TRAINING THE WORKFORCE FOR HIGH-PERFORMANCE BUILDINGS:

ENHANCING SKILLS FOR OPERATIONS AND MAINTENANCE

BY ROHINI SRIVASTAVA, MOHAMMED AWOJOBI, AND JENNIFER AMANN

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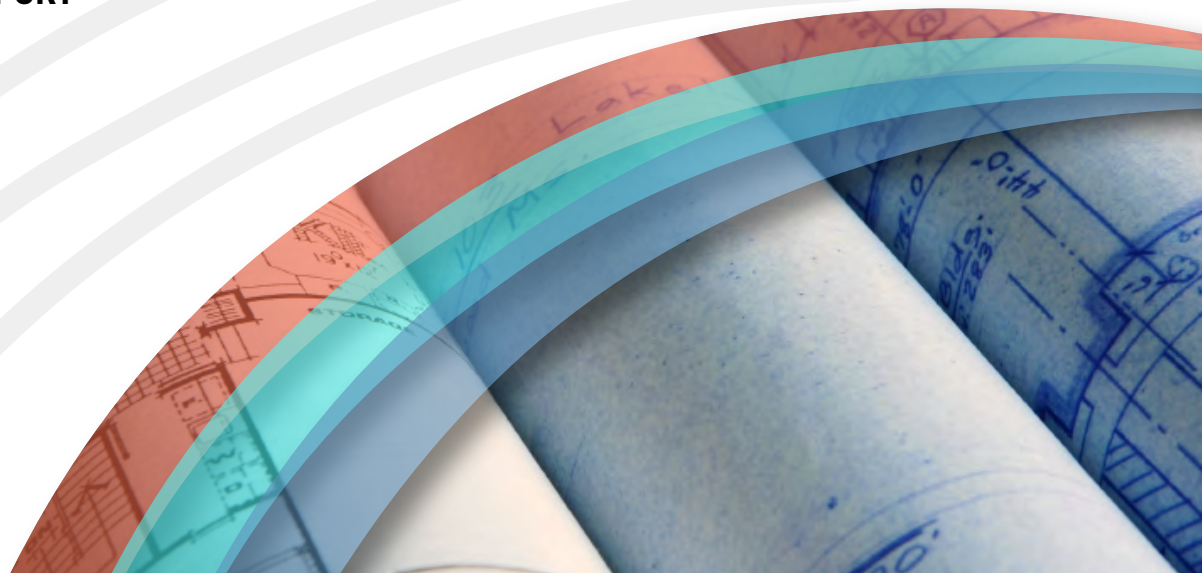

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Executive Summary

KEY FINDINGS

- Today's high-performance buildings place new skill and knowledge demands on facility managers, building operators, engineers, equipment installers, and other onsite technicians. Skill deficiencies among these professionals can prevent high-performance buildings from delivering on their promise, adversely impacting their energy savings, indoor environmental quality, cost effectiveness, and long-term viability.
- According to our survey of 111 building owners/managers, operators, tradespeople, technicians, and service providers, five categories of technical skills are essential for the high-performance buildings workforce. Ninety-two percent of respondents said **operations and maintenance** (O&M) skills are the most critical. O&M uses cost-benefit analysis to refine efficiency goals, optimize systems, and diagnose and correct problems before systems fail; it also involves operating and maintaining equipment, control, and automation systems.
- Other critical technical skills include **systems integration** (cited by 78% of respondents), **systems testing and evaluation** (78%), **data acquisition and analysis** (68%), and **system design and performance modeling** (42%). Critical thinking, communication, and teamwork were cited as the most essential nontechnical skills.
- Exemplary training programs are revealing the most effective approaches to training high-performance buildings professionals. Two general approaches are (1) "upskilling," or continuing education and certification programs for professionals who need to fill knowledge gaps, and (2) career-oriented training for new entrants to the field, including high school and community college students.
- Utilities, program administrators, and policymakers can take the following steps to begin addressing skills gaps: Establish skill and credentialing standards with the help of periodic job task analyses, reach out to high school students, integrate and coordinate training efforts to avoid duplication, create and promote a clearinghouse of curricula, and create building training and assessment centers at institutions of higher education.

Improving the energy efficiency of the U.S. building stock could reduce building-related carbon emissions by as much as 50%.[1] Upgrading existing buildings with energy efficiency technologies, incorporating smart controls, and electrifying remaining loads are key strategies that will make our buildings more efficient. However, the advanced technologies, greater systems integration, and expanded automation found in high-performance buildings place new demands on the staff who service them. Proper training of workers entering the field and continuing education for the existing workforce are both essential to achieving the energy efficiency, comfort, and other benefits these buildings are designed to

[1] Nadel, S., and L. Ungar. 2019. *Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050*. Washington, DC: ACEEE.

deliver. Although it is clear that building staff need skills beyond those taught in traditional building management and maintenance courses, what they need to know remains poorly defined.

IMPACTS OF WORKFORCE SKILLS GAPS

The skills gaps identified in this report have negative consequences for building owners and occupants alike. If a building's systems are improperly installed, commissioned, or maintained, the building will not function as intended, not only hindering its energy and indoor environmental performance but also dissuading customers from future investments in energy-efficient technologies, thereby slowing their adoption. Energy use may increase, negatively affecting the building owner's or leaseholder's ability to meet energy or sustainability goals. Other impacts include higher installation costs and compromised work quality. A building that operates outside its intended parameters will not reach its full potential to provide good indoor environmental quality, leading to occupant discomfort and reduced productivity.

ESSENTIAL BUILDING PERFORMANCE SKILLS

According to interviews with experts and review of existing literature, five categories of technical skills are essential for the high-performance buildings workforce: **operations and maintenance (O&M), systems integration, systems testing and evaluation, data acquisition and analysis, and systems design and performance modeling**. According to the literature, expert interviews, and survey responses, the most critical skill set is building O&M, which includes the use of cost-benefit analysis to refine efficiency goals, optimize systems, and perform diagnostic and corrective procedures before a system fails; it also includes operating and maintaining equipment, control, and automation systems. As in other scientific and engineering fields, the workforce also needs training in nontechnical skills to perform effectively, the most essential being critical thinking, communication, and teamwork. These skills will only increase in importance as building technologies evolve and systems are integrated to optimize performance.

SKILLS GAPS

In contrast to the buildings workforce of the past, and as mentioned above, today's professionals must also be competent in data acquisition and analytics to ensure that high-performance buildings reach their full potential. Notably, we found a disconnect between building professionals and academics with regard to these critical skills. Further job task analyses can help develop training to ensure proficiency in data analytics. Our research also shows that building professionals need focused training in other key proficiencies: using cost-benefit analysis models to manage and influence building efficiency decisions; optimizing systems; ensuring cybersecurity; managing and programming multiple building systems including HVAC, lighting, building automation, and energy management systems; and performing commissioning, retrocommissioning, and energy audits. More work is needed to map out the skills that will improve high-performance building operations and identify potential pathways to bridge the gaps in skills currently found in the industry.

APPROACHES TO WORKFORCE TRAINING

Given the urgent need for expanded training in building performance skills, it is fortunate that several exemplary training programs are demonstrating which approaches can work well. These programs provide technical education on high-performance technologies and operations, combining in-class instruction, hands-on learning, and practical training in the field or in the lab. There are two general approaches to teaching these skills: (1) "upskilling," or continuing education and certification programs for building professionals who need to fill knowledge gaps and learn about new technologies and practices, and (2) career-oriented training for new entrants to the buildings workforce. A number of utilities, labor unions, and other parties offer continuing education courses, seminars, and certifications that can meet the need for highly specialized training in areas such as cybersecurity and systems programming and integration. Career training programs such as apprenticeships and those offered in community colleges and universities can help develop building performance skills from the ground up and address needs in fields such as data analytics and systems measurement and verification.

RECOMMENDATIONS

We recommend the following actions to develop the necessary workforce for high-performance buildings:

- *Establish skill and credentialing standards* that utilities and building service providers can promote; this will ensure that building operators and technicians have the requisite skills and will help scale effective training programs. Conduct periodic job task analyses to help identify workforce needs and current training opportunities and to inform decision making on educational needs.
- *Integrate training approaches* based on an understanding of the building staff's skill deficiencies; identify short- and long-term training opportunities to bridge skills gaps. Coordinate training initiatives based on best practices in workforce development to avoid duplication of efforts and ensure that high-quality, up-to-date programs are offered.
- *Reach out to high school students* to increase their awareness of opportunities in the industry. Develop resources for educators and guidance counselors to help them understand career pathways and the skills that are needed to succeed.
- *Coordinate training efforts and share best practices* to avoid duplication of efforts and ensure high-quality programs are offered throughout the country to allow greater dissemination of key skills.
- *Establish and promote a clearinghouse of curricula, training programs, and certifications* to reduce confusion around which competencies should be acquired and where the necessary training can be obtained.
- *Create building training and assessment centers* at institutions of higher learning that can educate and train engineers, building scientists, and other professionals in efficient building design and operations and commercial building energy assessments.

Introduction

High-rise commercial offices, retail buildings, hospitals, and university buildings are energy and capital intensive. To address this, an increasing number of businesses and organizations are constructing or upgrading their existing portfolio with high-performance buildings.[2] These move beyond simple component efficiency to an approach that considers coordination and efficiency of building systems and relies on advanced technologies and operations to deliver greater energy savings (Alliance to Save Energy 2017). Lower energy use leads to a reduction in carbon and pollutant emissions, helping businesses meet their climate and sustainability goals. Energy and operations and maintenance (O&M) savings contribute to lower operating expenses and increase the net operating income for real estate investors and managers, which improves the property's value (WGBC 2013; IMT 2015). Additionally, high-performance buildings provide a range of nonenergy benefits including improvements in occupant comfort, health, and productivity, all at a low life-cycle cost.

Workforce skills are a critical factor in the implementation of advanced technologies and operation of high-performance buildings. The use of sophisticated technologies, greater systems integration, and expanded automation of functions through sensors and controls place new demands on the engineers, operations staff, equipment installers, and others who maintain and service these buildings. These changes require additional skills beyond those taught in traditional building management and maintenance courses; some may even require specialized skills such as computer programming. Proper training can provide staff with greater insight and ability to manage their building's energy use while maintaining occupant comfort in a high-quality indoor environment.

As new technologies are adopted, the skill sets required for the workforce to operate and maintain high-performance buildings will continue to increase in depth and breadth. Education and training programs and apprenticeships can prepare new workers for technically complex jobs in the field and help experienced professionals keep up with current best practices (NASEO and EFI 2020). Additionally, programs designed specifically to reach high school students can make them aware of possible careers in the field and the skills they will need to succeed (Heinemeier et al. 2016). This in turn helps the industry recruit and train young workers to replace those who will retire in coming years (Stern 2019).

While there is agreement on the need for training, the buildings industry lacks consensus on what knowledge, skills, and credentials the workforce should possess (Ehrlich et al. 2010; DOE 2018a). The usual practice is to hire candidates with no prior experience and then train them to meet a building's needs; however, this can be time consuming (Goldman et al. 2010). Further, if building owners, property managers, and others involved in hiring are not aware of the skills needed to get the most efficient performance out of their buildings, or if they fail to prioritize energy performance, adequate training and credentials will be undervalued. Efforts are underway to reduce the confusion around energy-related

[2] ASHRAE defines a high-performance building as "a building that consistently delivers a highly productive environment without wasting resources. Such buildings may have specialized systems or assemblies that require specific knowledge and awareness on the part of both operators and maintenance technicians to achieve the intended operation and performance" (ASHRAE 2018).

professional credentials. The U.S. Department of Energy (DOE) and the National Institute of Building Sciences along with industry stakeholders have established national guidelines for select energy-related jobs to help in the development of a qualified workforce.

This report aims to help address the need for formal workforce training and professional development efforts by (1) assessing specific workforce skills gaps and their impacts, and (2) analyzing available training to bridge skills gaps in professionals operating or servicing buildings every day. We also offer strategies to improve workforce education and training to broaden the pool of skilled workers.

From this point on we use the term "building performance skills" as shorthand for "skills needed for the O&M of high-performance buildings requiring onsite operations staff." Figure 1 shows the building performance professionals who can use these skills to ensure better performance in terms of energy and nonenergy benefits.

Figure 1. Building performance professionals critical to the robust operations and maintenance of buildings

Energy and Nonenergy Impacts of Workforce Skills Gaps

Skill deficiencies in the workforce can increase energy use in buildings, negatively affecting the building owners' or leaseholders' ability to meet their energy or sustainability goals. If advanced controls and systems are improperly installed and commissioned, they will not function as intended, compromising operations and failing to deliver the energy savings anticipated (Mowris, Jones, and Eshom 2012; Zabin et al. 2014). Buildings operating outside intended parameters—because of lack of proper commissioning, ineffective operations, or failure of components—can compromise energy savings by 16–30% in inefficient buildings and by up to 19% in buildings with some advanced efficiency measures (Fernandez et al.

2017; Herr and Dunfee 2020; Mills 2011).[3] A study of utility bills by North American Technician Excellence, Inc., found that HVAC systems installed by certified technicians used 10% less energy than those installed by uncertified technicians (Messenger 2008). Another study, on advanced lighting controls, found that incorrectly installed systems operated outside their design parameters and that improperly maintained systems can lose 24-38% of expected energy savings (Jackson, Avery, and Ouellette 2012; Williams et al. 2011).

Failure to properly program and operate automated building systems and controls, such as automated shading devices and dimmable lighting, can compromise indoor environmental quality by causing temperature swings, excessive glare on surfaces near windows, and other issues. This can lead to higher energy use as occupants respond to indoor conditions in different ways—using a space heater, for example, to stay warm when the building is in cooling mode, or running a desk fan to stay cool during heating season. Poorly controlled indoor environments also reduce productivity due to occupant discomfort (Lee et al. 2013). They may also lead to complaints from tenants, and increased complaints to building staff result in higher facility management costs (IFMA 2009).

Building operators can add to O&M costs if they don't understand how to commission specialized systems and perform day-to-day equipment operation, maintenance, and repairs (Herr and Dunfee 2020). Conversely, professionals trained in innovative operations techniques and knowledgeable about proactive maintenance can substantially reduce O&M costs. An evaluation of Commonwealth Edison's retrocommissioning program found that participating buildings cut their electricity use by 15–35% by implementing operational improvements and optimization measures (Gunn and Malek 2013). Common improvements included setting equipment schedules, addressing air distribution issues, and ensuring proper economizer and outside air cycles.

Understanding the potential of proper design, advanced technologies, and systems integration can significantly influence energy decision making, which can improve occupant comfort, health, and productivity. For example, a high-performance façade design may require operating and integrating different light-redirection devices, shading devices, and daylighting controls. This combination helps manage heat gain and loss through the envelope, reducing the energy required to maintain comfortable indoor temperatures. It can also lower indoor lighting energy use by distributing daylight deep into the building, and it can control excessive glare. Providing access to daylight with shading for comfort, along with improved views, can enhance worker productivity for specific office tasks by up to 4% (Münch et al. 2012; Thayer 1995).

A workforce without the skills mentioned above can lead to higher equipment installation costs, compromised work quality including subpar installation and setup, and improper operation and maintenance, which can compromise overall building performance

[3] A 2011 study of 643 buildings across the United States that underwent commissioning and addressed building faults revealed median whole-building energy savings of 16% in existing buildings and 13% in new construction. See Mills, E. 2011. "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse-gas Emissions in the United States." *Energy Efficiency* 4 (2): 145-73. https://doi.org/10.1007/s12053-011-9116-8.

(Katipamula and Rice 2012; EMI 2012). This means owners may pay for high-performance building technologies but not realize the full range of benefits. This situation, combined with the uncertainty around how much energy could actually be saved, may dissuade customers from future investment in these technologies and slow down their adoption (Zabin et al. 2014; Jovic, Segan, and Perry 2018). Figure 2 highlights the primary impacts that workforce skills can have on building performance.

Figure 2. Impacts of workforce skills

Research Objectives and Methodology

To better understand the need for workforce training, to identify relevant building performance skills, and to gather insights into where those skills are lacking in the workforce, we reviewed the literature, interviewed experts, and developed and circulated an online survey to building owners, technicians, and service providers. The review of existing literature and the expert interviews provided insight into technical, cognitive, and interpersonal skills. They also helped to identify existing training programs that offer relevant workforce education. The online survey helped identify the current gaps between

key skills and what the workforce currently possesses; it also offered information on existing resources that address those gaps.

LITERATURE REVIEW

Our literature review was a starting point to identify the technical and nontechnical skills professionals will need if advanced buildings are to fulfill their promise, and to gather information on organizations that are already working to address skills gaps through education and training programs. We reviewed 60 published reports and articles from the United States and Canada on energy efficiency jobs and training programs; technical standards and recommendations for building O&M; and utility workforce training efforts. The data on the skills needed to install advanced technologies, operate and maintain integrated systems, and evaluate their performance informed the design of the online survey and our recommendations for addressing the skills gaps.

EXPERT INTERVIEWS

In parallel with the literature review, we conducted 20 interviews with a diverse set of stakeholders to understand the state of current workforce skills and how they impact the adoption and operation of advanced technologies and systems. We interviewed building managers, workforce training program administrators, and experts from trade organizations such as the International Facility Management Association (IFMA), building services firms such as Johnson Controls and EMCOR Services, and labor/workforce associations including the International Brotherhood of Electrical Workers and the BlueGreen Alliance.

Experts were asked to evaluate how current workforce skills match the building performance skills needed; to prioritize key skills; to discuss the main training programs for professionals seeking advanced skills; and to reflect on how a lack of the requisite skills can negatively impact building performance. The negative impacts they cited included increased energy use, failure to meet energy savings targets or other sustainability goals, increased occupant discomfort, poor indoor environmental quality, and slowed adoption of advanced technologies.

ONLINE SURVEY

Using the information from our literature review and expert interviews, we designed a survey and circulated it online using the survey software SurveyGizmo. This small-scale, qualitative survey was designed to gather building professionals' perceptions and understand how they compared with the literature and field expert evaluations with regard to the most critical skills for the buildings workforce.

The survey was distributed to three professional groups:

- building **owners/managers** including developers, property managers, and facility managers;
- building **operators, tradespeople, and technicians** including electricians, HVAC engineers, and mechanical engineers; and

- building **energy service providers** like HVAC and lighting firms as well as energy service companies (ESCOs).

To recruit participants for the survey, we sent personalized emails to individuals and organizations informing them about the survey and requesting their engagement. We also circulated the survey link at the 2019 Better Building Summit conference, in the online member newsletters produced by ASHRAE and the Green Building Alliance, and in emails to Building Operator Certification program graduates. We asked professionals in these groups a series of questions to identify the key skills needed, assess the skills gaps, and gather data on the types of training that can bridge these gaps. The survey questions are listed in Appendix A. Although this is not necessarily a representative sample of buildings professionals, their survey responses provided insight into the proficiencies needed to operate and maintain advanced technologies and systems.

We collected 176 responses, of which 111 were included in our analysis. We excluded 65 because participants did not answer more than 20% of the questions. Of the total responses,

- 32 were from building owners/managers; 39 were from building operators, tradespeople, and technicians; and 40 were from building service providers.
- 88% of the respondents were male and 12% were female. Women are typically underrepresented in the energy efficiency sector, with representation as low as 5% in occupations critical to O&M of buildings (U.S. DOL 2019).
- 67% had more than 20 years of experience in the commercial building industry.
- 75% were directly involved in daily management or operation of their building.
- 85% were from respondents who provided services to offices, 81% were from those who served university campuses, and 62% were from those who worked for K–12 schools (participants could select multiple building types for which they provided services). Other building types included hospitals and retail structures.

Findings

In this section we synthesize the findings from the literature, expert interviews, and online workforce survey and organize the results under three headings:

- Building performance skills
- Gaps in building performance skills
- Strategies for improving workforce training

We also discuss the similarities and differences between what we found in the literature, expert interviews, and survey responses. These comparisons helped inform our work in identifying the key areas to focus on in future workforce training efforts.

BUILDING PERFORMANCE SKILLS

Described below are the skills building performance professionals will need in order to keep up with new technologies and practices and improve systems efficiency. Later we use these same skills categories in discussing where workforce training is needed.

Technical Skills

The literature frequently cites five categories of technical building performance skills as important; these were highlighted as well by the professionals surveyed and interviewed. Table 1 lists the five categories and the relevant proficiencies that we review in this study.

Table 1. Five skills categories and specific proficiencies for each

Skills category	Proficiencies
Operations and maintenance	Use cost-benefit analysis to refine efficiency decisions
	Optimize building systems
	Perform diagnostics and corrective procedures
	Operate and maintain equipment, controls, and building automation systems
Systems integration	Ensure cybersecurity
	Integrate and manage smart technology and controls
	Program controls
	Select and install advanced equipment
	Select and install building automation systems
Systems testing and evaluation	Perform retrocommissioning
	Perform commissioning
	Do energy audits
	Set benchmarks
Data acquisition and analysis	Interpret and use data analyses
	Analyze data
	Monitor and measure system performance
	Install sensors and meters
Systems design and performance modeling	Use modeling and simulation software
	Understand advanced building systems
	Be familiar with codes and regulations
	Know advanced system assemblies

OPERATIONS AND MAINTENANCE

According to 92% of our survey respondents, robust O&M skills are the most critical for achieving the expected energy efficiency and overall performance of buildings as designed.

Proper operation and maintenance of systems minimizes energy use while improving indoor environmental conditions for occupant comfort and productivity. Building energy professionals must be knowledgeable about building science and must have technical understanding of equipment, controls, and automation systems to optimize their performance (ASHRAE 2018; Ehrlich et al. 2010). Digital tools such as computerized maintenance management systems and computer-aided facility management (CAFM) can

enable personnel to manage building information and use it to evaluate performance, schedule maintenance, and analyze complaints and equipment failure patterns (Lewis, Riley, and Elmualim 2010).

Building operators should use planned, scheduled, preventive, and predictive maintenance techniques to ensure efficient operations, facilitate long equipment life, and avoid emergency repairs (ASHRAE 2018). This requires a shift from a reactive to a fully proactive approach and the use of emerging technologies and practices like computerized maintenance systems and fault detection diagnostics (Herr and Dunfee 2020).

Also critical is the ability to manage and refine efficiency goals by balancing the costs for building O&M relative to facility capital investments (GSEP 2013). Industry-standard analysis techniques such as simple payback and return-on-investment calculations are often used to justify investments in high-cost and high-performing building technologies (Deringer et al. 2012). Further training in cost-benefit analysis can help operators better manage facility capital investments and support their efforts to convince leadership to invest in high-performance systems (Ehrlich et al. 2010; Deringer et al. 2012).

SYSTEMS INTEGRATION

The role of smart technology is expected to grow in buildings with the integration of network-connected devices and controls, creating the need for professionals who understand system configurations and are able to use software to program controls (Mukhopadhyay, O'Toole, and Kalonde 2019). More than three-quarters (78%) of our survey respondents said they consider the ability to integrate and manage systems an important skill.

Advanced network-connected systems must be programmed and integrated to optimize energy use. This requires a deep understanding of the building's systems and the ability to connect and manage the interoperability among different software platforms on the building's information network (Ehrlich et al. 2010). For example, integrating a new smart lighting system requires developing the desired control logic and programming it into the building automation system (BAS) using knowledge of how the new lighting and existing HVAC system operate independently and together. Technicians—whether in-house staff, manufacturer representatives, or third-party integrators—with an understanding of hardware and software needs and a building's operations sequence will be more proficient at developing the control logic for operating different systems. For example, they will be skilled at developing schedules and setting day/night setbacks to optimize HVAC energy use, improve occupant comfort, and better manage indoor conditions.

Building operators should be trained to use advanced systems and develop expertise in controls programming (Thomas Myers, president, IBEW Local Union 26, pers. comm., August 21, 2019). Prior experience operating and programming a system can improve operations, lead to better onsite maintenance, and help troubleshoot issues. While an HVAC technician may understand the basics of how a heat pump operates using the refrigeration cycle, an opportunity to operate different types of units, like ductless mini-split heat pumps and variable refrigerant flow heat pumps, can familiarize them with the different programming sequences.

Advanced networked systems may expose the building to cybersecurity issues; therefore, in addition to integrating different building systems, technicians need training in how to protect the building against cyberattacks and maintain the integrity of data and communications systems (Alliance to Save Energy 2017; Johnson Controls and Booz-Allen-Hamilton 2017).

SYSTEMS TESTING AND EVALUATION

Evaluation and verification of building system performance brings greater accountability and an improvement in energy efficiency. This category of skills was ranked on par with systems integration skills, considered critical by 78% of our survey respondents.

Increasingly, commissioning, retrocommissioning, energy audits, and performance benchmarking are being used to identify buildings' inefficiencies and improve their performance (Brooks et al. 2012).[4] Commissioning and retrocommissioning can help identify and address O&M issues. Furthermore, benchmarking can provide operators much-needed feedback from operation of different technologies and help ensure consistency in field data collection practices (Lewis, Riley, and Elmualim 2010).

There are several reasons for the growth in use of these strategies — increased regulatory requirements and a shift to pay-for-performance program approaches, among others. To effectively perform the tasks in this skills category, professionals need a range of competencies including technical knowledge of building engineering and operations, as well as training on tools and equipment to perform evaluations.

DATA ACQUISITION AND ANALYSIS

Building personnel use operations data to help improve performance, achieve deeper energy savings, enhance indoor air quality, and increase occupant comfort, all of which impact a facility's operational bottom line. More than two-thirds (68%) of our survey participants said they consider proficiency in acquiring, analyzing, and using relevant building data for decision making to be key skills in the O&M of buildings.

As automation, advanced controls, and meters enable buildings to become more efficient, building performance professionals must acquire new skills in information science and data analytics to use the collected data effectively (Shoemaker and Ribeiro 2018). For example, training in data analysis techniques used in fault detection and diagnostics, automated system optimization, and energy information systems can help improve performance and maximize savings potential. Building personnel must be proficient in sensor instrumentation and installing meters at relevant locations, acquiring and analyzing data, and interpreting the results for use in decision making (Ehrlich et al. 2010; Gregg Ander, managing director, Gregg D. Ander, LLC, pers. comm. June 6, 2019).

Data analytics can also lead to better return on investment and cost-effectiveness values for high-performing technologies, helping facility managers and operators make better energy

[4] Building commissioning tests new building systems and equipment (e.g., HVAC, lighting, and water heating) to ensure the building operates as it was originally intended. Retrocommissioning uses similar methods on existing buildings to address changes to building occupancy and use (LBNL 2020).

decisions (Zhai and Salazar 2020). Performance data can further encourage growth of advanced technologies as more customers are able to see the benefits of investing in them (Barnwell 2018).

SYSTEMS DESIGN AND PERFORMANCE MODELING

Familiarity with advanced codes and guidelines, system assemblies, and modeling tools can help building operations professionals improve performance and ensure that systems integrate efficiently (Henry, Schiedermayer, and Walker 2010). Among our survey participants, 42% considered this category of skills important.

Building operators and engineers, in addition to understanding advanced systems, need proficiency in modeling tools to understand the design intent and use modeled data from the design phase to assess the building's actual performance. Modeling skills can support electronic documentation of existing mechanical and electrical systems, allow the archiving of control sequences of operations, and help operators understand the energy-use impacts of systems. This information helps operations staff make informed choices from among the various available alternatives that will improve the building's performance. Although these skills are not typically needed every day, they may be critical for those entering the field. They help new entrants progress in their careers, as they develop better understanding of processes and performance data.

Cognitive and Interpersonal (Soft) Skills

The buildings workforce needs education and training in nontechnical skills to perform effectively, and these skills will rise in importance as building technologies evolve (National Academies of Sciences, Engineering, and Medicine 2016; ILO 2011). We asked our survey respondents to assess four nontechnical skills required for the workforce:

- Critical thinking and problem solving
- Communication
- Teamwork
- Leadership

Critical thinking and problem solving are essential for professionals using sophisticated technology and management practices. High-performance buildings rely on the integration of complex technologies, and these skills can simplify the integration process; they can also help professionals identify issues that might affect multiple systems and correct them (Ehrlich et al. 2010). Operators with problem-solving skills will likely be more successful, for example, at using building energy data from energy management systems to locate inefficiencies, identify problems, and resolve specific equipment or system issues (Autodesk Foundation and Monitor Institute 2019).

Effective verbal and written communication skills are important within the facilities team and during interactions with other departments like finance, purchasing, and accounting (Crabtree et al. 2012). For example, during interactions between facilities staff and nontechnical groups including management, facility operators with strong communication skills will be able to better explain the value of advanced systems and persuade decision makers to invest. These skills will also help them convey measurable goals to senior management and share clear progress reports on systems once they are in operation

(Catherine Lin, energy manager and stormwater program administrator, Arlington Public Schools, pers. comm. July 7, 2019).

Professionals also need the ability to work in teams and coordinate with technicians and tradespeople to ensure they can integrate and operate different systems in the appropriate way (Thomas Myers, president, IBEW Local Union 26, pers. comm., August 21, 2019). This skill is of particular importance in buildings that require coordinated work from many specialists including lighting, HVAC, and automation technicians to install, operate, and maintain equipment and optimize its performance.

While technical knowledge is critical for scaling high-performing technologies and operations, leadership qualities can help advance their adoption (GSEP 2013). Building energy professionals with leadership skills understand the building's energy needs and are able to guide their teams to address the issues with more efficient technologies. Good leadership can also simplify project management and coordination challenges that are common in complex buildings with greater systems integration (ILO 2011).

Figure 3 shows the percentage of our respondents who identified particular nontechnical skills as being critical for operating and maintaining buildings.

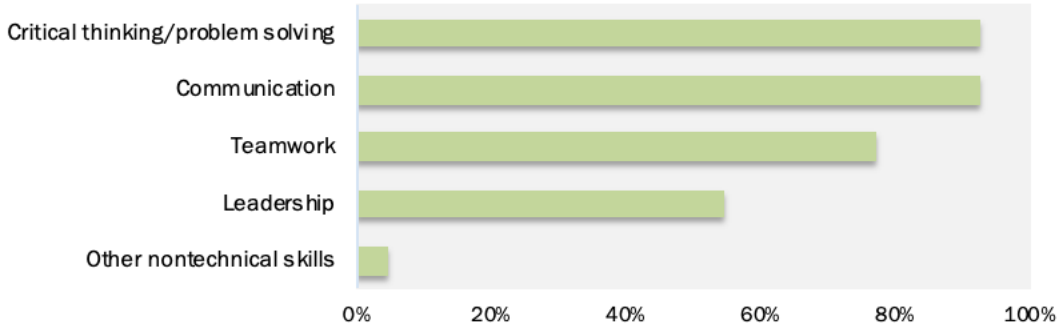

Figure 3. Percentage of survey participants who view various nontechnical skills as important for effective building O&M

Education and training in cognitive and interpersonal skills can be effectively provided using a problem-based learning approach in technical training programs (Crabtree et al. 2012). In this type of instructional strategy, students are asked to explore complex and realistic problems that could occur in real-life work situations. This helps them develop problem-solving skills, collaboration skills, and intrinsic motivation (Barell 2006). The open-ended nature of the problems encourages critical thinking to develop a range of solutions. For example, Laney College in California relies on this approach, and its instructors have developed several real-life scenarios — some even using real building data —to help students develop critical thinking and expertise in optimizing performance (Crabtree et al. 2012).

SKILLS GAPS

To evaluate skills gaps and identify areas that need greater focus, we asked our survey respondents to weigh in on the importance of each building performance skill set and then

assess proficiencies within that category. Among the three types of respondents —building owners/managers, operators/tradespeople/technicians, and service providers — it was the building operators, tradespeople, and technicians who most often rated current skills as inadequate.

In this section, we discuss respondents' assessments of proficiencies within each technical skill category. We use diverging stacked bar charts divided into three agreement levels to show the proficiency assessments. The number of respondents who agree that the workforce is adequately skilled in a given function is shown to the right of the zero line in green, the number who disagree is shown to the left in red, and the number of respondents who neither agree nor disagree straddles the zero line and is shown in gray.

Operations and Maintenance

As mentioned above, survey participants regarded this skills category as the most critical of the five, with 92% rating it important for effective management of high-performance buildings. Respondents assessed these particular O&M proficiencies:

- Use cost-benefit analysis to refine efficiency decisions
- Optimize building systems
- Perform diagnostics and corrective procedures
- Operate and maintain equipment, controls, and building automation systems (BAS)

Figure 4 illustrates respondents' assessment of how proficient the workforce is in each of these areas.

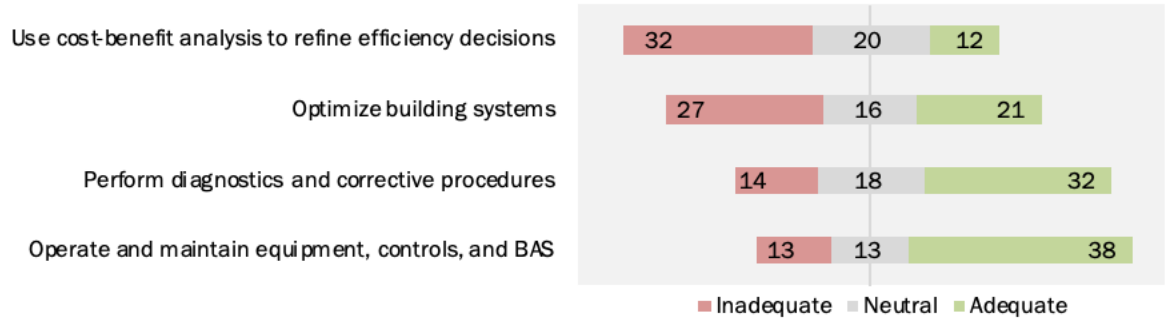

Figure 4. Survey assessment of buildings operation and maintenance skills (n=64)

Thirty-two of the 64 survey respondents cited inadequate skills in using cost-benefit analysis models to refine energy-related decisions.[5] Twenty-seven specified inadequacy in optimizing building systems. In contrast, half and about three-fifths of the participants indicated they thought training was adequate in diagnostics and operations, respectively.

Even though the survey responses did not clearly signal that building professionals' training was inadequate in the use of digital tools to perform diagnostics, carry out

[5] Although the total number of respondents was 111, not all respondents answered every question. Therefore, when analyzing certain topics, we were limited to a smaller pool of responses.

preventive maintenance, and operate automated systems, we concluded from the expert interviews and our literature review that training efforts should focus on these areas (Herr and Dunfee 2020; Lewis, Riley, and Elmualim 2010; ASHRAE 2018; Adele Ferranti, program manager for workforce development and training, NYSERDA, pers. comm., August 22, 2019). An energy manager with the Community College of Allegheny County in Pittsburgh, Elaine Sadowski, said that education on automated systems and electrical circuits "can ensure systems are accurately operated and labeled so that technicians are able to fine-tune the building schedules as they vary through the year, especially in the months of June and July when the college operates on a four-day work week."

Our analysis shows substantial training needs in this skills category. Programs with classroom instruction and a hands-on learning component can equip the workforce with the knowledge needed to use financial models, strategies to optimize operations and skills to operate advanced equipment and controls.

Systems Integration

Close to 78% of the survey participants selected systems integration skills as being necessary to effectively operate and maintain buildings, making this the second most often cited technical skill set (tied with systems testing and evaluation). Proficiencies include:

- Ensure cybersecurity
- Integrate and manage smart technology and controls
- Program controls
- Select and install advanced equipment
- Select and install building automation systems (BAS)

Figure 5 shows respondents' assessment of these proficiencies.

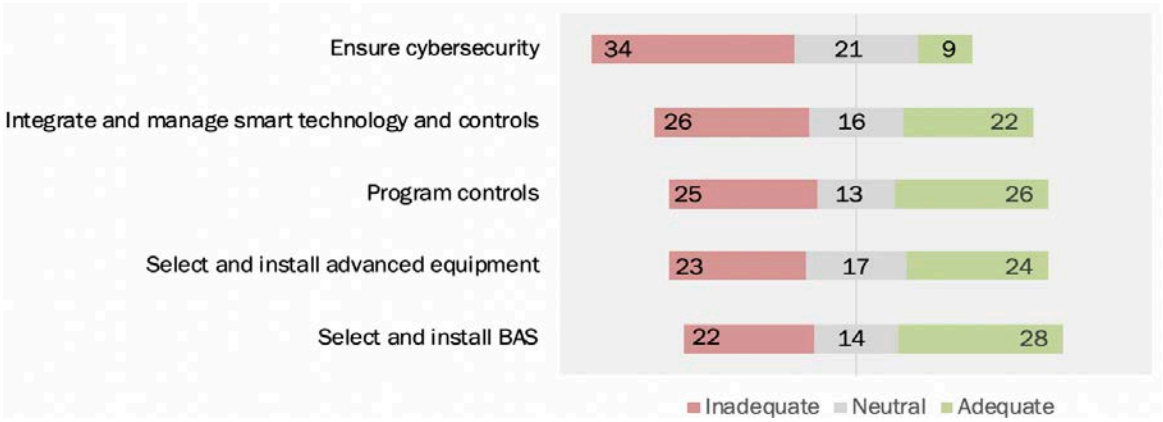

Figure 5. Survey assessment of building systems integration skills (n=64)

Thirty-four of the 64 respondents indicated there is a skills gap in ensuring cybersecurity. More than one-third of participants deemed skills in integrating and managing smart technology, programming controls, and dealing with advanced equipment and automated systems as inadequate, while roughly equal numbers deemed them adequate. A reason for the balance of adequate and inadequate ratings may reflect respondents' individual experiences working with technicians with varied skill sets; for instance, some may work

more with external firms whose personnel specialize in these services. Further analysis can help determine the extent of skills gaps and support development of training programs to bridge the gaps.

Survey results indicate that future training efforts should prioritize instruction on how to protect buildings from and resolve issues related to cyberattacks, and how to manage smart technologies and interoperability issues among network-connected technologies. A number of field experts and the literature point to inadequate skills in other areas of focus, including controls programming and helping professionals make informed choices by educating them on how to install advanced equipment like heat pumps, solar photovoltaics, and automated systems (Adam Hinge, managing director, Sustainable Energy Partnerships, pers. comm., May 18, 2019; Mike Bobker, director, CUNY Building Performance Lab, pers. comm., June 14, 2019; Gleniss V. Brown Wade, workforce development program manager, DC Sustainable Energy Utility, pers. comm., August 5, 2019; GSEP 2013).

Systems Testing and Evaluation

About 78% of the survey respondents chose this category of skills as critical. Proficiencies include:

- Perform retrocommissioning
- Perform commissioning
- Do energy audits
- Set benchmarks

Figure 6 shows respondents' assessment of these proficiencies.

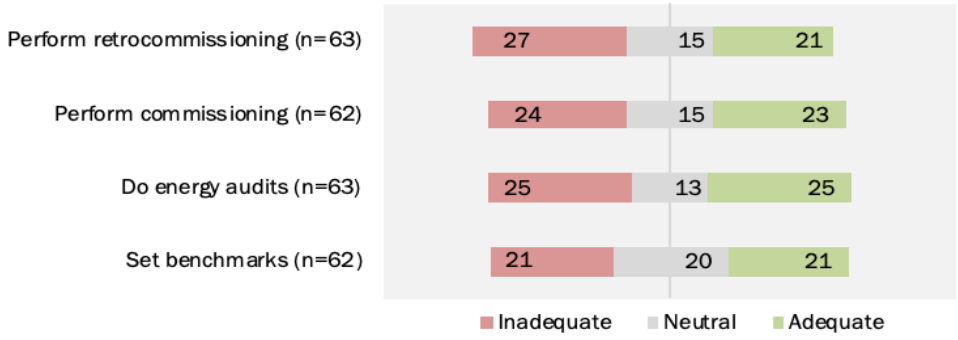

Figure 6. Survey assessment of building systems evaluation skills

For each proficiency, at least one-third of respondents said the workforce lacks adequate skills. An equal proportion of participants indicated the workforce does have adequate skills. However, these activities are performed less frequently during routine building O&M, and some services such as retrocommissioning and commissioning are often performed by third-party providers (Powell 2017). Therefore, it is possible that our survey respondents are not aware of how well trained these service providers actually are. Further analysis is needed to identify the benchmarking skills that building performance professionals need if they are going to improve facility performance.

Although our small-scale survey does not indicate a significant skills gap in this area, the expert interviews and the literature review do highlight a need to prioritize workforce skill development in retrocommissioning, commissioning, and benchmarking to achieve greater energy savings (BCxA 2018). Existing building commissioning, which may include retrocommissioning and ongoing (or "continuous") commissioning, can correct operational inefficiencies and "save between 10–20% of the energy that is lost due to annual deterioration, sensor drift, and controls error" (Michael Bobker, director, CUNY Building Performance Lab, pers. comm., June 14, 2019). Coupled with the shift to stricter regulations for building energy efficiency and greenhouse gas emission targets in many cities, commissioning and building re-tuning skills are likely to become more important (Adam Hinge, managing director, Sustainable Energy Partnerships, pers. comm., May 18, 2019).

The relative overall importance of this category of skills suggests that future efforts should focus on developing abilities needed to perform building system evaluation.

Data Acquisition and Analysis

Close to 68% of survey respondents deemed this category of skills important for operating and maintaining buildings. Proficiencies include:

- Interpret and use data analyses
- Analyze data
- Monitor and measure system performance
- Install sensors and meters

Figure 7 shows respondents' assessment of how proficient the workforce is in each of these areas.

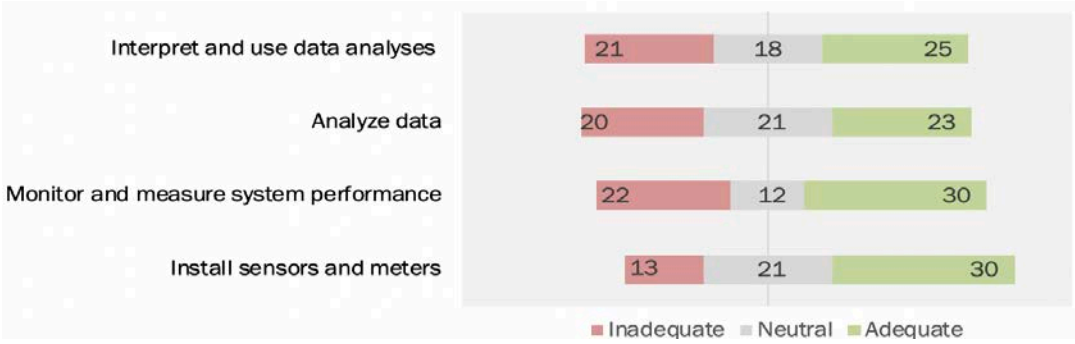

Figure 7. Survey assessment of data acquisition and analysis skills (n=64)

Slightly less than one-third of the survey participants noted a lack of expertise in today's professionals in monitoring performance, analyzing data, and interpreting analyses. In contrast, approximately one-third to one-half of participants indicated adequate skills in these areas. Many participants also chose "neutral," possibly indicating that they are less familiar with this skills category. This could be because building data analytics is still an emerging field in the building sector, with many different kinds of analysis techniques (Koseleva and Ropaite 2017).

Data analytics is likely to become crucial for tracking O&M and measuring changes in energy consumption (Barnwell 2018). Tracking of energy use trends and greater adoption of smart features require collecting and analyzing building data to identify energy savings opportunities and optimize ongoing operations (GSEP 2013). Data analysis is also used extensively in the initial and ongoing commissioning of building systems to ensure peak performance (BCxA 2018). Even though data analytics is key to energy-saving efforts, very few have mastery in this field, which requires knowledge of where to place sensors, how to acquire and analyze data, and how to use it to improve operations (GSEP 2013; Grueneich 2015; Gregg Ander, managing director, Gregg D. Ander, LLC, pers. comm., June 6, 2019).

Systems Design and Performance Modeling

Fewer respondents (42%) ranked this skills category as key for building operations relative to the other categories covered in our survey. However, our expert interviews and literature review do indicate that this is an essential skill for ensuring robust O&M of buildings. The proficiencies include:

- Use modeling and simulation software
- Understand advanced building systems
- Be familiar with codes and regulations
- Know advanced system assemblies

Figure 8 shows respondents' assessment of these proficiencies.

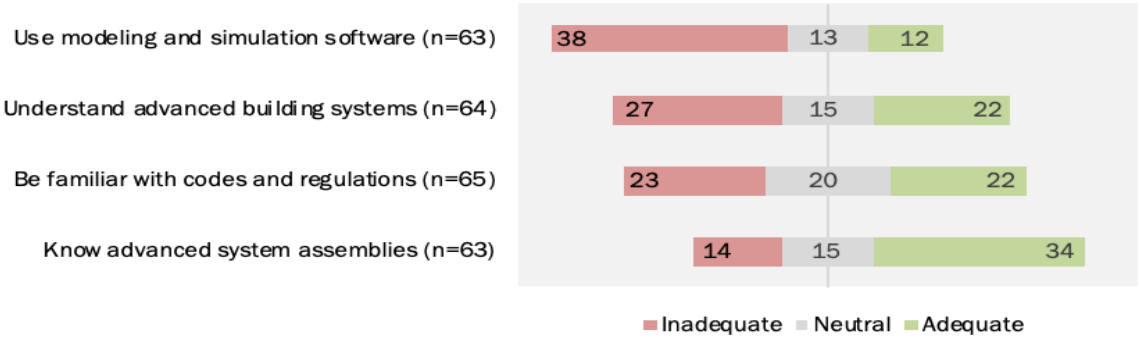

Figure 8. Survey assessment of building system design and performance modeling skills

Over half of respondents—38 out of 63—indicated that building performance professionals have inadequate skills in the use of modeling and energy simulation software. More than one-third of the participants also noted inadequacies in knowledge of advanced building systems, codes, and regulations. In contrast, only about one-fifth rated the workforce as having inadequate knowledge of advanced system assemblies.

The responses reveal the workforce has borderline inadequate systems design and modeling skills. The experts we interviewed and the literature both stress the need to further expand modeling skills, especially proficiency in tools that model, analyze, and optimize building

parameters.[6] Other potential areas to focus on include interpreting guidance on advanced technologies and using analytical tools to ensure codes and standards compliance (Thomas Myers, president, IBEW Local Union 26, pers. comm., August 21, 2019; Alliance to Save Energy 2017; Cohan 2012). These skills can help professionals understand the impact of interactions among building systems and maximize energy savings. They may even influence building operators' energy-related decisions by making them aware of new efficiency measures (Ehrlich et al. 2010; Henry, Schiedermayer, and Walker 2010).

Although 42% of survey respondents consider systems design and programming skills important, the need for developing training in this area is not as urgent as the need for curricula on operations and maintenance, systems integration, and evaluation skills that were considered important by large majorities of respondents.

Areas of Focus for Workforce Skills Development

Although survey respondents' views on workforce skills differ from the literature and field experts' evaluations in some areas, it is clear that building performance professionals need additional skills beyond those taught in traditional management, operations, and maintenance courses. Curricula on advanced technologies and operations can ensure that established professionals are able to fill knowledge gaps and keep up with current best practices.

Based on the relative importance of the five skills categories and evaluation of skills gaps in specific proficiencies, we identify these key areas for increased workforce training:

- Operations and maintenance
    - use of cost-benefit models to manage efficiency decisions
    - ability to optimize systems
    - performing diagnostics and preventive maintenance
- Systems integration skills
    - ensuring cybersecurity
    - integrating, managing, and programming smart technologies and controls
- Systems and evaluation skills
    - commissioning
    - retrocommissioning
    - setting benchmarks

Developing quality training programs and professional certifications in emerging fields like data analytics, however, needs more work. A job task analysis (JTA) can help to clarify skills

[6] Several such tools exist: DOE's OpenStudio enables users to design "what if" scenarios and make changes to test building response, and Autodesk has incorporated DOE's EnergyPlus modeling software to enable annual energy simulations.

that are adequate and those that need improvement and to develop training to ensure proficiency in this area.[7]

Given the day-to-day demands of building O&M, developing proficiency in skills like systems design and modeling may not be a priority. But this skill set can be important for new entrants in the field, providing them with a broader base of knowledge and tools to guide them as they make decisions with significant implications for building energy performance. It can give them greater perception and appreciation of building system interactions and the need for careful adjustment of controls.

STRATEGIES FOR WORKFORCE TRAINING

We have identified skills gaps in specific proficiencies, such as ensuring cybersecurity, addressing concerns in programming and integration, and managing system interoperability. Continuing education and certification programs, including onsite workshops and other training programs offered by utilities, professional associations, unions, and manufacturers, can offer specialized training focused on these and other new and emerging skills. Such programs offer convenient, local training opportunities for already employed professionals, helping them augment their skills and stay up-to-date on trends and technologies.

However, to develop the five major skill sets from the ground up and address building performance professionals' needs in emerging fields such as data analytics and systems evaluation, a more intense effort is needed. This may include formal apprenticeships and career training programs that award associate's and bachelor's degrees. Degree programs and apprenticeships can produce a pool of skilled building professionals, help overcome the hiring challenges many employers face, and increase the level of expertise new entrants bring to the workforce.

Building performance professionals rely on several approaches to receive training in the areas critical for building O&M. In our survey, respondents most frequently suggested in-house training, followed by certification programs and learning on the job (see figure 9).[8]

[7] The JTA is a procedure for analyzing the tasks performed by individuals in a specific job and the knowledge, skills, and abilities necessary to perform those tasks. JTAs are critical elements of quality training programs and professional certifications.

[8] In-house training programs bring staff from another building, or an instructor, into a facility to train employees in specific skills. In-house training can be customized to specific requirements of an organization and even have follow-up modules. In contrast, learning in the field is a more informal and hands-on method of teaching skills and competencies needed to perform a specific job. Professionals learn in the environment where they will eventually practice the skills obtained.

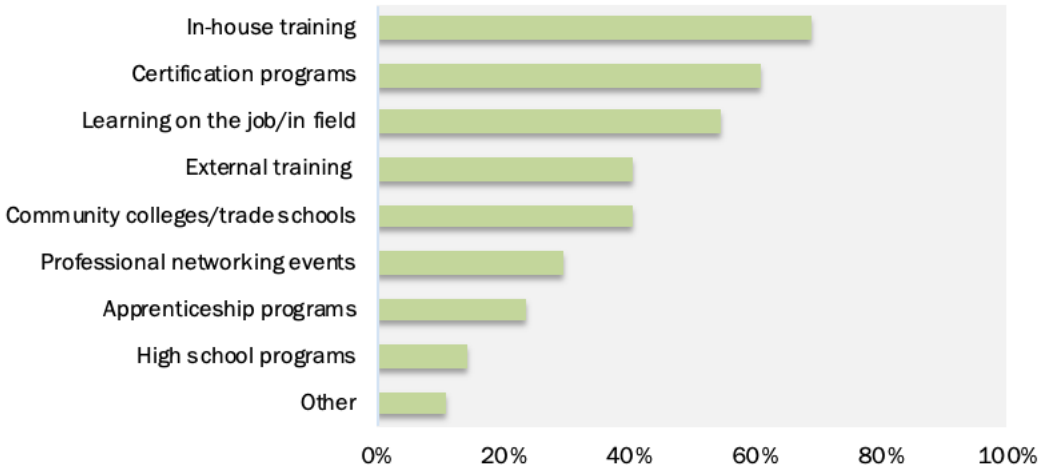

Figure 9. Suggested ways to bridge the skills gap (n=64)

To understand the landscape of existing workforce development programs, we organized the options selected by the survey respondents in figure 9 into two categories: (1) continuing education and certification programs for established professionals, and (2) intensive career training programs to expand and maintain a robust workforce. For each, we found exemplary programs that illustrate the skills participants can develop, and we analyzed the training approaches used to enhance their learning.

Continuing Education and Certification Programs

These programs can vary from short, one-time classes, seminars, online courses, or field trainings, to complete certification programs. We present some approaches in table 2 and highlight case studies on continuing education programs in boxes interspersed through the discussion that follows.

Table 2. Training pathways for continuing education and certification programs

Program type	Skills category					Learning approaches		
	Operations and maintenance	Systems Integration	Systems testing and evaluation	Data acquisition and analysis	Systems design and modeling	Classroom instruction	Hands-on learning	Practical/field training
Field or in-house training								
NYSERDA On-the-Job Training	•	•				•	•	•
Rheem Innovation and Learning Centers	•					•	•	•
External workforce programs								
PG&E Energy Centers	•				•	•	•	
Pepco Energy Savings for Business	•		•			•		•
CALCTP program	•	•	•			•	•	

Program type	Skills category					Learning approaches		
DCSEU workforce training program*	•	•				•	•	•
IBEW-NJACT joint BAS program	•	•				•	•	•
SEIU Local 32BJ Green Supers Program	•					•		•
AEE's Certified Energy Auditor program			•	•		•	•	
BOMI-HP Designation program	•					•		
Urban Green Crushing the Code training					•	•		
Third-party programs								
BOC certification	•	•	•			•	•	•
Dollars to $ense workshops	•	•	•			•	•	
Urban Green Council GPRO training	•					•	•	•
Informal training opportunities								
Building Energy Exchange, New York City	•	•			•	•	•	
BOMA, IFMA, and AESP conferences	•			•	•	•	•	

* Includes soft skills training

FIELD OR IN-HOUSE TRAINING

Traditionally, commercial building technicians have learned their skills on the job by observing others and performing work under supervision or by participating in training sessions facilitated by manufacturers and building service providers. A large part of training still happens this way through instruction on the specific equipment and systems found at a given building site, and this approach can be greatly scaled up to meet the building performance professional's training needs identified in this report. For example, the New York State Energy Research and Development Authority (NYSERDA) has formalized this approach in a program that provides financial support to energy efficiency businesses if they hire new employees and offer on-the-job training to help advance their skills.

Field training teaches experienced professionals (and new hires) how to operate and maintain equipment and integrate different building systems. It also familiarizes them with common issues that may arise and gives them the skills to diagnose faults that can compromise operations and occupant comfort as well as potential energy savings.

Manufacturers and service providers can provide training on specific systems in the field or in simulated environments. For example, Rheem educates contractors and plumbers on the latest energy-efficient HVAC and water heating equipment at the company's innovation learning centers. The hands-on learning centers have interactive classrooms, demonstration labs where equipment can be disassembled and reassembled, a virtual reality lab for diagnostics training, and a showroom for Rheem products. Instruction is offered on basic products as well as the most advanced systems and controls integration. In-person field training is also offered.

On-the-Job Training for Energy Efficiency and Clean Technology Program, NYSERDA

In 2019, NYSERDA began offering its on-the-job training program in collaboration with the New York State Department of Labor, as part of its Clean Energy Workforce Development effort. The program adopts a formal approach to field training to help develop a workforce that can perform jobs in the energy efficiency and clean technology sectors. It offers financial incentives to eligible energy efficiency and clean technology businesses to hire and provide on-the-job training to new employees (Adele Ferranti, program manager for workforce development and training, NYSERDA, pers. comm., August 22, 2019).

Eligible applicants are provided with the support needed to assess their workers' skills and to develop on-the-job training plans. The program offers funding for workers to acquire technical skills, credentials, and training in clean energy technology so that they are capable of designing, installing, operating, and maintaining in-demand systems and gain field experience that cannot be obtained via classroom instruction (NYSERDA 2018).

Funding is available on a cost-share basis at two levels. For businesses with 100 employees or fewer, the program pays 50% of a new employee's hourly wage for 16 weeks, or for 24 weeks if the employee belongs to a priority participant group that includes veterans, Native Americans, individuals with disabilities, low-income individuals, and 18- to 24-year-olds participating in work preparedness programs. Businesses with more than 100 employees are eligible for incentives only for employees from a priority population, at 50% of the hourly wage for 24 weeks. A recent change to the program offers an even higher incentive for businesses hiring workers to install heat pumps. In such a case, the program covers 75% of the new employee's hourly wage for 16 weeks or for 24 weeks if he or she is from a priority group.

More details are available from NYSERDA.

EXTERNAL WORKFORCE PROGRAMS

Utility programs. Efficiency program administrators play a critical role in advancing worker skills by implementing programs and helping to train the workforce to comply with and become eligible to participate in these programs. By leveraging their market power in promoting energy efficiency measures, program administrators can demand higher-quality work in their programs while helping to ensure that professionals receive the relevant skills training to properly install and operate building systems and maintain them over their life cycles. Such programs increase overall work quality and establish a minimum skill level for contractors and professionals who participate. Utilities benefit too as their customers lower their energy use, reduce the demand on the grid, and help them meet their energy efficiency and carbon emission reduction goals.

Shorter utility-led trainings can provide technology-specific skill sets as they evolve. A few utilities offer direct professional training, online courses, and access to utility experts. Educational materials are often developed in collaboration with industry partners to enhance workforce skills to support installation of new technologies and promote rebate programs. For example, Pacific Gas & Electric (PG&E) offers resources through its energy centers to educate professionals and contractors on a range of energy-related topics to help them design, build, and operate buildings efficiently. The energy centers' training curriculum, along with PG&E's online resources and other professional development opportunities, all focus on supporting efficiency and energy conservation. Other utilities, like Southern California Edison, offer hands-on training on new technologies like energy storage systems to ensure that the workforce has the right skills to install and operate the technologies the utility promotes in its service areas.

Another approach taken by utilities is to offer financial incentives to cover the cost of approved building O&M training. For instance, Pepco's Energy Savings for Business program offers incentives to building operators who complete training courses that focus on reducing electricity use within buildings. Operators can receive reimbursement of course fees for completing BOC training that focuses on HVAC systems and controls and commercial building re-tuning (Jamie Donovan, program analyst, DC Department of Energy and Environment, pers. comm., August 13, 2019). However, even with incentives, many organizations find these trainings cost-prohibitive. The typical cost of a program like BOC training can range from $1,595 to $1,895, with additional travel expenses and lost work productivity.

California Advanced Lighting Controls Training Program (CALCTP)

CALCTP is a statewide collaborative effort of investor-owned utilities, government agencies, universities and colleges, and labor associations. The program was established in 2008 to overcome the market barriers and knowledge gaps electricians and contractors face when installing and commissioning lighting control systems and to increase the use of such systems in commercial and industrial facilities (CALCTP 2020). The hands-on laboratory course allows participants to practice technical skills needed for a variety of advanced lighting components. It also gives them skills to effectively sell and bid for lighting controls projects.

The program is offered across California at 21 Joint Apprentice Training Centers, 6 Advanced Transportation Technology and Energy community college campuses, and 1 utility training center (Jackson, Avery, and Ouellette 2012). Qualified CALCTP instructors must be state-certified general electricians, must complete the requisite technical and train-the-trainer coursework, and must pass the accompanying exam.

CALCTP comprises two training programs. The first is a technical installation program with 10 hours of lecture and 40 hours of laboratory instruction. It educates, trains, and certifies C-10 licensed electrical contractors and state-certified general electricians in the proper installation, programming, and maintenance of lighting control systems. Typical lighting systems include dimmers, occupancy sensors, photo sensors, relay modules, and communication-based control devices. The second program is an acceptance-test technician program for technicians and employers that supports a Title 24 requirement. Employers and technicians earn certifications that enable them to then conduct tests of installed lighting controls.

The program has achieved significant success in training California contractors. Data indicate 10–30% cost savings in installations carried out by CALCTP-certified contractors due to more accurate bids, faster installation, and improved system performance (Zabin et al. 2014). This initiative has also generated many green technology jobs. ICF International has developed the CALCTP model for use beyond California, under the National Advanced Lighting Controls Training Program initiative.

More details about the program are available at www.calctp.org/.

State-administered programs. Some statewide program administrators subsidize third-party training for designers, building officials, and program implementers to ensure that people in the trades have the skills to install and implement efficiency measures and operate buildings to maximize savings. For example, the District of Columbia Sustainable Energy Utility coordinates a workforce training program that matches program participants with employers in need of trained building professionals. Participants receive instruction and guidance on technical and soft skills to ensure their overall professional development and success on the job (Gleniss V. Brown Wade, workforce development program manager, DC Sustainable Energy Utility, pers. comm., August 5, 2019).

Union programs. A number of trade unions offer classroom instruction in advanced technologies, giving existing tradespeople an opportunity to learn about new technologies from experienced professionals. For example, the International Brotherhood of Electric Workers (IBEW) Local 26 offers a course in building automation system technologies and control software in partnership with the Electrical Training Alliance (The Electrical Alliance 2011). Another example is the Service Employees International Union (SEIU), Local 32BJ's Green Supers Program, which offers short-term courses on green technologies for its members in New York City.

The Green Supers Program, Service Employees International Union (Local 32BJ)

In 2009, SEIU Local 32BJ began offering the Green Supers training to union members in the New York City area as part of the 32BJ Training Fund. This fund is a joint labor/management benefit program for members of Local 32BJ, the largest building service workers union in the country. Participants in the Green Supers training attend a series of in-person classes and field training in a multifamily building to gain practical and theoretical knowledge of the field and acquire skills needed for sustainable building O&M practices.

Over the years, the Green Supers training has evolved into a series of courses for commercial and multifamily building staff with options for participants to earn industry-recognized certifications. Instruction covers critical low- and no-cost O&M strategies such as tuning boilers, insulating pipes, and air sealing and incorporates training modules from the Urban Green Council's Green Building Professional skills courses, building analyst training, Building Operator Certification, and LEED professional training. As students complete a course, they qualify to take a certification exam to earn the specific credential. Participants also may opt to combine courses and trainings to earn a diploma, typically over a two-year period. Required courses remedy skills deficiencies in the areas of integrating and managing smart technology and optimizing energy management systems.

In 2019 with funding from NYSERDA, the program was expanded to include the Green Supers onsite training and coaching initiative. It provides organizations with an assessment of their building staff's training needs, offers hands-on interactive training tailored to their building systems, and follows up with onsite coaching to assist staff as they apply the concepts and strategies learned (Muldoon 2019).

More details on the program are available at http://training.32bjfunds.org/en-us/green.aspx.

Trade-group programs. Workforce training needs are also met through in-person or online instruction led by professional trade groups. For example, the Association of Energy Engineers (AEE) offers a four-day exam preparation course for individuals seeking accreditation as a Certified Energy Auditor. Participants learn how to conduct a detailed audit, analyze the results, and identify energy conservation opportunities. They work through examples and discuss ways to apply what they have learned in their operations.

Another notable example is the Building Owners and Managers Institute's BOMI-HP® Designation program. It is offered in the United States and Canada and provides participants with the in-depth knowledge needed to create and apply sustainable initiatives that can optimize operations (BOMI International 2020). Through O&M-focused courses, certificate programs, and designation programs, BOMI offers the property management industry extensive training options.

THIRD-PARTY PROGRAMS

Third party–administered certificate and certification programs, such as the Green Professional Building Skills (GPRO) certificate and Building Operator Certification (BOC),

provide assurance that a trainee has developed a well-recognized skill set from a credible organization.[9] Third-party programs therefore ensure quality control, enable existing workforce members to improve their technical skills, and teach new hires the most relevant set of proficiencies while giving them a clear and simple way to demonstrate their qualifications to potential employers.

Green Professional Building Skills, Urban Green Council

In 2010, the Urban Green Council developed the GPRO training program to provide trades and operations professionals with specialized training in how to build, maintain, and renovate buildings. GPRO includes classroom training as well as a module that includes skills assessments and onsite learning laboratories as well as mentorships, apprenticeships, and internships.

Training materials are flexible and can be customized to different building types and regions. As a result, GPRO is now offered through select U.S. Green Building Council chapters, unions, nonprofits, and educational institutions in more than 50 cities. Program delivery partners recruit, train, and test students at the end of the program.

Five training modules develop participants' knowledge of leading-edge practices in resource efficiency and healthy buildings. Instruction is offered in the fundamentals of building green, O&M essentials, electrical systems, mechanical systems, and plumbing. At the end of each module, participants receive a certificate if they have attended all classes and pass the multiple-choice GPRO exam.

The O&M module is the most popular course offered by the Urban Green Council. At the end of the module, participants propose three actionable items that they can implement at their facility. The course addresses several workforce skill deficiencies we identify in our survey, such as the skills needed to set and perform benchmarking and to program building energy management systems.

In 2018, the Urban Green Council began offering a variation of the GPRO program called GPRO at Work through its Building O&M Workforce Development and Training program. This initiative provides coaching and guidance on soft skills and helps participants implement the practices learned through GPRO training (Liz Thomas. associate director for operations, Urban Green Council, pers. comm,, September 12, 2019).

More details about this program are available at www.gpro.org/.

Established certification programs provide individuals with the knowledge and skills to manage day-to-day O&M of buildings and traditional systems. Industry-recognized certifications include Building Operator Certification (BOC), the BOMA Energy Efficiency Program (BEEP), the Operations and Performance Management Professional certification (OPMP), and various certification titles offered by the Association of Energy Engineers.[10] Unfortunately, these programs often do not include instruction on new technologies, controls programming, and cybersecurity, all of which are critical to the O&M of technologically complex buildings. The curricula in the established programs can be supplemented with instruction on emerging categories of skills.

[9] Certificate programs typically require attendance or completion of a course or a specific series of courses, but without a certifying exam. Certification programs, on the other hand, include a training and education component and require participants to pass an exam to receive the industry credential. Some also require practitioners to stay current in their field through continuing education courses.

[10] The BOC was developed and is maintained by the Northwest Energy Efficiency Council, BEEP is a program of the Building Owners and Managers Association (BOMA), and OPMP is an ASHRAE program.

Building Operator Certification, Northwest Energy Efficiency Council

Developed by the Northwest Energy Efficiency Council in the 1990s, BOC is a nationally recognized training and credentialing program targeting facilities engineers, building operators, maintenance workers, and technicians. It focuses on teaching the skills needed to operate facilities more efficiently while making occupants comfortable and improving overall system performance. With a focus on hands-on-learning, the BOC program model combines classroom lectures, group exercises, and daily assessments with project assignments that are completed at the participant's home facility. In 2019 the program joined the Smart Buildings Center, which now oversees program development.

The program is administered by a large network of partner organizations across 37 states and Canada. For example, in the Midwest region, the Midwest Energy Efficiency Alliance (MEEA) coordinates and facilitates the program with support from utilities, companies, and state agencies. Independent evaluation of MEEA's BOC training program reveals that the average annual energy savings per graduate is 100,500 kWh and 1,400 therms, adding up to $10,500 in operational cost savings (MEEA 2017).

Two levels of trainings are designed to meet the needs of operators with different levels of experience. Level I, building systems maintenance, requires completion of 8 one-day classes, while Level II, equipment troubleshooting and maintenance, requires 7 one-day classes. Participants earn a certificate upon completion of these courses and are then eligible to sit for the Certified Building Operator exam and earn BOC certification.

Though not explicitly focused on high-performance buildings and operations, the certification provides operators with working knowledge and experience in building systems management, integration, and interoperability. Efforts are underway to add smart buildings content to the BOC curriculum (Melanie Danuser, education director, Smart Buildings Center, pers. comm, September 12, 2019).

More details about the program are available at www.theboc.info/.

To be impactful, certification programs should be high quality and widely recognized and should provide building professionals with a standard set of skills (DOE 2020a). This helps reduce confusion around different credentials and also addresses issues related to the quality, consistency, and scalability of skills learned from different programs.

The DOE's Better Buildings Workforce Guidelines, developed in collaboration with the National Institute of Building Sciences and other stakeholders, recognizes relevant job requirements and skills needed for four energy-related jobs in commercial buildings: energy auditors, commissioning professionals, operations professionals, and energy managers. The guidelines also recognize available credential programs for three job titles. These programs are accredited by the American National Standards Institute, the International Accreditation Service, or an ISO/IEC 17024:2012–compliant accreditation body (DOE 2018c). Table 3 lists some of the DOE-recognized programs that are offered in the United States and Canada.

Table 3. Certification programs recognized by the DOE's Better Buildings Workforce Guidelines

Job	Recognized programs
Energy auditor	ASHRAE, Building Energy Assessment Professional (BEAP) certification
	Association of Energy Engineers, Certified Energy Auditor (CEA)
Commissioning professional	Certified Commissioning Group, CxA certification
	ASHRAE, Building Commissioning Professional (BCxP) certification
	Building Commissioning Association, Certified Commissioning Professional (CCP)

Job	Recognized programs
	National Environmental Balancing Bureau, Commissioning Process Professionals (CxPP)
Energy manager	Association of Energy Engineers, Certified Energy Manager (CEM)
	Energy Management Association, Energy Management Professional (EMP)

Source: DOE 2020a

Certification programs benefit employers and utilities. Because many of these programs require participants to engage in continuing education to maintain their credentials, they are incentivized to stay up-to-date on codes, new technologies, and operations techniques.

INFORMAL TRAINING OPPORTUNITIES

Many organizations rely on informal training to ensure that their facilities' staff gain new skills and learn about energy efficiency solutions and practices. These opportunities include exhibits, technology demonstrations, and learning sessions on cutting-edge research. The Building Energy Exchange (BE-Ex) in New York City functions as a knowledge hub to connect building decision makers and the design community to new and advanced building technology solutions and strategies for the design, construction, and operation of zero-energy buildings. BE-Ex is active in efforts to expand the network of high-performance buildings hubs in the United States and Canada.

Other networking events such as industry conferences, vendor-sponsored lunch-and-learn events, and lectures offered by trade and professional groups provide access to on-the-job training for mid- and senior-level engineers and managers (Charlie Fletcher, executive vice president, EMCOR Services Mesa Energy Systems, pers. comm., June 19, 2019). Many annual conferences and trade shows provide opportunities to earn continuing education credits for professional certifications as well as a venue to learn about new products and services through peer-to-peer exchanges.

Degree Programs and Formal On-the-Job Programs

More extended training is needed to teach in-demand skills to new entrants to the building operations field with no prior experience and to expand the pool of qualified candidates. Career training programs are offered in collaboration with high schools, trade and labor groups, technical and community colleges, and universities. They include education on cutting-edge technologies to enhance the skills of new hires and may help to generate interest in the profession by offering students an established career path. Table 4 describes some promising programs.

Table 4. Degree programs and formal-on-the-job programs

Program type	Skills category					Learning approaches		
	Operations and maintenance	Systems integration	Systems testing and evaluation	Data acquisition and analysis	Systems design and modeling	Classroom instruction	Hands-on learning	Practical/field training
Career and technical education for high school students								
E-House learning laboratories	•	•		•	•	•	•	•
Apprenticeship programs								
UVA Facilities Management program	•					•	•	•
IUOE Stationary Engineers program	•	•				•	•	•
Community college programs								
Laney College* A.S. degree and certificate in building automation systems	•	•	•		•	•	•	•
Valencia College A.S. degree in energy management and controls technology	•	•	•		•	•	•	•
University degree and programs								
Cal Poly mechanical engineering program	•	•			•	•	•	
CUNY Building Performance Lab	•	•	•	•		•	•	

* Includes soft skills training

CAREER AND TECHNICAL EDUCATION FOR HIGH SCHOOL STUDENTS

High school programs have trained students to perform skilled work for many decades, and some even teach green building technologies. For example, the Connecticut Technical High School System's technology exploration program for ninth-grade students offers hands-on experience in energy conservation, energy efficiency, and renewable energy technologies. Eight schools in the system have energy efficiency, weatherization, and renewable energy labs, known as E-House laboratories, that serve as spaces for students to explore efficient technologies.

For the most part, there has been a decline in public school investment in vocational education. Although there are a few high school programs offering training in green technologies, most existing programs instead focus on teaching the skills required for traditional construction and manufacturing jobs. This is in part due to the inability of schools to provide a direct career path or a specific job title for students interested in training in new technologies (Curley 2010).

Another issue impeding high school students' training in advanced controls and technology is the building O&M profession's association with physical work as well as the persistent perception in the United States that entering a trade is less valuable or respected than

attending a four-year college or university (EGIA 2018; Heinemeier et al. 2016). The experts we interviewed stressed the need to expand students' and parents' understanding of the O&M profession so they can see how information networks and the latest technology can be used to operate buildings and save energy (Alison Diehl, director, National Sustainable Structures Center, Pennsylvania College of Technology, pers. comm., August 20, 2019; Thomas Myers, president, IBEW Local Union 26, pers. comm., August 21, 2019). Collaboration with professional associations and trade groups to offer instruction and hands-on training on advanced controls can showcase the diverse skills required and encourage students to consider a career as a building technician.

E- House Learning Laboratories, Connecticut's Technical High School System

In 2010, the green construction technology lab (E-House) program was created as an onsite training laboratory to help ninth-grade students and trade instructors learn about and experiment with energy savings initiatives. The program was developed as a collaboration of the technical high school system, the state's energy efficiency and renewable energy funds, electric utilities, and private industry to provide hands-on training and curriculum in energy conservation, energy efficiency, and renewable energy technologies (Meyer 2012).

The program gives instructors the opportunity to introduce their students to cutting-edge and future clean energy technologies. Students design and build an E-House laboratory using green construction technologies. Initially, the plan was to build only one E-House, at New Britain's E.C. Goodwin Technical High School, to serve all the schools in the system. However, with additional funding, eight more E-Houses have been built at high schools across the state.

E-House labs serve as a space for training students in energy efficiency and renewable energy technologies and practices like ductless heat pumps, radiant floors, weatherization, rooftop solar, and solar thermal systems. It also works as a building analysis lab for future technicians, builders, and carpenters. Students practice sealing and insulating measures to make the structure more energy efficient, and they perform tests to study their impacts. Through OSHA, they have the opportunity to complete a 10-hour safety training and 30-hour construction and general outreach training. Through partnerships with vendors, manufacturers, and contractors in construction-related trades as well as solar PV and solar thermal, students are given further opportunities for work-based learning.

The program is nationally recognized as the first green construction laboratory for high school students (Energize Connecticut 2017).

APPRENTICESHIP PROGRAMS

Unions can be instrumental in providing education and training in new technologies and controls as part of their role in helping professionals develop in-demand skills. In collaboration with local employers and community colleges, unions offer structured apprenticeship programs that are designed to put participants on a career path and provide them with the skills needed to succeed in their chosen field (Ehrlich et al. 2010).[11] Apprenticeships are multiyear commitments that combine on-the-job, hands-on training with the teaching of relevant technical skills. These programs can easily incorporate training

[11] A few examples of union apprenticeship programs include the Washington State-approved IUOE Local 302 Stationary Engineer Apprenticeship Program, the NECA Washington DC Chapter/IBEW Local 26 Joint Apprenticeship and Training Committee's Telecommunications Apprenticeship Program, and the Energy Innovation Center's training programs.

modules on the skills we have identified as being critical to effective O&M of high-performance buildings.

Apprenticeship programs play a vital role in developing participants' expertise and increasing companies' pools of new talent. For example, people in the younger demographic interested in computers can, while earning a stipend, acquire the relevant programming skills, as some apprenticeships include curricula on advanced controls in high-technology buildings (Stever 2018). Apprentices tend to continue working for the organizations that hire them, as they become eligible for promotions when they gain additional skills and experience, which then improves the organization's retention rate (Stern 2019).

A few universities offer apprenticeship programs certified through the U.S. Department of Labor's Registered Apprenticeship system, with programs ranging from one to six years depending on the occupation's skill requirements (Stern 2019). At the end of the program, apprentices have journeyman-level experience and are eligible for a trade-specific license. These programs can include curricula on advanced technologies and system operations. For example, the four-year University of Virginia (UVA) Facilities Management Apprenticeship program requires participants to complete 400-plus hours of technical education and classroom instruction and about 8,000 hours of on-the-job training in the fields of HVAC, electrical work, plumbing, carpentry, and more, all while being full-time employees in the facilities management department. The program recruits high school graduates and puts a major emphasis on providing a pathway to a managerial position.

COMMUNITY COLLEGE PROGRAMS

Community colleges can play a key role in providing the education and training needed for a highly skilled buildings workforce. They generally have established STEM curricula that incorporate math, engineering, energy management, and technical knowledge with hands-on skill development (Bobker, Joseph, and Aslanian-Persico 2010). These can be leveraged to provide education for building performance professionals.

A number of community colleges offer relevant programs especially around building controls. These programs synergize theory and practice by requiring students to develop solution sets and solve real-life building problems in teams, which develops both technical and interpersonal skills. For example, Laney College in Oakland, California, offers a comprehensive program of system-level education along with the energy efficiency content and soft skills needed in the profession. The certificate and associate's degree in building automation systems includes courses on energy efficiency principles and practices, technical details of commercial HVAC systems, and BAS. Students are encouraged to build teamwork skills, systems-level thinking, and problem-solving capabilities by solving real-life, open-ended problems (Crabtree et al. 2012). Another example is Valencia College's associate of science degree in energy management and controls technology, which meets the demands of high-technology buildings by instructing students in emerging areas of cybersecurity and network operations.

Some community colleges have also partnered with nonprofit organizations like the National Partnership for Environmental Technology Education and the Advanced Technology Environmental Education Center (ATEEC) to develop curricula and resources

for specific green technologies. For example, ATEEC in partnership with Eastern Iowa Community Colleges offers an associate of applied science degree in the renewables field (Eastern Iowa Community Colleges 2020). The program integrates technical instruction and hands-on training in the field, providing students real-world learning opportunities.

Energy Management and Controls Technology Program, Valencia College, Orlando, Florida

Valencia Technical College offers a two-year associate of science degree in energy management and controls technology to prepare students for careers in building energy management and automation technology. Through in-class instruction in current and emerging technologies and a practicum, students learn how to manage, and control building electrical and mechanical systems and develop skills to communicate with technical and nontechnical audiences.

The 60-credit-hour degree includes courses in building science and automated systems. Students learn about commercial HVAC and refrigeration systems; control theory, logic, and programming; and how to install, design, and integrate control systems. The curriculum requires students to complete a project on BAS hardware and software to help them understand the time, materials, and resources needed. The program is intended to prepare students to work as skilled technicians capable of designing, installing, servicing, and troubleshooting complex control systems (Valencia College 2020).

Advanced courses in automation system and controls integration, local area networks, and cybersecurity operations, as well as practicums in energy management and controls technology are also offered (Valencia College 2020). These modules directly address the workforce skills deficiencies we identify in our survey and provide training that can help students get high-skill jobs upon graduation.

Students have the option of transferring into Valencia's bachelor's degree program. The program also encourages students to earn other certifications, including the International Society of Automation Certified Control System Technician certification, the Association of Energy Engineers Certified Energy Efficiency Practitioner certification, and the Project Management Institute Certified Project Management Professional certification.

More details about the program are available at Valencia College.

COLLEGE AND UNIVERSITY DEGREES AND PROGRAMS

For students interested in entering the buildings workforce, there are few four-year college programs with education and hands-on training options that go beyond an associate's degree. Such opportunities are often offered through an architectural engineering or mechanical engineering program or department and may include instruction in building systems and efficient practices. For example, California Polytechnic State University's mechanical engineering program focuses on HVAC and building energy management systems. In this program, students learn technical skills to design components, fans, boilers, pipes, and other pieces of technology, and seniors complete a project-based design course in which they get hands-on training in the HVAC field (Robinson, Knowles, and Sun 2010).

Colleges can work with industry stakeholders to integrate course content that reflects the needs of the industry. Such partnerships help establish communication between industry and educational institutions and prepare the next generation of employees with relevant industry expertise and capacity for innovation. For example, publicly funded two- and four-year colleges can collaborate with the Building Efficiency for a Sustainable Tomorrow (BEST) Center to offer technical programs in advanced technologies and high-performance building operations. Initiated at Laney College in Oakland, California, and supported by the National Science Foundation, the BEST Center is a national collaborative that advances building science and technical education programs in HVAC, building automation, building

performance and facilities/energy management (Mukhopadhyay, O'Toole, and Kalonde 2019). It facilitates training on the most up-to-date research and data by matching industry needs to cutting-edge curricula in HVAC systems, building controls, and automation.

College and universities also offer continuing education courses. The courses vary in length, depending on the topic and specialization. Focus areas include building energy management systems, facilities management, effective communication, and computer skills. For example, the Building Performance Lab at the City University of New York (CUNY) frequently offers courses on new and relevant technologies to professionals in the region.

Energy Efficiency Training and Professional Development, Building Performance Lab at the City University of New York

Since 2004 the Building Performance Lab (BPL) at the Institute for Urban Systems at the City University of New York (CUNY) has been offering continuing education programs for facility and real estate managers, building operators, maintenance professionals, and energy service consultants. Programs are offered in collaboration with the CUNY School of Professional Studies, NYSERDA, New York City agencies, trade unions, and community organizations. Focusing on energy efficiency and energy management practices and on developing each participant's overall technical and professional skills, the program model combines a number of approaches. These include instruction on basic science concepts and calculations, practical projects that teach team-based improvement processes, and use of schematics to explain systems and relationships between systems (Bobker, Joseph, and Aslanian-Persico 2010).

BPL offers a wide variety of programs to help participants improve existing building performance and enhance operations in the New York City region. The completion time for these courses and programs varies from two days to 15 weeks. Current programs include New York City Building Operator Training for operators of small to medium-size apartment buildings, Building Operator Certification, and the Building Re-Tuning program, which helps operating engineers improve their buildings' performance. Other short courses include advanced energy performance online training, high-performance boiler and hydronic system O&M training (HPBO), small commercial energy audit training, and learning to sell efficiency effectively.

BPL courses and programs have trained more than 3,000 building operators, energy managers, auditors, and sales professionals. Even after completing a specific course or program, participants can continue their education and training using an online catalog of research papers, presentations, reports, software tools, and other publications.

More details on this program are available at: www.cunybpl.org/training/.

Recommendations for Addressing Skills Gaps and Attracting New Workers

Our research shows that building performance professionals need training in several skills to ensure robust operation of high-performance buildings. Examples of existing programs summarized in tables 2 and 4, and those highlighted through the case studies above, illustrate some of the successful and promising programs already in place.

We recommend the following actions to further develop the necessary workforce for high-performance buildings. Utilities and program administrators can take action on the first three recommendations to ensure that building performance professionals have the requisite skills. The next three solutions for bridging the skills gaps require greater partnership, collaboration, and the support of policymakers.

ESTABLISH SKILL AND CREDENTIALING STANDARDS

Utilities and building service providers like HVAC firms must play an active role in promoting standard certifications. By specifying workforce standards such as licenses, skill certifications, and contractor requirements, they can ensure that building performance professionals have the requisite skills. Setting these standards will also facilitate the rapid launch of effective training programs that address workforce needs. For example, California's investor-owned utilities PG&E and Southern California Edison (SCE) support the CALCTP program by requiring CALCTP certification for participating contractors and including rebates for customers using CALCTP-certified contractors. By having an eligibility requirement, the utilities identify a clear baseline of skills for contractors entering the program. They are also able to achieve lower installation costs and higher initial performance from lighting systems installed through the program, as skilled technicians install and commission the systems.

Training organizations and certification bodies should use job task analyses to improve the quality and consistency of credentials and develop relevant training programs in emerging fields, like data analytics, that are likely to play a more prominent role in the future. In 2020, the Northwest Energy Efficiency Council (NEEC) conducted a nationwide study validating a job task analysis for the position of commercial building operator/engineer. The analysis will support the development of a new course on advanced controls and technologies that will supplement NEEC's existing BOC curriculum (Melanie Danuser, education director, Smart Buildings Center, pers. comm., September 12, 2019). The supplemental class will include emergent concepts like networking, security, systems integration, analytics, and operational strategies.

INTEGRATE MULTIPLE TRAINING APPROACHES

A company's management must understand the skill deficiencies in its building staff and identify short and career-oriented training options to bridge those gaps. A combination of training approaches will ensure that the existing workforce gets the relevant knowledge to keep pace with changing technology and that new candidates start their careers with skills that meet industry demands (Autodesk Foundation and Monitor Institute 2019).

Continuing education and certification programs focused on the specific technical skills identified in our survey, combined with the hands-on learning components found in manufacturer-led trainings, certification programs, and utility-offered instruction, can facilitate the dissemination of skills needed for quality equipment installation and operation of buildings. Such programs could be supported by trade organizations, labor unions, and utility energy efficiency programs.

Apprenticeships, community college courses, and university programs are more intensive than continuing education or company-sponsored training. These programs provide in-depth technical knowledge, offer soft skill training, and include practical training in the field or laboratory. They educate new candidates on skills they will need as they enter the profession, thus helping to develop a strong pool of skilled professionals. Because apprenticeships include a substantial on-the-job learning component, they can also play a key role in the transfer of knowledge from experienced professionals to new candidates and overcome concerns regarding loss of knowledge as members of the workforce retire.

The delivery model for these programs should integrate technical knowledge on advanced technologies and best practices, supplement it with hands-on learning, and include opportunities for developing cognitive and interpersonal skills. The course content should target specific skills and responsibilities we identify in our analyses. To support participant learning, course instruction should be offered through in-class lectures, field training, and online classes. Online delivery of instruction is particularly important for experienced professionals who require continuing education but are in locations with no nearby training. However, a balance must be made between the use of online media and the need to include hands-on, practical training.

REACH OUT TO HIGH SCHOOL STUDENTS

As public schools have cut funding for vocational training, student awareness of and interest in construction and technology-driven building jobs have declined. Organizations such as STEM networks are working regionally across the nation to address this challenge and ensure that young people benefit from career learning opportunities. West Sound STEM is one regional network, currently leading career-connected learning experiences in Kitsap County, Washington. The organization has partnered with employers, unions, labor groups, and several other regional community and technical colleges to establish a controls programmers apprenticeship program for youth and adults (England and Andrade 2019). To create a talent pipeline, the program involves educators from elementary to postsecondary institutions in work site and industry interactions and development of competencies and standards. These connections help educators and guidance counselors understand the career pathways available and what skills are needed to succeed.

Employers and efficiency program administrators need to reach out to high school students to increase awareness of opportunities in the industry and must offer relevant training to students. For example, the Connecticut Technical High School System's E-House program, funded by the Connecticut Energy Efficiency Fund and administered in partnership with Connecticut Light and Power and United Illuminating, provides students the education and practical experience needed to operate advanced energy-efficient and renewable technologies. More such collaborations should be developed to encourage interest among students and help them get involved in building O&M.

COORDINATE TRAINING EFFORTS AND SHARE BEST PRACTICES

Several different workforce development programs and courses exist to address the need for technical education and training and to ensure that professionals will be available to deliver energy efficiency services. For example, a number of cities run programs to increase the skills of tradespeople eligible to participate in their weatherization and building shell efficiency improvement programs. To avoid duplication of efforts, coordination is needed among training program providers within states. In 2020, DOE launched the Better Buildings Workforce Accelerator to coordinate efforts that will help clarify career pathways to increase building efficiency and productivity and advance the level of knowledge in the buildings-related workforce (DOE 2020b).

In addition, best practices developed in states well versed in energy efficiency design and performance need to be shared with stakeholders in other states who have less experience in these areas. For example, two exemplary programs, the SEIU Local 32BJ Green Supers

program and the CUNY Building Performance Lab's energy efficiency training and professional development program, were designed for the New York City market in response to the city's rigorous goals to make its building stock energy efficient. Lessons from these programs can help advance the development of new programs in other parts of the country, thus ensuring greater dissemination of key skills throughout the United States.

ESTABLISH A CLEARINGHOUSE OF CURRICULA, TRAINING PROGRAMS, AND CERTIFICATIONS

Because many buildings professional are unsure which competencies to acquire and where to pursue the necessary training, national guidelines should be established that specify the required qualifications and potential certifications and trainings that can help them commission, operate, and maintain buildings. For example, DOE's Better Buildings Workforce program identifies technical standards, job skill requirements, curricula and training programs that teach in-demand skills, and industry-recognized certifications with third-party accreditation (DOE 2018b). These national guidelines for energy-related professional credentials should be followed industry wide to improve the quality and consistency of the commercial buildings workforce.

CREATE BUILDING TRAINING AND ASSESSMENT CENTERS

Similar to the successful federally funded network of Industrial Assessment Centers that offer energy efficiency training programs to the manufacturing sector, a hands-on building training and assessment center (BTAC) should be created to address the skill needs of the commercial buildings workforce. According to Trombley, Amann, and Kissock (2010), BTAC programs can utilize institutions of higher learning to educate building engineers and scientists on advanced controls and BAS and to train professionals to design and operate buildings with optimal efficiency. The programs should offer free energy performance assessments of individual commercial and institutional buildings, provide recommendations for additional energy-saving measures to owners and operators, and provide practical, hands-on experience to trainees. This combination has been a key to success in the Industrial Assessment Center program and would bring great benefits to the commercial buildings sector.

Conclusion

Our research shows the need for a diverse system of education and training to bridge workforce skills gaps. A number of approaches show promise and are providing valuable resources to help existing and new building professionals keep pace with advanced technologies and practices, ranging from continuing education and certification programs to degree programs and formal on-the-job career training. The programs most likely to be successful at bridging the skills gaps are those with a combination of technical courses on the proficiencies needed for operating and maintaining buildings combined with a hands-on learning component and the opportunity to develop cognitive and interpersonal skills. By investing in workforce training, the commercial sector can see a full return on investment in high-performance buildings, meeting expectations for energy savings and emissions reductions and providing better indoor conditions to building occupants.

References

Alliance to Save Energy. 2017. *Going Beyond Zero: A Systems Efficiency Blueprint for Building Energy Optimization and Resilience.* Washington, DC: Alliance to Save Energy. www.ase.org/sites/ase.org/files/ase-sei_going_beyond_zero-digital-vf050317.pdf.

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). 2018. *ASHRAE Guideline 32-2018 Management for Sustainable High-Performance Operations and Maintenance*. Atlanta: ASHRAE. webstore.ansi.org/standards/ashrae/ashraeguideline322018.

Autodesk Foundation and Monitor Institute by Deloitte. 2019. *Supporting Worker Success in the Age of Automation*. San Rafael, CA: Autodesk Foundation. Cambridge, MA: Monitor Institute by Deloitte. www2.deloitte.com/us/en/pages/monitor-institute/articles/bridging-the-manufacturing-and-construction-skills-gap.html.

Barnwell, R. 2018. "The Building Data Analytics Revolution in Three Acts." *DLR Group Insights Blog*, August 31. www.bdcnetwork.com/blog/building-data-analytics-revolution-three-acts.

Barell, J. F. 2006. *Problem-Based Learning: An Inquiry Approach*. Thousand Oaks, CA: Corwin Press.

BCxA (Building Commissioning Association). 2018. *Value of Commissioning: 2018 Market Survey*. Hillsboro, OR: BCxA. www.bcxa.org/wp-content/uploads/2019/07/Cx-Market-Survey-Report-Final-2019.07.16-V.3..pdf.

Bobker, M., V. Joseph, and A. Aslanian-Persico. 2010. "Addressing the Operator as a Driver of Building Performance." In *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 37–47. Washington, DC: ACEEE. www.aceee.org/files/proceedings/2010/data/papers/2246.pdf#page=1.

BOMI (Building Owners and Managers Institute) International. 2020. "High-Performance Sustainable Buildings BOMI-HP®." www.bomi.org/HPDesignation.aspx.

Brooks, B., K. Pinit, L. Webster, and L. Fischer. 2012. "Bridging the Training Gap: Development of New Curriculum for the Commissioning Industry Analyzing the Training Gap." In *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 17–28. Washington, DC: ACEEE. www.aceee.org/files/proceedings/2012/data/papers/0193-000316.pdf#page=1.

CALCTP (California Advanced Lighting Controls Training Program). 2020. "What Is CALCTP? Why Advanced Lighting Controls?" Accessed August. www.calctp.org/what-calctp.

Cohan, D. 2012. "A Comprehensive Approach to Energy Code Education and Training." In *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Industry* 10: 43–52. Washington, DC: ACEEE. www.aceee.org/files/proceedings/2012/data/papers/0193-000325.pdf#page=1.

Crabtree, P., C. Frost, N. Kyriakopedi, and B. Widhalm. 2012. "Preparing Building Technicians for Energy Efficient Operations of High Performance Facilities." In *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 65–76. Washington, DC: ACEEE. aceee.org/files/proceedings/2012/data/papers/0193-000338.pdf.

Curley, E. 2010. "Youth Onramps to Green Jobs in the Energy Sector." In *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 60–70. Washington DC: ACEEE. aceee.org/files/proceedings/2010/data/papers/2251.pdf.

U. S. DOL (U.S. Department of Labor). 2019. "Employment and Earnings by Occupation." www.dol.gov/wb/occupations_interactive.htm.

Deringer, J., J. Nahman, K. Heming, M. Wetter, X. Pang, and M. Konstantoglou. 2012. "LearnHPB and eLAD—Two Related Online eLearning Platforms for High Performance Buildings." In *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 99–110. Washington, DC: ACEEE. www.aceee.org/files/proceedings/2012/data/papers/0193-000334.pdf#page=1.

DOE. 2018a. "About Better Buildings Workforce Guidelines." betterbuildingssolutioncenter.energy.gov/workforce/better-buildings-workforce-guidelines.

——. 2018b. "Better Buildings Workforce." Better Buildings U.S. Department of Energy. betterbuildingssolutioncenter.energy.gov/workforce.

——. 2018c. "DOE Recognition." betterbuildingssolutioncenter.energy.gov/workforce/participating-certifying-organizations.

——. 2020a. *Better Buildings Workforce Accelerator Fact Sheet.* Washington, DC: DOE. betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Workforce_Accelerator_FactSheet_FINAL.pdf.

——. 2020b. "Workforce Accelerator." betterbuildingssolutioncenter.energy.gov/accelerators/workforce.

Eastern Iowa Community Colleges. 2020. *Renewable Energy System Specialist: Program Description*. Davenport: Eastern Iowa Community Colleges. www.eicc.edu/future-students/our-programs/renewable/Renew-Engergy-System-Specialist-Fact-Sheet.pdf.

EGIA (Electric & Gas Industries Association) Foundation. 2018. 2018 Industry Study Bridging the HVAC Employment Gap. Sacramento: EGIA Foundation. egiafoundation.org/report.

Ehrlich, P., R. Kupritz, A. Lewis, and J. Seewald. 2010. *Current Situation and Trends in Buildings and Facility Operations.* Prepared by Building Intelligence Group LLC. Oakland,

CA: Laney College. laney.edu/environmental_control_tech/wp-content/uploads/sites/98/2010/09/BuildingOperationsReport_Full.pdf.

EMI (Energy Market Innovations, Inc.). 2012. *California HVAC Contractor & Technician Behavior Study*. Rosemead, CA: Southern California Edison Company. San Francisco: Pacific Gas & Electric Company. www.calmac.org/publications/CA_HVAC_Behavior_Study_FinalReport_2012Sept14_FINAL.pdf.

Energize Connecticut. 2017. *Connecticut's Ninth E-House Opens at Middletown's Vinal Tech High School*. Hartford: Energize Connecticut. portal.ct.gov/-/media/OCC/FINALVinalTechEHousePostEventPressRelease102417pdf.pdf?la=en.

England, P., and R. Andrade. 2019. "Creating a Path to the Workforce for More Kitsap Students." *Kitsap Sun*, April 18. www.kitsapsun.com/story/opinion/columnists/2019/04/18/your-turn-state-can-invest-students-through-career-connect/3511006002/.

Fernandez, N., S. Katipamula, W. Wang, Y. Xie, M. Zhao, and C. Corbin. 2017. *Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction*. Prepared by Pacific Northwest National Laboratory. Washington, DC: DOE. buildingretuning.pnnl.gov/publications/PNNL-25985.pdf.

Goldman, C., J. Peters, N. Albers, E. Stuart, and M. Fuller. 2010. *Energy Efficiency Services Sector: Workforce Education and Training Needs*. Prepared by Berkeley Lab. Washington, DC: DOE. emp.lbl.gov/publications/energy-efficiency-services-sector-0.

Grueneich, D. M. 2015. "The Next Level of Energy Efficiency: The Five Challenges." *The Electricity Journal*, *28*(7), 44–56. https://doi.org/10.1016/j.tej.2015.07.001

GSEP (Global Superior Energy Performance Partnership). 2013. *Knowledge and Skills Needed to Implement Energy Management Systems in Industry and Commercial Buildings: Multi-Country Analysis and Recommendations*. Paris: Clean Energy Ministerial. www.cleanenergyministerial.org/sites/default/files/2018-08/Knowledge_Skills_EnMS_Implementation_Report.pdf.

Gunn, R., and G. Malek. 2013. "An Evaluation of ComEd's Retro-Commissioning Program." *21st National Conference on Building Commissioning*. Hillsboro, OR: BCxA. www.bcxa.org/wp-content/2013BCAPresentations/Gunn_Malek-Utility%20Programs_ComEd_RCx_Evaluation.pdf.

Heinemeier, K., M. Saucke, K. Bannor, I. Valenzuela, G. Harmon, and M. Howe. 2016. *California Community Colleges: Attracting Students to the Skilled HVACR Trades*. Davis: University of California. www.bestctr.org/wp-content/uploads/2016/11/HVACR-Barriers-and-Opportunities-Final-Report-8-1-2016.pdf.

Henry, S., K. Schiedermayer, and T. Walker. 2010. "Integrating Technical Education and Training into Energy Efficiency Program Delivery: A Strategy to Drive Program

Participation and Create Short Term Impact and Long Term Market Effects." In *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings* 6: 87–99. Washington, DC: ACEEE. www.aceee.org/files/proceedings/2010/data/papers/2099.pdf#page=1.

Herr, T., and L. Dunfee. 2020. *Best Practices in Remote Building Management: Operating Buildings from Your Bedroom*. Washington, DC: USGBC (United States Green Building Council) National Capital Region. www.rateitgreen.com/green-building-resources/sustainable-building-events/best-practices-in-remote-building-management-hosted-by-usgbc-national-capital-region-april-29-1-2-30-edt-pm/4379.

IFMA (International Facility Management Association). 2009. *Temperature Wars: Savings vs. Comfort*. Houston: IFMA. www.ifma.org/docs/default-source/surveys/hvacsurvey2009.pdf?sfvrsn=2&sfvrsn=2.

ILO (International Labour Office). 2011. *Study of Occupational and Skill Needs in Green Building*. Geneva: ILO. www.ilo.org/wcmsp5/groups/public/---ed_emp/---ifp_skills/documents/publication/wcms_166822.pdf.

IMT (Institute for Market Transformation). 2015. *High-Performance Buildings and Property Value: A Primer for Lenders*. Washington DC: IMT. www.imt.org/wp-content/uploads/2018/02/LenderGuide_FINAL.pdf.

Jackson, C., D. Avery, and M. Ouellette. 2012. "California's Advanced Lighting Controls Training Program: Building a Skilled Workforce in the Energy Efficiency Market." In *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 173–83. www.aceee.org/files/proceedings/2012/data/papers/0193-000331.pdf#page=1.

Johnson Controls and Booz Allen Hamilton. 2017. *Cybersmart Buildings: Securing Your Investments in Connectivity and Automation*. Milwaukee: Johnson Controls. McLean, VA: Booz Allen Hamilton. www.johnsoncontrols.com/-/media/jci/be/united-states/specialty-pages/files/be_wp_cybersmartbuildings.pdf.

Jovic, N., D. Segan, and C. Perry. 2018. "Smart-Building Strawman: Leveraging Data to Overcome Energy Savings Skepticism." In *Proceedings of the 2018 ACEEE Summer Study on Energy Efficiency in Buildings*. Washington, DC: ACEEE. www.aceee.org/files/proceedings/2018/index.html#/paper/event-data/p377.

Katipamula, S., and D. Rice. 2012. "Transforming Building Operation and Maintenance Practices through Interactive Building Re-Tuning e-Learning." In *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 199–210. Washington, DC: ACEEE. aceee.org/files/proceedings/2012/data/papers/0193-000312.pdf.

Koseleva, N., and G. Ropaite. 2017. "Big Data in Building Energy Efficiency: Understanding of Big Data and Main Challenges." *Procedia Engineering* 172: 544–9. doi.org/10.1016/j.proeng.2017.02.064.

LBNL (Lawrence Berkeley National Laboratory). 2020. "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse-Gas Emissions." cx.lbl.gov/definition.html.

Lee, E., L. Fernandes, B. Coffey, A. McNeil, R. Clear, T. Webster, F. Bauman, D. Dickerhoff, D. Heinzerling, and T. Hoyt. 2013. *A Post-Occupancy Monitored Evaluation of the Dimmable Lighting, Automated Shading, and Underfloor Air Distribution System in The New York Times Building*. Prepared by Berkeley Lab. Washington, DC: DOE. buildings.lbl.gov/sites/all/files/lbnl-6023e.pdf.

Lewis, A., D. Riley, and A. Elmualim. 2010. "Defining High Performance Buildings for Operations and Maintenance." *International Journal of Facility Management* 1 (2): 1–16. mail.seedengr.com/Defining%20High%20Performance%20Buildings%20for%20Operations%20and%20Maintenance.pdf.

MEEA (Midwest Energy Efficiency Alliance). 2017. "Commercial Building Operator Training." www.mwalliance.org/initiatives/training-education/commercial-training.

Messenger, M. 2008. *Strategic Plan to Reduce the Energy Impact of Air Conditioners*. Sacramento: CEC (California Energy Commission). docplayer.net/6285926-Staff-report-strategic-plan-to-reduce-the-energy-impact-of-air-conditioners-california-energy-commission-june-2008-cec-400-2008-010.html.

Meyer, R.A. 2012. "Forgoing the Fossils: "E-Houses" Serve as Energy Efficiency Learning Laboratories for Technical High School Students." In Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings 10: 226–237. Washington, DC: ACEEE. www.aceee.org/files/proceedings/2012/data/papers/0193-000311.pdf.

Mills, E. 2011. "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions in the United States." *Energy Efficiency* 4 (2): 145–73. doi.org/10.1007/s12053-011-9116-8.

Mowris, R., E. Jones, and R. Eshom. 2012. "Laboratory Measurements of HVAC Installation and Maintenance Faults." *ASHRAE Transactions* 118 (2): 165. go.gale.com/ps/anonymous?id=GALE%7CA311560277&sid=googleScholar&v=2.1&it=r&linkaccess=abs&issn=00012505&p=AONE&sw=w.

Mukhopadhyay, J., L. O'Toole, and G. Kalonde. 2019. *ASHRAE Research Project Report: RP-1650 Training Requirements for Sustainable High Performance Building Operations*. Atlanta: ASHRAE. www.techstreet.com/standards/rp-1650-training-requirements-for-sustainable-high-performance-building-operations?product_id=2101011.

Muldoon, R. 2019. "Building Operator Training in the Time of Climate Change." *Sallan Foundation Snapshot*, January 2. www.sallan.org/Snapshot/2019/01/building_operator_training_in_the_time_of_climate_change.php#.Xl2YtJNKhTZ.

Münch, M., F. Linhart, A. Borisuit, S. Jaeggi, and J. Scartezzini. 2012. "Effects of Prior Light Exposure on Early Evening Performance, Subjective Sleepiness, and Hormonal Secretion." *Behavioral Neuroscience* 126 (1): 196–203. doi.org/10.1037/a0026702.

NASEO (National Association of State Energy Officials) and EFI (Energy Futures Initiative). 2020. *2020 U.S. Energy and Employment Report Jobs.* Arlington, VA: NASEO. Washington DC: EFI. www.usenergyjobs.org/.

National Academies of Sciences, Engineering, and Medicine. 2016. *Promising Practices for Strengthening the Regional STEM Workforce Development Ecosystem*. Washington DC: The National Academies Press. doi.org/10.17226/21894.

NYSERDA (New York State Energy Research and Development Authority). 2018. *On-the-Job Training for Energy Efficiency and Clean Technology (PON 3982).* Albany, NY: NYSERDA. portal.nyserda.ny.gov/CORE_Solicitation_Detail_Page?SolicitationId=a0rt000000MdOBsAAN

Powell, J. 2017. "The Value of Commissioning." *Steven Winter Associates Blog*, February 9. www.swinter.com/party-walls/value-of-retro-commissioning/.

Robinson, B., M. Knowles, and J. Sun. 2010. "Training Engineers for Managing Intelligent HVAC Systems in Modern Office Buildings." In *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 183–8. Washington, DC: ACEEE. aceee.org/files/proceedings/2010/data/papers/2244.pdf.

Shoemaker, M., and D. Ribeiro. 2018. *Through the Local Government Lens: Developing the Energy Efficiency Workforce.* Washington, DC: ACEEE. www.naesco.org/data/industryreports/ACEEE%20%20EE%20Workforce%20June%202018.pdf.

Stern, B. 2019. *Addressing the Workforce Skills Gap in Construction and CRE-Related Trades*. Herndon, VA: NAIOP (Commercial Real Estate Development Association) Research Foundation. www.naiop.org/en/Research-and-Publications/Reports/Addressing-the-Workforce-Skills-Gap-in-Construction-and-CRE-related-Trades.

Stever, R. 2018. "Building the Next Generation." *Building a Next Generation Workforce for Next Generation Buildings*. Washington, DC: DOE. betterbuildingssolutioncenter.energy.gov/sites/default/files/Building_a_Next_Generation_Worforce.pdf.

Thayer, B. 1995. "Daylighting & Productivity at Lockheed." *Solar Today* 9: 3. www.osti.gov/biblio/258772-daylighting-productivity-lockheed.

The Electrical Alliance. 2011. "Washington, D.C. JATC Announces New Building Automation Class." Lanham, MD: The Electrical alliance - Washington DC Chapter NECA and Local 26 IBEW. www.electricalalliance.org/press-releases/washington-d-c-jatc-announces-new-building-automation-class/.

Trombley, D., J. Amann, and K. Kissock. 2010. "How Building Assessment Centers Can Leverage the Success of the Industrial Assessment Centers to Train the Next Generation of Efficiency Experts." In *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 228–36. Washington, DC: ACEEE. aceee.org/files/proceedings/2010/data/papers/2256.pdf.

Valencia College. 2020. "Future Students: Energy Management and Controls Technology." net1.valenciacollege.edu/future-students/degree-options/associates/energy-management-and-controls-technology/.

WGBC (World Green Building Council). 2013. *The Business Case for Green Building: A Review of the Costs and Benefits for Developers, Investors and Occupants.* London: WGBC. www.worldgbc.org/sites/default/files/Business_Case_For_Green_Building_Report_WEB_2013-04-11-2.pdf.

Williams, A., B. Atkinson, K. Garbesi, F. Rubinstein, and E. Page. 2011. *A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings.* Prepared by Berkeley Lab. Washington, DC: DOE. efficiency.lbl.gov/sites/all/files/a_meta-analysis_of_energy_savings_from_lighting_controls_in_commercial_buildings_lbnl-5095e.pdf.

Zabin, C., J. Halpern-Finnerty, M. Scott, B. Jones, R. Walther, C. Estolano, A. Paxton, C. Guzman, L. Collins, A. Richards, and P. Simon. 2014. *Workforce Issues and Energy Efficiency Programs: A Plan for California Utilities.* Berkeley: Donald Vial Center on Employment in the Green Economy, University of California. aborcenter.berkeley.edu/workforce-issues-and-energy-efficiency-programs-a-plan-for-californias-utilities/.

Zhai, Z., and A. Salazar. 2020. "Assessing the Implications of Submetering with Energy Analytics to Building Energy Savings." *Energy and Built Environment* 1 (1): 27–35. doi.org/10.1016/j.enbenv.2019.08.002.

Appendix A. High-Performance Buildings Workforce Skills Survey

1) Which of the following categories best describes you?

☐ Building owner or manager (developer, property manager, facility manager)

☐ Building operator, tradesperson, or technician (operating engineer, electrician, HVAC engineer, plumber)

☐ Service provider (ESCO, manufacturer, building service firm)

(2) Are you directly involved with the daily management or operation of your building(s)?

☐ Yes

☐ No

3) Which of these categories best describes your job profile?

☐ Work directly for a building manager in one building

☐ Work directly for a building manager in multiple buildings

☐ Work for a service contractor

4) How many years of total experience do you have in the commercial building industry (all jobs)?

☐ 5 years or less

☐ 6 – 10 years

☐ 11 – 15 years

☐ 16 – 20 years

☐ More than 20 years

5) Select the category(ies) that best describes the type of building(s) you are responsible for.

☐ Offices

☐ University campus

☐ K-12 school

☐ Hospitals

☐ Retail

☐ Hotel/Lodging

Other - Write In (Required): _____*

6) Select the category(ies) that best describes the type of building(s) you provide service(s) for.

☐Offices

☐University campus

☐K-12 school

☐Hospitals

☐Retail

☐Hotel/Lodging

Other - Write In (Required): _____*

7) What type of formal education did you complete? (Select all that apply)

☐High school

☐Apprenticeship program (please specify): _____

☐Certification program (please specify): _____

☐Community or technical college

☐4-year college or university

☐I had no formal education

Other - Write In (Required): _____*

8) In what specific degree and program?

Degree (Bachelors, Associate, etc.):

Program (Architecture, Electrical Engineering, etc.):

9) What skills are needed for the effective operation of a high-performance building? (Select all that apply)

Technical Skills

☐Systems design and performance modeling

☐Systems integration (programming, automation, and interoperability)

☐Operations and maintenance

☐Systems testing and evaluation (performance evaluation, measurement, and verification)

☐Data acquisition and analysis (analyses and interpretation)

Other - Write In:

Non-technical Skills

☐Leadership

☐Communication

☐Teamwork

☐Critical thinking/problem-solving

Other - Write In:

10) When thinking about the skills required for effective operation of a high-performance building, how trained are the people operating and maintaining your building? *(please provide assessment across the trades involved, including contractors)

☐Untrained, require on the job training

☐Very poorly trained

☐Poorly trained

☐Adequately trained

☐Well trained

☐Very well-trained, have skills beyond current job duties

11) When thinking about the skills required for effective operation of a high-performance building, how trained are the people operating and maintaining the building you are responsible for? *(please provide assessment across the trades involved including contractors)

☐Untrained, require on-the-job training

☐Very poorly trained

☐Poorly trained

☐Adequately trained

☐Well trained

☐Very well-trained, have skills beyond current job duties

12) When thinking about the skills required for effective operation of a high-performance building, how trained are your employees in operating and maintaining your client's building(s)? (please provide assessment across the trades including contractors)

☐Untrained, require on the job training

☐Very poorly trained

☐Poorly trained

☐Adequately trained

☐Well trained

☐Very well-trained, have skills beyond current job duties

13) When thinking about the skills required for effective operation of a high-performance building, how trained are the onsite O&M staff(s) you interact with in operating

and maintaining your client's building(s)? (please provide assessment across the trades involved)

☐Untrained, require on the job training

☐Very poorly trained

☐Poorly trained

☐Adequately trained

☐Well trained

☐Very well-trained, have skills beyond current job duties

14) Please rate the people operating and maintaining your building on the following building systems design and performance modeling skills

	Highly inadequate	Inadequate	Neutral	Adequate	Highly adequate
Be familiar with codes and regulations	( )	( )	( )	( )	( )
Understand advanced building systems	( )	( )	( )	( )	( )
Use modeling and simulation software	( )	( )	( )	( )	( )
Know advanced system assemblies	( )	( )	( )	( )	( )

15) Please rate the people operating and maintaining your building on the following building systems integration (programming, automation, and interoperability) skills.

	Highly inadequate	Inadequate	Neutral	Adequate	Highly adequate
Select and install advanced equipment	( )	( )	( )	( )	( )

Select and install building automation systems (BAS)	( )	( )	( )	( )	( )
Program controls (i.e., control logic for BAS, night setback)	( )	( )	( )	( )	( )
Integrate and manage smart technology and controls	( )	( )	( )	( )	( )
Ensure cyber-security	( )	( )	( )	( )	( )

16) Please rate the people operating and maintaining your building on the following building operation and maintenance skills.

	Highly inadequate	**Inadequate**	**Neutral**	**Adequate**	**Highly adequate**
Operate and maintain equipment, controls, and BAS	( )	( )	( )	( )	( )
Perform diagnostics & corrective procedures	( )	( )	( )	( )	( )
Optimize building systems	( )	( )	( )	( )	( )
Use cost benefit analysis to refine efficiency decisions	( )	( )	( )	( )	( )

17) Please rate the people operating and maintaining your building on the following building system testing and evaluation (performance evaluation, measurement, and verification) skills.

	Highly inadequate	Inadequate	Neutral	Adequate	Highly adequate
Do energy audits	( )	( )	( )	( )	( )
Set benchmarks	( )	( )	( )	( )	( )
Perform commissioning	( )	( )	( )	( )	( )
Perform retro-commissioning	( )	( )	( )	( )	( )

18) Please rate the people operating and maintaining your building on the following building data acquisition and analysis skills.

	Highly inadequate	Inadequate	Neutral	Adequate	Highly adequate
Install sensors and meters	( )	( )	( )	( )	( )
Monitor & measure system performance	( )	( )	( )	( )	( )
Analyze data	( )	( )	( )	( )	( )
Interpret and use data analyses	( )	( )	( )	( )	( )

19) What other technical skill(s), if any, does the current workforce lack in the operation and maintenance of high-performance buildings?

20) What is/are the most common reason(s) for any skill(s) gap? (Select all that apply)

☐ Lack of qualification (e.g., education or certification)

☐ Insufficient technical skills

☐ Lack of field experience

☐ Insufficient non-technical skills (e.g., leadership, critical thinking)

☐ Competition with other industries for talent

☐Lack of interest in trades from qualified candidates

Other - Write In (Required): *

21) How do any skills gaps identified above impact the operation and maintenance of high-performance buildings? (Select all that apply)

☐Unnecessarily high energy use and bills

☐Failure to meet energy efficiency or other sustainability/green goals

☐Increased occupant discomfort or other complaints

☐Poor indoor environmental quality

☐Slower rate of adoption of new technology

☐Increased work load for other staff

Other - Write In (Required): *

22) For people lacking some or all the necessary skills needed for the operation and maintenance of high-performance buildings, how would you suggest improving their skills? (Select all that apply)

☐Apprenticeship programs (please specify): _____

☐Certification programs (please specify): _____

☐Community colleges/Trade schools' programs (please specify): _____

☐External training (please specify): _____

☐High school programs (please specify): _____

☐In-house training

☐Learning on the job/in the field

☐Attend professional networking events

Other - Write In (Required):

23) What career skills, if any, are you looking to enhance in the future?

24) How old are you?

☐18-25 years

☐26-35 years

☐36-50 years

☐51 years or above

25) What is your gender?

☐Female

☐Male

☐Other

26) Any additional comments or feedback?

27) Could we contact you for a more in-depth interview? If yes, please provide your contact information:

Email address:

Contact:

Thank You!