- Validation by an external study in support of findings made at other campuses where such may be beneficial to the acceptance of similar results at a campus.

## METHODOLOGY

The campus energy assessments were performed so that CUNY and the respective colleges could better ascertain the current state of energy-related matters at the college and to identify ECMs. The level of effort for the energy assessment aligns with an ASHRAE Level 2 Energy Survey and Analysis. ASHRAE "Procedures for Commercial Building Energy Audits (PCBEA)—Second Edition" is the generally accepted guide in the U.S., defining best practices for planning and performing facility energy assessments. This document classifies a commercial building energy audit into three levels of effort:

Level 1—Walk-through Analysis

Level 2—Energy Survey and Analysis, and

Level 3—Detailed Survey and Analysis.

This approach would be typical for both energy audit and energy master plan efforts, and utilizes data from the PCBEA. Since the energy master plan often involves a larger portfolio of buildings, the scope of the effort would be substantially greater than for a single building energy audit. The Level 1 analysis establishes the general savings potential of the building or campus to establish which buildings have the greatest savings potential and to set priorities for conducting Level 2 and Level 3 audits. The Level 2 audit involves a more detailed building survey, including energy consumption and peak demand analysis. A Level 2 energy analysis identifies the savings and costs associated with ECMs that meet the owner's constraints and economic criteria, along with proposed changes to O&M procedures. The Level 3 engineering analysis focuses on potential capital-intensive projects identified during a Level 2 analysis.

This energy assessment was consistent with the following Level 2 criteria:

- Provides a detailed building survey of systems and operations

- Includes a breakdown of energy source and end use
- Identifies ECMs
- Develops the savings and costs associated with the identified ECMs
- Establishes the simple payback period and ranks each ECM to help evaluate which projects should be subjected to a more thorough analysis, such as that provided by a feasibility or ASHRAE Level 3 investment grade study.

The following activities were performed as part of the campus energy assessment:

- Survey of designated buildings to identify major energy-consuming systems and equipment
- Review of available record drawings, maintenance records, prior energy studies, reports, and recent energy projects
- Review of energy procurement records
- Interviews with campus facility directors, stationary engineers, trades and O&M staff
- Lighting fixture survey and calculation of lighting watts per square foot for each building
- Performance of a night survey to determine light levels and unoccupied lighting behaviors
- Survey of domestic water lavatory, toilet and urinal fixtures for water conservation performance
- Survey of computer laboratories and data centers
- Review of current utility metering systems and equipment for fossil fuel, electrical, steam, heating hot water, chilled water, and water usage, and an assessment of the potential for additional metering.

The intent of the assessments that were performed was to establish a baseline of the condition of existing systems and equipment, maintenance practices, and occupant behavior throughout the campus. Based on these observations, opportunities for improvement were identified in the systems assessed. From these identified opportunities, a select number of ECMs were developed that, if implemented, would contribute to significantly reducing a campus' energy profile, energy costs and GHG emissions.

**Categories of Energy Savings Opportunities**

Observations were recorded for 36 subcategories of facility infrastructure and O&M with implications either directly or indirectly on energy use, which were described as energy opportunity areas; these elements were aggregated into 12 categories. The following lists the subcategories and describes the basis of the assessment for each subcategory. They involved observations of physical condition, actual use or operation as compared to observed or anecdotal information, discussions with campus staff and operators, review of operating records, and experience regarding the estimated life expectancy of infrastructure or equipment. Unless specifically noted below, testing or measurements were not conducted; collection of samples and invasive testing were not performed.

**Building Envelope**

Building envelope improvements reduce energy use by reducing thermal transmission through the building enclosure, and by reducing excessive air infiltration. When renovations are performed, it is important to consider the energy benefit of improvements to the building envelope and to capture their contributions to reducing energy use, energy cost, maintenance time and costs, and GHG impacts.

***Roof/Insulation***—Physical condition was observed, and age and construction methods of roofing and envelope components were obtained from campus records. Thermographic surveys for water infiltration were not performed.

A white roof may reduce the urban heat island effect that contributes to higher temperatures in cities. Vegetative "green roofs" also can reduce the heat island effect, although with much higher installation and maintenance costs. Roofing projects provide an opportunity to upgrade or replace the roof insulation systems, further enhancing the energy performance of the building.

***Windows***—Windows are the natural modulators of heat, light and ventilation air in a building and have an important influence on energy use and occupant comfort in exterior perimeter spaces. While windows affect the heating and cooling in the areas nearest the exterior walls, daylight and ventilation can provide a greater impact area if the windows and the spaces are properly designed.

High-performance windows can reduce peak building heating and cooling loads, which reduces the capacity and first cost of equipment needed to condition the building along with annual heating and cooling energy requirements. Since electrical peak loads usually occur on summer days when demand charges are highest, windows that reduce peak loads can result in energy demand cost savings as well.

While operable windows may provide a local comfort or ventilation benefit, the performance of the central HVAC system can be adversely affected by occupant behavior, potentially resulting in higher energy costs. To prevent windows from being opened while central heating and cooling systems are running, it may be advisable to permanently secure the windows in a closed position, or disable HVAC systems when windows are open.

***Walls/Insulation***—In 2014, ASHRAE updated Standard 189.1: "Standard for the Design of High-Performance Green Buildings" to provide total building sustainability guidance for designing, building and operating high-performance green buildings. ASHRAE 189.1 sets the requirements for wall construction and building insulation significantly higher than ASHRAE 90.1-2013, "Energy Standard for Buildings Except Low-Rise Residential Buildings."

While adding insulation to walls and roofs can improve a building's energy performance in heating and cooling seasons, adding insulation in existing buildings is unusually complicated and cost-prohibitive. An exception would be replacing or adding to roof insulation when roofing systems are replaced, or adding exterior insulation as part of a siding project. Interior renovation projects can also provide opportunities to add insulation to the interiors of existing walls and roof systems.

***Air Infiltration***—Infiltration can be one of the leading causes of discomfort and energy use in a building. Uncontrolled leakage of outside air introduces moisture, particulates, noise, odors, and otherwise unwanted influences. Repairing or replacing window and door weather stripping, sealing openings in the exterior building envelope and providing vestibules and revolving doors are strategies that can be engaged to reduce unnecessary building air infiltration on campus.

***Lighting***

***Interior Lighting Fixtures***—Incandescent, metal halide, and T-12 fluorescent fixtures no longer represent best practices for campus interior lighting, where (light emitting diode (LED), and T-5 and T-8 fluorescent fixtures are now common in modern energy-efficient designs. Campus buildings are often subject to being re-purposed, rooms modified (split or combined), with utility services often impacted by these alterations. With respect to lighting, light levels that were adequate for previous room uses may become inappropriate as the room or building is reprogrammed. When lighting fixtures originally were installed, energy efficiency may not have been a prime consideration. LED lighting technologies offer a wide variety of fixtures that were not available until recently. Depending on the lighting requirements of the space, a one-for-one fixture replacement often is not the best approach for lighting retrofits. Engaging the services of a qualified lighting design professional generally is recommended for all but the simplest lighting retrofit projects.

***Interior Lighting Controls***—The 1990s saw a surge in lighting retrofit projects on campuses, including the installation of occupancy sensors. However, in the intervening decades, sensor sensitivity and reliability have improved significantly and replacement should be considered, depending on age and condition. While some public spaces (such as entryways, hallways, stairways, and common areas) may remain lit throughout the night for security purposes, light levels can be reduced in these areas when they are largely unoccupied, with the use of installed sensors to increase an area to full lighting upon entry of an occupant. In many cases, behavioral issues also are at play; these energy assessments observed sensors that were blocked by furniture, equipment or supplies, or that were no longer functioning due to their age.

***Exterior Lighting***—The primary functions of exterior lighting are personal security, way finding and architectural feature illumination. It is possible to provide these functions cost effectively through the use of efficient LED fixtures and controls that respond to the presence of pedestrians and turn off when sufficient natural ambient light is present. Once again, lighting retrofits of campus site lighting typically involve more than simple replacements and are best implemented with the assistance of an exterior lighting design professional.

## HVAC

***Demand Control Ventilation (DCV)***—Historically, building ventilation strategies have utilized fixed quantities of outside air that are scheduled based on maximum anticipated occupancies, often resulting in excessive ventilation during lightly occupied periods. DCV utilizes carbon dioxide sensors in the space or return air ductwork to provide an indication of the level of occupancy in the space. Outside air dampers are modulated based on the carbon dioxide levels, thereby reducing excess ventilation air and its associated heating and cooling requirements.

***Outside Air Economizer***—Air handling unit economizers save energy in buildings by using outside air for cooling when ambient temperature and humidity conditions are sufficiently low to eliminate the need for mechanical cooling. Buildings with high internal heat loads associated with people, equipment and lighting can benefit from economizer "free" cooling for many hours per year, resulting in significant cooling energy savings; since the only energy an economizer uses is for blower operation, an economizer system in conjunction with a traditional HVAC system can significantly reduce energy consumption by drawing in cooler outdoor air, hence the term "free."

***Enhanced Air-side Controls***—Advanced building automation strategies also can be used to modulate air handling unit supply air temperature and flow in response to interior loads and outdoor conditions to improve energy efficiency. Manual control of air handling unit setpoints, however well intentioned, should be avoided.

***Exhaust Heat Recovery***—Utilizing the heat present in building exhaust airflows to preheat-required ventilation air is a sound energy conservation strategy. In new buildings subject to the New York State Energy Conservation Construction Code (NYECC), any non-toxic exhaust over 2,000 cubic feet/minute (CFM) is required to utilize energy recovery. Attempting to recover waste heat from air volumes of less than 2,000 CFM typically does not result in favorable payback time.

In existing buildings, the cost-effectiveness of heat recovery is largely determined by the relative locations of the air exhaust and intake points. Where these are consolidated and in close proximity, exhaust heat recovery may be cost-effective.

## Plumbing

***Water Saving Fixtures***—Improved water use efficiency can reduce energy expenditure when the production of less hot water or chilled water can be achieved. Fixtures installed prior to 1994 use considerably more water that those installed in subsequent years as shown in Table 1. The U.S. Energy Policy Act of 1992 (EPAct) created a set of unified national standards for fixture maximum water use that is shown in Table 2. Many local building codes recently have adopted the more stringent water efficiency standards of the U.S. Environmental Protection Agency's (USEPA) WaterSense Program (see a description of WaterSense approved products at www.epa.gov/WaterSense/products/index.html) that are presented in Table 3.

To reduce water consumption, it often is recommended that a phased plan be developed to replace older, inefficient plumbing fixtures at a campus. Where existing bathrooms are in need of renovation or general repair, fixture replacement can be easily accomplished as part of the renovation. Where no renovations are pending, it may be worthwhile to consider replacing toilets and lavatories with new water-efficient fixtures as an ongoing maintenance project until all fixtures have been upgraded.

**Boiler Plant**

***Stack Economizers*—**The addition of an economizer/feedwater heater to preheat boiler feedwater as it leaves the deaerator prior to entering the boiler, has the potential to increase the efficiency of the boiler system by an additional 3%, increasing the overall system efficiency to as much as approximately 83%.

***Blowdown Heat Recovery*—**Waste heat from boiler blowdown in the form of flash steam can be recovered for use in the deaerator or for other low pressure steam loads. Heat recovery also has the benefit of reducing blowdown temperature before it is discharged to a municipal sewer, for which there usually are thermal limits.

***Hot Water Boiler Plant*—**Modern campuses are increasingly moving away from central steam distribution systems that have lower boiler efficiencies and higher distribution losses to medium-temperature hot water (MTHW) or high-temperature hot water (HTHW). MTHW is the most energy efficient central heating medium, because it is generally produced and distributed at a maximum temperature of 300°F, which is considerably lower than HTHW (400°F) or medium pressure steam (300°F, or higher).

**Table 1. Pre-EPAct Plumbing Fixture Water Consumption**

| Year of Building Construction | Water Consumption |
|---|---|
| **Pre-1977** | 4.5-5.0 gallons / flush toilet |
| **1977 to mid-1990s** | 3.5 gallons / flush |
| **Mid-1990s to present** | 1.6 gallons / flush toilet, 1.0 gallon / flush urinals |
| **Sinks (all years)** | 3.5-5.0 gallons / minute |
| **Shower heads (all years)** | 3.5-5.0 gallons / minute |

**Table 2. Post-EPAct Plumbing Fixture Water Consumption**

| Fixture | Water Consumption |
|---|---|
| **Toilet** | 1.6 gallons / flush toilet |
| **Urinals** | 1.0 gallons / flush |
| **Shower heads** | 2.5 gallons / min at 80 PSI |
| **Lavatory faucets** | 2.5 gallons / min at 80 PSI |
| **Kitchen faucets** | 2.5 gallons / min at 80 PSI |

**Table 3. U.S. Environmental Protection Agency WaterSense Program Plumbing Fixture Water Consumption**

| Fixture | Water Consumption |
|---|---|
| **Toilet** | 1.28 gallons / flush toilet |
| **Urinals** | 0.5 gallons / flush |
| **Shower heads** | 2.0 gallons / min at 80 PSI |
| **Lavatory faucets** | 1.5 gallons / min at 80 PSI |
| **Kitchen faucets** | 2.5 gallons / min at 80 PSI |

**Chiller Plant**

***Chiller Source Energy*****—**Chilled water can be generated using high pressure steam (turbine driven chiller), low pressure steam or hot water (absorption chiller), electrical power (motor driven chiller compressor), a natural gas engine, or direct fired natural gas (absorption). The selection of a chiller's energy source should consider fuel supply availability and reliability, future energy commodity costs and demand charges, energy efficiency, equipment maintenance and mechanical complexity. Since fuel costs may change from year to year, it is worth performing a life cycle cost analysis to evaluate the most cost effective chiller system for a given application. Electrical motor driven, water cooled centrifugal chillers generally have the highest mechanical efficiency when compared with these alternatives. However, the potential for cost savings by replacing chillers by type may be a site-specific consideration.

***Optimize Chiller Operating Sequence*****—**Chiller plant controls that schedule the operation of chillers, pumps, and cooling tower fans can provide significant energy savings compared to manual plant operating strategies. Using advanced monitoring of loads, ambient weather conditions and equipment electrical demand, chiller and pump sequencing, cooling tower temperature controls, and leaving water, temperatures can be optimized to provide the most efficient operating scenario for a given set of conditions.

**Building Automation System (BAS)**

***Building /Energy Management*****—**Control of HVAC systems at many campuses may still be performed with outdated pneumatic temperature control systems. Transitioning to a direct digital control (DDC) BAS can optimize performance of the mechanical systems within any given building or group of buildings. The BAS can monitor and control a much larger number of individual points with no limit to the sophistication of the control sequences.

Where the capability is present, a campus may not be taking advantage of the opportunity to sequence operations by time of day, season, or in response to environmental factors. This may include the establishment of supply air temperature setpoints, fan speed controls within certain tolerances, unoccupied heating and cooling modes, or morning startup/evening shutdown schedules. However, building systems may be inactivated and instead operated manually with the potential for inexact and significantly inefficient operations, with a concomitant waste of energy and of energy costs.

The following are advantageous strategies to be employed by a campus BAS:

- Optimize variable volume pumping and fan control for air handling systems.
- Provide feedback that confirms the status of control points, such as limit switches on actuators for systems that currently have no feedback.
- Provide for monitoring of all HVAC equipment.
- Provide operating trend data to observe process variations and troubleshoot problems.
- Provide real-time energy usage data and estimated energy costs so that facility operators can monitor building performance, predict maintenance issues and make necessary adjustments to how facilities run.
- Provide calculations and predict optimal start and stop times for equipment, in order to maximize setback times and minimize discomfort by pulling down or warming up spaces to anticipate occupancy.
- Interface with the campus maintenance management program (for CUNY this is DASNY's Archibus system) to provide automated service requests and closure, based on alarms and manufacturer's suggested operation and maintenance procedures.

In cases where existing HVAC systems are at or near the end of their useful life, upgrading to a BAS by itself is not recommended. The consideration of BAS as part of any major HVAC system renovation, including integration as part of a campus-wide system, is strongly recommended. As a corollary to adding BAS to the campus HVAC systems, adequate budget for BAS service must be set aside as part of the rollout. A simple 30-day annual service contract may not be sufficient to cover repair, calibration, and other maintenance issues with the BAS system that may not be appropriately covered by the existing personnel.

***Advanced Utility Metering***—The first step in managing energy consumption and resulting costs is to measure and track the energy consumption of the individual buildings on campus using building level sub-meters. Sub-meters allow energy use patterns for each building to be developed on a much more detailed level than is achievable with monthly utility consumption. Data from sub-meters is typically collected continuously at 15-minute intervals, which allows variations in energy consumption to be evaluated based on time-of-use, rather than net quantities. Therefore, it provides temporal patterns of energy use.

Finally, if implemented at the necessary level of detail, the college may use sub-metering as a method of applying greater accountability for energy use, including the option of billing individual departments for their energy consumption. This can result in a higher adoption rate of low-cost behavior driven ECMs, as the impact of energy conserving behaviors will directly reward each department via lower energy charges. The task of analyzing data, determining trends and recommending actions must be an assigned duty.

**Applicability of Electrical Sub-meters**

In a campus environment, electrical sub-meters are typically installed to monitor electricity consumption of either individual buildings, specific areas (i.e., lab areas and server rooms), or equipment (chillers and cooling towers) inside individual buildings. Sub-metering can bridge this information gap, and allow an electricity consumption history to be developed for each building. The sub-metered data can then be analyzed for variations in energy use patterns either with time, such as load profiles useful in demand curtailment projects, or against an independent variable such as ambient temperature useful in developing the relationship between temperature-dependent cooling and heating loads, and temperature-independent equipment and process loads. Sub-metered data can also be used to extend building benchmarking down to the department or zone level. This allows for the internal ranking of departments or zones which is useful for the prioritization of energy efficient upgrade projects. Building electrical sub-meters would be installed at each existing building's main distribution panel.

**Applicability of Thermal Sub-meters**

A Btu meter consists of two temperature sensors, with one sensor each placed in the supply piping and in the return pipe from the building, and a flow meter that measures the fluid flow corresponding to the measured temperature difference. Often, these measurements are connected to a Btu meter controller that performs the heat transfer calculation and reports the thermal use directly to the BAS or other monitoring system.

**Other Metering Locations**

In addition to metering the electricity consumption on a per building basis, it is useful to measure the power, fuel gas, and water consumption dedicated to the primary heating and cooling functions of each building. Heating and cooling functions utilize the greatest percentage of energy of all building systems and variations in the energy consumption of these components (electrical chillers, natural gas boilers, and domestic makeup water for both systems) can be dramatic.

In general, it is recommended that within each building, when applicable, additional sub-metering be applied to each electrical chiller's electrical service, each cooling tower's electrical service, pump electrical services, boiler natural gas supplies, boiler makeup water and boiler feedwater. Installing these meters will allow for the actual efficiency of each system to be measured directly. By measuring and tracking efficiency of the plant components, intelligent decisions for operation of the plant can be made, rather than relying on rules of thumb and estimates of operating efficiency across different operating modes.

While metering domestic water consumption does not have a direct impact on energy consumption, its production, treatment and delivery from the source of supply can represent a significant amount of imbedded energy. Understanding where water is used is an important step in managing the resource.

**Utility Distribution**

***Chilled Water*—**Chilled water can be produced in building-level chillers or distributed campus-wide from a central plant. The physical condition of piping can contribute to water losses that will result in an energy cost to replace. Variable speed drive chilled water pumps will be more energy efficient than constant speed drive units when chilled water flow varies with load through the use of two-way control valves. Additional energy savings can be realized by resetting chilled water supply temperatures based on ambient conditions. Also, poorly controlled piping "bridges" that connect individual buildings to the chilled water distribution loop can lead to undesirable operating conditions such as "low delta T syndrome," resulting in inefficient operation, and concomitant energy inefficiencies.

***HTHW and MTHW Systems***—These are typically pressurized systems that operate above the boiling point of water. Since these are closed piping systems, identifying and correcting water leaks as they occur is essential. Leaks are critical in these systems—heated water will boil off at leak points, requiring additional water to replace that which is lost, energy to heat it to a high temperature, and additional energy to pump this replacement water. Therefore, the integrity of piping systems is an important factor in energy losses. Likewise, maintaining the integrity of piping insulation reduces unnecessary heat loss and the delivery of lower-than-optimum temperature water. As with chilled water, additional energy savings can be realized by resetting hot water supply temperatures based on ambient conditions. On campuses where HTHW or MTHW is used to heat domestic water in buildings, these loads may be the only systems served by the central plant in summer months when HVAC loads are not present. Since boilers operating at part load are less efficient than at full load, this can waste a great deal of pumping and heating energy. It may be more cost-effective to employ building-level water heaters fueled by electricity or fossil fuel in summer than to use hot water generators served by the central plant. In some cases, it may even be possible to shut down the central plant completely.

***Steam Systems***—Steam traps are vital components in steam systems. They are designed to remove condensate from the steam distribution piping and heat exchange equipment. They also remove non-condensable gases, which impede heat transfer and result in corrosion. System debris, improper sizing, and improper application are common causes of steam trap failure. A well-maintained steam system will typically experience a 20% trap failure in a one-year period. To minimize losses associated with steam trap failures, a concerted effort must be applied to managing the steam trap population. A steam trap management program should incorporate the following activities:

1. Develop the program and the steam trap database template
2. Purchase testing equipment
3. Train personnel on the program procedures and the proper use of testing equipment
4. Locate and identify every trap, replacing failed traps as they are identified
5. Assess the operating condition of every trap at least annually

6. Update the established steam trap database
7. Estimate annual energy savings to demonstrate program effectiveness.

A steam trap assessment should be conducted by personnel with knowledge in the operation and selection of steam traps. Therefore, training is critical to the success of the management program. The steam trap assessment should cover:

1. Trap operation,
2. Trap selection (type and size),
3. Trap installation, and
4. Condensate return.

***Domestic Water***—Domestic water is a utility that offers modest opportunities for improved energy efficiency. Metering water use, including submeters at the delivery points to individual buildings, allows an evaluation of water use and potential losses inside buildings. Losses (leakage) require additional energy to pump makeup water; leaks also can encourage mold growth, impacting health of building occupants, and resulting in the deterioration of internal building infrastructure (adjacent walls, floors, equipment). Constant volume high-rise domestic water pressurization systems can benefit by change-out to variable volume flow units.

***Electrical Power***—It may be difficult to identify many specific items in the electrical distribution system that could be the focus of energy efficiency measures. The replacement of old transformers, especially oversized units, with new equipment will result in energy savings. However, this type of replacement generally would not be cost effective based on energy savings alone. Periodic infrared thermal surveys of critical electrical equipment and conductors can provide an early indication of potential problem areas, possibly preventing equipment failures.

**Electrical**

***High Efficiency Motors***—Existing motors that are oversized for the loads they serve operate at lower efficiencies at part load. A properly sized smaller motor operating near its rated horsepower is more efficient that an oversized motor operating at part load. Prior to replacing a motor, it is recommended that the brake horsepower requirements of the existing installation be checked by measuring the motor amp draw under load using an electrical multimeter. With typical simple payback periods between 5 to 15 years, premium efficiency motor replacements can make sense if a motor is near the end of its useful life. As motors fail or are replaced as part of a scheduled maintenance project, installing new U.S. National Electrical Manufacturer's Association (NEMA) premium efficiency motors should be a consideration.

***Variable Speed Drives (VSDs)***—Major fan and pump motors throughout the campuses may be a combination of constant speed and variable speed drive operation. VSD systems can significantly reduce electrical costs associated with fans and pumps when they operate at part load. The USEPA's EnergyStar Building Manual advises that, when controlled properly, VSDs can reduce motor energy requirements by 40 to 60%. Campuses should evaluate the installation of VSD systems in conjunction with future HVAC equipment or controls upgrades associated with campus buildings. VSD applications save energy only when they are part of a control strategy that results in significant annual motor run hours at reduced speed.

***Plug Loads***—These consist of equipment; personal space heaters and fans; and the use of private microwaves, refrigerators, toaster ovens, and coffee pots when central kitchenettes are not available. Computer peripherals, such as monitors, printers and scanners, continue to use energy, even after they are turned off. Power strips are readily available that provide electrical power surge protection and line noise filtering in addition to sensing how much power computer peripherals use. When the power strip senses that the computer is off, it automatically shuts off the associated peripherals, preventing them from drawing an idle current. Depending on the number of peripherals, these power strips can have a payback of as little as six weeks. On modern campuses, computers and copiers are programmed to go into low power mode on a schedule that is communicated to the equipment through the campus IT network using power management software.

Vending machines also are in this category and are an often overlooked waste of energy. Refrigerated and non-refrigerated vending machines on the campuses that were assessed did not appear to include occupancy-sensing controls. Refrigerated and non-refrigerated vending machines that incorporate these sensors are available from vendors and can reduce electrical energy consumed during unoccupied periods. In non-refrigerated machines, the controls turn off the vending machine lighting when no one is in the vicinity after a preset interval. In refrigerated machines, the controls turn off machine lights and the refrigeration compressor after completion of the cooling cycle. For beverage coolers, the cooling system will repower on a preset interval of 1-3 hours to keep products cold. These controls should not be used on machines vending perishable foods, such as dairy products.

**Special Systems**

These are systems or equipment, such as data centers, lab hoods, natatoriums, ice rinks, water towers and other energy using systems, that generally are not present in all buildings. Therefore, the number of findings for these systems in the respective energy assessments is a reflection of this limited number of instances where they are present on a campus. For this reason, ECMs may be limited.

***Laboratory Fume Hoods***—Proper fume hood use and operation is difficult to achieve in practice, and so may result in safety issues, as well as unnecessary energy use. Hoods exhaust large quantities of air from the building. The make-up air that replaces it must first be filtered, heated, cooled, or dehumidified, with concomitant energy and financial costs. The primary concern with fume hood design is the safety of the occupants. To meet codes, minimum air flow velocities must be maintained across all hood sash openings. Hood face velocities must be periodically tested to demonstrate compliance. The design challenge becomes how to meet these requirements in the most energy efficient way. Behavioral changes are important in optimizing sash operation to maximize safety and minimize wasted energy; regular education and inspection are keys to this process.

***Natatoriums***—A natatorium (building with a swimming pool) creates special energy demands and can present special challenges for HVAC and other building energy systems. Higher humidity levels correspond to higher heating and cooling loads for the corresponding HVAC system. Natatoriums with fixed outdoor air ventilation rates without dehumidification generally have seasonally fluctuating space temperature and humidity level. Since these systems usually cannot maintain constant humidity conditions, they may facilitate mold and mildew growth and poor indoor air quality. In addition, varying activity levels also will cause the humidity level to vary and, thus, change the demand on ventilation air. In general, there are advantages to having provisions to modulate the amount of outdoor air introduced through the HVAC system.

Retractable pool covers can be used to effectively reduce the evaporative heating load on the pool, the humidity gain to the pool environment, and the associated energy loads to the HVAC system. According to the U.S. Department of Energy, covering a pool when not in use can save between 50% and 70% of the total energy required to heat the pool by reducing evaporation losses from the water surface (http://energy.gov/energysaver/articles/swimming-pool-covers).

***Data Centers***—Data centers consume 25-50% or more energy per square foot than standard office spaces. Consequently, they are prime targets for applying energy conservation measures that can reduce electricity consumption. An important feature to consider in a data center is the air flow pattern within the room. Commonly referred to as "air management," the fundamental principle is simple: minimize or eliminate mixing cooling air supplied to the equipment with hot air rejected from the equipment. According to "High Performance Data Centers—A Design Guidelines Sourcebook" (Pacific Gas and Electric Company, January 2006), a properly designed air management system can reduce operating expenses, reduce first cost equipment investment, increase the data center's power density (measured in watts/$ft^2$) capacity, and reduce heat-related processing interruptions or failures.

A most useful strategy for good air management is implementation of hot zones and cold zones. For most data centers, the basic concept of a hot zone/cold zone system is achieved by orienting the equipment racks such that cooling air is supplied into a common "cold" aisle while return air registers pull air from a common "hot" aisle.

Equipment is installed into the racks to achieve a front-to-back airflow pattern, in close proximity to the return airflow registers. This minimizes the degree to which the hot and cold air streams mix and significantly improves cooling efficiency. Such strategies can double the effective cooling capacity of the system. Furthermore, as a consequence of this design, the return air temperature from the room is higher, which can extend air-side economization hours considerably by increasing the ambient outdoor temperature range acceptable for economizer use.

Other strategies that can be pursued by campus staff to improve the energy and performance characteristics of the overall data center system are available.

## O&M Issues

The objective of O&M activities is to maintain equipment and infrastructure in an optimum operational profile. Deferred maintenance, which is an issue with many facilities in academic institutions across the country, is a function of budget exigencies. The result of deferred maintenance can be a continued degradation of condition and function, and the need for capital investment earlier than life cycle expectations otherwise would indicate; and possible health and safety issues to facilities staff or to the campus community at large.

***Duct and Piping Leaks***—Needing to replace water, heating and cooling elements is the most obvious evidence of energy losses from leaks. Similar energy losses can occur from the leakage of conditioned air or infiltration of unconditioned air from HVAC systems. In addition to energy costs associated with leaks, there are also facility repair and remediation costs resulting from water damage and potential mold growth, the latter of which represents a potential health risk. Failure to repair pipe leaks creates safety issues, wastes energy, and reduces the effective life of the equipment.

***Duct and Piping Insulation***—Wear or loss of insulation will result in thermal losses, whether from water or air, with a concomitant increase in operating costs. When the result is a decrease in air temperature, there will be a reduction in occupant comfort within the affected spaces. These thermal losses waste energy both from a micro (single incident) and macro (across the campus) perspective, and more immediately, waste financial resources to achieve and maintain thermal requirements.

## Retro-commissioning

Existing Building Commissioning (EBCx)—This process, also referred to as retro-recommissioning, is "a systematic process for investigating, analyzing, and optimizing the performance of building systems by applying" (Building Commissioning Association 2015) the commissioning process to existing buildings. Depending upon the age of the building, EBCx can often resolve problems that occurred during design or construction, or address problems that have developed during the building's life. Buildings frequently undergo operational and occupancy changes that challenge mechanical, electrical and control systems, hindering optimal performance. Overall, EBCx improves a building's O&M procedures and enhances overall performance.

As with new building commissioning, EBCx when performed correctly can provide significant benefits for the owner such as:

- Improved energy performance
- Improved equipment performance
- Increased asset value
- Improved thermal comfort and indoor air quality
- Increased training opportunities for building maintenance staff
- Improved building documentation (a systems manual).

In the EBCx process, building sub-systems are functionally tested and demonstrated capable of being operated and maintained according to the current facility requirements (CFR) of the building. According to the USEPA's EnergyStar Building Manual, researchers at three of the foremost building commissioning authorities in the U.S., Lawrence Berkeley National Laboratory (LBNL), Portland Energy Conservation, Inc., and the Energy Systems Laboratory at Texas A&M University, concluded in a study that EBCx is one of the most cost-effective means of improving energy efficiency in commercial buildings. The researchers statistically analyzed more than 643 buildings that had been commissioned, representing 99 million square feet of floor space from 26 states. The results revealed that the most common problems were associated with the HVAC system. They identified numerous non-energy benefits as well. According to the study (Mills 2009), the median cost of commissioning at existing buildings was $0.27 per GSF and generated a median savings of 15 percent, with a simple payback period of 0.7 years. EBCx particularly is recommended for buildings over 100,000 GSF, less than 10 years old, and equipped with direct digital controls.

## RESULTS

A total of 169 buildings were included in the energy assessments of the 13 campuses reported herein. For the 12 building infrastructure and system categories of energy conservation opportunities used in these assessments, Table 4 presents the number of buildings where opportunities were found in the respective subcategories.

**Table 4.**
**Opportunities for energy conservation by building and system subcategories.**

| Infrastructure/System Category | Subcategory | Number of Buildings (of 169) |
|---|---|---|
| Building Envelope | Roof/Insulation | 31 |
| | Windows | 80 |
| | Walls/Insulation | 24 |
| | Air Infiltration | 74 |
| Lighting | Interior Lighting Fixtures | 53 |
| | Interior Lighting Controls | 115 |
| | Exterior Lighting | 72 |
| HVAC | Demand Control Ventilation (DCV) | 87 |
| | Outside Air Economizer | 80 |
| | Enhanced Air-side Controls | 89 |
| | Exhaust Heat Recovery | 38 |
| Plumbing | Water Saving Fixtures | 74 |
| | Other Water Reduction Opportunities | 12 |
| Boiler Plant | Stack Economizers | 12 |
| | Blowdown Heat Recovery | 9 |
| Chiller Plant | Fuel Switching | 4 |
| | Optimize Operating Sequences | 27 |
| Building Automation Systems (BAS) | Building/Plant Energy Management | 159 |
| | Advanced Utility Metering | 149 |
| Utility Distribution | Chilled Water | 43 |
| | Medium/High Temperature Hot Water | 27 |
| | Steam | 67 |
| | Domestic Water | 12 |
| | Electrical Power | 19 |
| Electrical | High Efficiency Motors | 64 |
| | Variable Speed Drives (VSD) | 100 |
| | Plug Loads | 35 |
| | Power Distribution | 2 |
| Special Systems | Laboratory Fume Hoods | 23 |
| | Natatoriums | 13 |
| | Data Centers | 22 |
| | Animal Research | 7 |
| O&M | Duct and Piping Leaks | 56 |
| | Duct and Piping Insulation | 44 |
| | Health & Safety Issues | 26 |
| Commissioning | Existing Building Commissioning | 32 |

The large number of findings associated with BAS encompass those systems requiring significant adjustment, which were significantly underutilized, or buildings where a BAS was not present.

There was sufficient information to summarize the findings similarly for buildings with specific uses: libraries, gymnasiums, administrative buildings and science buildings. These findings are for single-use buildings; that is, they represent buildings that are (for example) only libraries (although they may have meeting rooms), or only science buildings (although they may be an amalgam of faculty offices, research and teaching labs), and classrooms. As a result, libraries would not be anticipated to have findings related to special systems such as laboratory fume hoods or natatoriums, as they do not apply to this building use; their presence would imply a mixed-use building. The results are presented in Table 5.

## CONCLUSIONS

Table 3 represents building or system categories for which energy savings have been identified in the respective buildings. These findings by themselves provide a benchmark for the types of opportunities that may commonly be found in campus buildings. They offer a road map for the planning of energy assessments, and a guide for similar assessments that may be performed. These observations may be especially helpful when resource limitations do not permit an energy assessment of as complete a nature as those described herein.

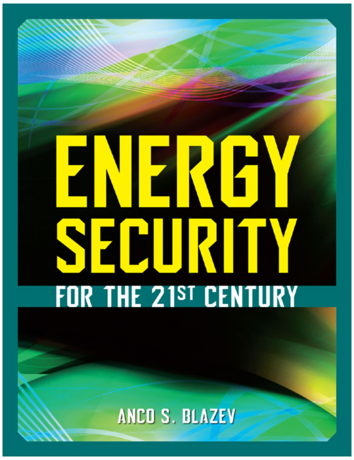
However, these data from the energy assessments, individually and collectively, are silent regarding:

- The magnitude of costs to achieve energy, cost or GHG reductions/savings;
- Whether costs to realize energy savings in a sub-category in one building or on one campus are directly comparable in another building or another campus, even if of the same size and character, because too many factors of construction, age, use, maintenance and management apply;
- The relative magnitude of energy savings per dollar expended in the various sub-categories.

**10% Online Discount**
**Use Code JR10**

# ENERGY SECURITY FOR THE 21st CENTURY

*Anco Blazev*




This book provides a detailed examination of energy security from a hands-on, technical point of view, with the goal of giving perspective to the overall role of energy in our society, as well as the key factors and variables impacting our energy security. The author reviews the major energy sources—coal, crude oil, natural gas, renewables, and other alternative fuels and technologies—in terms of both how they influence our energy security now, and what impact may likely be expected in the future. Topics include the full scope of technical, logistic, regulatory, social, political and financial aspects of modern energy products and technologies. The advantages and disadvantages of the different fuels, technologies, energy strategies, regulations, and policies are reviewed in detail. This book is a "must read" for energy executives, environmental specialists, investors, bankers, lawyers, regulators, politicians, and anyone involved or interested in today's and tomorrow's energy production, use and security.

ISBN: 0-88173-738-0

*8.5 x 11, 760 pp., Hardcover*
*$150*

*Order Code 0703*

CONTENTS



## BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

| Quantity | Book Title | Order Code | Price | Amount Due |
|---|---|---|---|---|
| | **Energy Security for the 21st Century** | **0703** | **$150.00** | |
| | | | Applicable Discount | |
| | | | *Georgia Residents add 6% Sales Tax* | |
| | | | *Shipping $10 first book $4 each additional book* | **10.00** |
| | | | **TOTAL** | |

② Indicate shipping address: CODE: Journal 2015

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order) EMAIL ADDRESS

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

**MEMBER DISCOUNTS—A 15% discount is allowed to AEE members (discounts cannot be combined).**
☐ **AEE Member (Member No.__________________)**

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

*Make check payable in U.S. funds to:*
**AEE ENERGY BOOKS**

CARD NO.

*Expiration date* *Signature*

④ Send your order to:
**AEE BOOKS**
P.O. Box 1026
Lilburn, GA 30048

**INTERNET ORDERING**
**www.aeecenter.org/books**
**(use discount code)**

**TO ORDER BY PHONE**
Use your credit card and call:
**(770) 925-9558**

**TO ORDER BY FAX**
Complete and Fax to:
**(770) 381-9865**

**INTERNATIONAL ORDERS**
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

**Table 5. Opportunities for energy conservation by building and system subcategories in buildings with specialized uses.**

| Infrastructure/ System Category | Subcategory | Libraries | Gymna-siums | Admin. Bldgs. | Science Bldgs. |
|---|---|---|---|---|---|
| **Number of Buildings in Use Category** | | **6** | **11** | **15** | **18** |
| Building Envelope | Roof/Insulation | 2 | 2 | 4 | 6 |
| | Windows | 4 | 2 | 8 | 8 |
| | Walls/Insulation | 1 | 1 | 2 | 4 |
| | Air Infiltration | 1 | 5 | 8 | 8 |
| Lighting | Interior Lighting Fixtures | 3 | 7 | 4 | 3 |
| | Interior Lighting Controls | 6 | 9 | 11 | 12 |
| | Exterior Lighting | 2 | 5 | 8 | 9 |
| HVAC | DCV | 4 | 8 | 9 | 9 |
| | Outside Air Economizer | 5 | 5 | 8 | 8 |
| | Enhanced Airside Controls | 4 | 6 | 10 | 9 |
| | Exhaust Heat Recovery | 1 | 4 | 4 | 6 |
| Plumbing | Water Saving Fixtures | 3 | 5 | 7 | 8 |
| | Other Water Reduction Opportunities | 0 | 1 | 0 | 1 |
| Boiler Plant | Stack Economizers | 0 | 0 | 1 | 0 |
| | Blowdown Heat Recovery | 0 | 0 | 0 | 1 |
| Chiller Plant | Fuel Switching | 0 | 0 | 0 | 0 |
| | Optimize Operating Sequences | 1 | 0 | 1 | 3 |
| Building Automation Systems (BAS) | Building/Plant Energy Management Advanced Utility Metering | 6 | 11 | 14 | 17 |
| Utility Distribution | Chilled Water | 3 | 4 | 3 | 6 |
| | Medium/High | 1 | 3 | 3 | 4 |
| | Temperature Hot Water Steam | 3 | 5 | 5 | 7 |
| | Domestic Water | 0 | 1 | 1 | 1 |
| | Electrical Power | 1 | 2 | 0 | 3 |
| Electrical | High Efficiency Motors | 2 | 3 | 9 | 7 |
| | VSDs | 5 | 6 | 11 | 12 |
| | Plug Loads | 1 | 1 | 4 | 3 |
| | Power Distribution | 0 | 0 | 0 | 0 |
| Special Systems | Laboratory Fume Hoods | 0 | 0 | 0 | 11 |
| | Natatoriums | 0 | 8 | 0 | 1 |
| | Data Centers | 3 | 0 | 1 | 1 |
| | Animal Research | 0 | 0 | 0 | 2 |
| O&M | Duct and Piping Leaks | 2 | 6 | 6 | 6 |
| | Duct and Piping Insulation | 2 | 3 | 3 | 5 |
| | Health & Safety Issues | 0 | 2 | 3 | 4 |
| Commissioning | Existing Building Commissioning | 2 | 3 | 3 | 2 |

- The payback period for the respective opportunities, and the extent of variation in payback period, within a sub-category or from building to building or campus to campus;
- The implementability of options, such as interior lighting options (for example, upgraded occupancy sensors) that can readily be installed at any time, while options in other categories may require more intensive capital costs and/or extensive building renovations to execute.

The information in Table 5 reflects the extent of the commonality of findings in buildings with specific uses. Opportunities relating to "Interior Lighting Controls" were identified for at least 67% of the buildings in each use category. Identified at even a higher rate were opportunities relating to BAS—"Building /Plant Energy Management" and "Advanced Utility Metering." These encompass a range of issues from incomplete use of existing BAS to the installation of BAS equipment; similarly, the advantages of existing metering may not be realized or, in many instances such metering, is not present or as far-reaching as could be for optimum effectiveness.

The commonalities observed may be related to the building uses. However, the authors are aware that correlation does not presume causation. Another explanation of the apparent confluence of these opportunities in like building types may be related more simply to the level of deferred maintenance and infrastructure rehabilitation faced by academic institutions in general, due to limited financial resources, especially for public institutions (Mitchell et al 2014, Quinterno 2012, U.S. Depts. Treasury/Education 2012). However, this information, assembled as it is from 13 campuses, provides a guide by which others may compare their energy audit results or inform their energy auditing planners.

## References

Building Commissioning Association. 2015. Best Practices in Commissioning Existing Buildings. www.bcxa.org, accessed April 23, 2015.

Doty, Steve, 2011, "Energy Saving Measure Interactions in Chilled Water Systems," Energy Engineering, Vol. 108, No. 5, pg. 7-35.

Eberly, David A., 2012, "Campus Energy Cost Savings Studies: Applications of Energy Best Practices," Strategic Planning for Energy and the Environment, Vol. 31, No. 4, pg. 65-80.

Kozman, Theodore A., Brittany N. Aulds, and Jim Lee, 2011, "Energy Assessment and

Conservation in a University Environment. Energy Engineering," Vol. 108, No. 5, pg. 54-62.

Mills, E., 2009, "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions," Lawrence Berkeley National Laboratory, Berkeley, CA (http://cx.lbl.gov/documents/2009-assessment/LBNL-Cx-Cost-Benefit.pdf)

Mitchell, Michael, Vincent Palacios, and Michael Leachman. 2014. States are Still Funding Higher Education Below Pre-Recession Levels. Center on Budget and Policy Priorities, Washington, DC.

Pacific Gas and Electric Company, 2006, "High Performance Data Centers—A Design Guidelines Sourcebook," San Francisco, CA.

Pitts, Adrian, and Jasmi Bin Saleh, 2007, "Potential for Energy Saving in Building Transition Spaces," Energy and Buildings, Vol. 39, pg 815-822.

Pullen, Stephen, 2000, "Energy Assessment of Institutional Buildings," 34th Annual Conference of the Australia & New Zealand Architectural Science Association, Adelaide, Australia.

Quinterno, John. 2012. The Great Cost Shift. Demos, New York, NY.

Ritter, Edward L., 2012. "Findings of an ASHRAE Level II Energy Audit of a Senior Living Facility," Energy Engineering, Vol. 109, No. 3, Pg. 31-40.

United Nations Environment Programme, 2014, Sustainable Buildings and Climate Initiative. http://www.unep.org/sbci/AboutSBCI/Background.asp (accessed August 24, 2014).

U.S. Department of Energy, 2011, Buildings Energy Data Book, Washington, D.C.

U.S. Department of the Treasury and the U.S. Department of Education. 2012. The Economics of Higher Education. Washington, DC.

U.S. Environmental Protection Agency, 2007. EnergyStar Building Manual, http://www.energystar.gov/index.cfm?c=business.bus_upgrade_manual.

Zhou, Xuan, Junwei Yan, Junwen Zhu, and Panpan Cai. 2013, "Survey of Energy Consumption and Energy Conservation Measures for Colleges and Universities in Guangdong Province," Energy and Buildings, Vol. 66, pg. 112-118.

## ABOUT THE AUTHORS

**Michael J. Madigan, P.E., LEED AP**, is an Engineer 3 at O'Brien & Gere Engineers, Inc., with more than 30 years of experience designing high-performance mechanical systems and providing energy consulting services for commercial, industrial, municipal and higher education clients. His recent energy engineering projects have involved advanced HVAC and control system design, energy efficiency feasibility studies, plant and campus energy assessments, campus submetering programs, building commissioning, and Leadership in Energy and Environmental Design (LEED) consulting services. Mike has an AS in humanities and social science and an AAS in engineering science from Corning Community College (NY), and a BS in mechanical and industrial engineering from Clarkson University. He is a professional engineer in New York, a LEED Accredited Professional, and a Qualified Commissioning Process Provider (QCxP). (email: Michael.Madigan@obg.com)

**Robert M. Neimeier** is a Project Manager 2 at O'Brien & Gere Engineers, Inc., and has 25 years of professional experience specializing in air and environmental compliance management. Rob has responsibility for major clients' environmental programs, particularly with respect to GHG and carbon management, and air resource management and compliance. His current clients include programmatic GHG and energy reduction assessments, and sustainability planning, for campuses of the City University of New York, and for several State University of New York (SUNY) campuses, as well as the management of county-wide GHG inventory programs. His background also includes climate action planning, air emissions inventories and permitting, regulatory compliance negotiation and source emissions testing. Rob has an AS in business from Onondaga Community College (NY) and a BS in environmental science with a minor in planning from SUNY at Plattsburgh. (email: Rob.Neimeier@obg.com)

**Stuart J. Spiegel** is a Senior Managing Scientist at O'Brien & Gere Engineers, Inc., with more than 40 years professional experience in the areas of environmental management planning, environmental audits, environmental compliance and permitting strategies, environmental due diligence, environmental impact analysis, and EH&S compliance assistance involving more than 1,000 facilities. In recent years, his activities have focused on sustainability and environmental management at academic institutions. Stu has written or co-authored more than 60 presentations and publications on a range of academic topics, and has served as an adjunct instructor at the College of Engineering at Syracuse University. He has a BS in biology and an MS in sanitary science from Syracuse University. (email: Stu.Spiegel@obg.com)

These co-authors are located at the Syracuse, NY, office at O'Brien & Gere Engineers, Inc.