ENERGY PERFORMANCE OF CAMPUS LEED® BUILDINGS: IMPLICATIONS FOR GREEN BUILDING AND ENERGY POLICY

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ABSTRACT

Many university campuses in the United States are working toward their sustainable goals by adopting energy or green building policies, which require Leadership in Energy and Environmental Design (LEED®) certification for new construction and major renovation projects. Because LEED certification heavily relies on whole building energy simulation to demonstrate building energy performance improvement, it is often assumed that the finished buildings will achieve the predicted level of energy efficiency. This paper presents a study that compares the energy model predictions with actual energy performance of three LEED buildings on a university campus. The study shows that one of the campus LEED buildings consumed twice the predicted energy usage while causing a high level of occupant dissatisfaction. Further investigation reveals a variety of contributing factors for these issues and provides insights to improve green building policy and practice. Not only are the research findings important for this particular campus (Ohio State University) on its way to sustainability, they also have widespread ramifications for other university campuses.

KEYWORDS

green buildings, energy modeling, energy efficiency, LEED, policy, university campus

INTRODUCTION

Large research university campuses usually consist of many energy intensive buildings and result in substantial environmental impacts. For example, the Columbus campus of the Ohio State University (Ohio State) serves nearly 60,000 students and more than 30,000 employees. With over 400 university buildings (approximately 24 million square feet) and large research expenditures, the campus consumed 4,998.87 billion British thermal units (Btu) of purchased energy in the fiscal year (FY) 2010, equivalent to 1.47 billion kilowatt-hours (kWh) of

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electricity (Ohio State Facilities Operations and Development [FOD] 2013). Also, at many U.S. universities, building-level energy metering does not exist and adding meters can be cost-prohibitive (e.g., the material cost for a steam meter alone could be over $50,000). Without metering individual buildings, anomalies in building energy use may go unnoticed. Furthermore, many campuses often do not intend to charge building users, usually individual units or academic departments, directly based on their energy use. This results in no or very little financial incentive for these units or departments to save energy. To reduce university campuses' energy use and environmental impacts, it is crucial for university leaders to consider investing in energy efficient building technologies. The establishment of proper university policy and oversight is also important to ensure that energy efficient buildings are designed and constructed properly and operated efficiently to reduce energy costs and carbon emissions.

The emergence of the Leadership in Energy and Environmental Design (LEED®) program from the U.S. Green Building Council (USGBC) has offered building professionals and owners a "nationally accepted benchmark for the design, construction, and operation of high-performance green buildings" (USGBC 2013). With the increasing popularity of LEED, some government departments/agencies such as the U.S. Department of Defense, municipalities (Chicago, New York City, etc.), and organizations have mandated it for their building development (Mazurkiewicz 2004; The National Academies 2013; Simcoe and Toffel 2014). While many universities are racing to invest in LEED to improve their energy and environmental sustainability, the current gap remains in verifying the actual energy performance of such LEED buildings constructed on campuses since pursuing the Measurement and Verification LEED point is not mandatory by LEED. Also, there often lacks a good understanding about the relationship between the additional cost of LEED and life cycle savings to the building owner.

The purpose of this study is three-fold: 1) to report the whole-building energy performance of three LEED buildings on a university campus at their post-occupancy stages, 2) to study the contributing factors in campus LEED building development and operations that could affect a building's energy use or other performances, and 3) to provide valuable insights into how universities could be effectively involved in and develop better policies/procedures to guide the LEED green building development and operations and ensure the energy efficiency of occupied LEED buildings. After identifying a poorly performing building through the whole-building energy assessment, this study adopted a qualitative research approach (i.e., interviews and focus group studies) to exploring the breadth of contributing factors and how these problems could be potentially addressed by improvements to green building and energy policy.

BACKGROUND AND LITERATURE REVIEW

Importance of Green Buildings and LEED

Buildings account for 39% of total U.S. energy use and 38% of carbon dioxide emissions (U.S. Department of Energy 2008). To protect our environment and national energy security, it is critical to reduce buildings' energy consumption and environmental impacts through sustainable design and construction. In response to this need, the contemporary green building movement has become mainstream industry practice (U.S. Environmental Protection Agency 2012). However, developing a green building, also known as a sustainable or high performance building, is not an easy task. An integrated design approach is necessary (USGBC

2005), and simply combining various existing green technologies will not automatically lead to a high performance building. To fill this knowledge gap and provide a practical guideline for green building practice, various green building assessment programs (e.g., LEED, Green Globes, and BREEAM) have been generated and implemented in recent years. In the U.S., LEED is the predominant building assessment tool (Kibert 2008).

USGBC has developed different LEED rating systems for different types of building projects. The Version 3 (V3) of LEED contains nine rating systems such as the LEED for New Construction (LEED-NC), LEED for Existing Buildings (LEED-EB), and LEED for Commercial Interiors (LEED-CI). Each rating system is a point based credit system consisting of multiple sustainable categories with specific predetermined criteria. For example, the LEED-NC rating system is a 110-point system with seven categories, including Sustainable Sites, Water Efficiency, Energy & Atmosphere, etc. Each category contains multiple LEED credits with associated points. Based on the number of points a project earns, four levels of certification, namely Certified, Silver, Gold, and Platinum, can be awarded.

As LEED has been widely adopted for guiding current green building practice, some issues related to the rating systems and their implementation arise, such as LEED being a price barrier, too focused on points (termed as "LEED brain"), the complexity of energy modeling, and misleading claims of green building benefits (Udall and Schendler 2005). Denzer and Hedges (2011) also noted that neutral and negative points are not accounted for in the system, which can foster a LEED points game versus achieving the ultimate goal of a green building. Similarly, an insightful recent publication (Lewis 2012) requested that project teams develop an end goal for each building versus LEED Silver, Gold or Platinum, making the interesting point that LEED should be the roadmap, not the destination.

LEED was also criticized for allowing a low energy performance level for certification (e.g., a building can earn LEED certification even without earning any Optimize Energy Performance point) and having a low transparency about the actual energy use of those certified buildings (Murphy 2009). On behalf of USGBC, the New Buildings Institute (NBI) (2008) once requested one full year of measured post-occupancy energy usage data from all the LEED projects that received certification by December 2006. Only 121 (22%) of 552 buildings were included in the energy performance analysis by having monthly whole-building energy usage data and basic building information provided. A follow-up study based on the NBI data confirmed that 28-35% of these surveyed LEED buildings actually used more energy than conventional buildings (Newsham et al. 2009). Furthermore, inadequacies existed in techniques for evaluating and comparing LEED buildings. For example, the definition of Energy Use Intensity (EUI) is dependent on which organization is assessing it, and it is inconsistent whether site energy versus source energy is evaluated (Scofield 2009).

LEED Buildings and Related Policies on University Campuses

Since the inception of the American College and University Presidents' Climate Commitment (ACUPCC) in 2007, 685 schools have signed this pledge with an ultimate goal of a climate neutral campus. So far, 533 (78%) and 364 (53%) of them have submitted their climate action plans and progress reports, respectively (ACUPCC 2015). As discussed previously, the largest energy driver for a campus typically comes from the building infrastructure. This makes a system like LEED more attractive since the LEED framework provides a common language (or goal) as well as practical guidelines for multiple departments/contractors to work together in green building development. Also, the LEED program intuitively works well on a university campus as campus buildings are built with priority for long term investment. In such scenarios, the LEED certification fees, potentially increased capital costs, and/or other expenses such as LEED consulting costs could be paid off by these buildings' lifetime energy savings. Challenges may exist on campuses utilizing a central utility plant. The proximity of the new building to the central plant, i.e., on or not on the steam and chilled water loops, may influence the LEED energy points to be obtained. However, adopting a proper strategy in LEED building development, e.g., incorporating a geothermal heating and cooling system, may result in even higher energy savings.

To provide the structure and consistency for LEED building planning on larger campuses, USGBC further developed a roadmap, referred to as LEED for Neighborhood Development (LEED-ND) on Campuses (USGBC 2010a). Real-world examples have shown that this tool helped universities and colleges plan for the long term and provided benefits to site location decisions. For example, at the University of Washington, the campus planners combined LEED-ND criteria with their internal considerations to form a point system, which was used to evaluate the potential sites for the best location of the university's new North Sound campus (USGBC 2010a). Some other campuses found that the Application Guide for Multiple Buildings and On-Campus Building Projects provided by USGBC fits their needs better (USGBC 2010b).

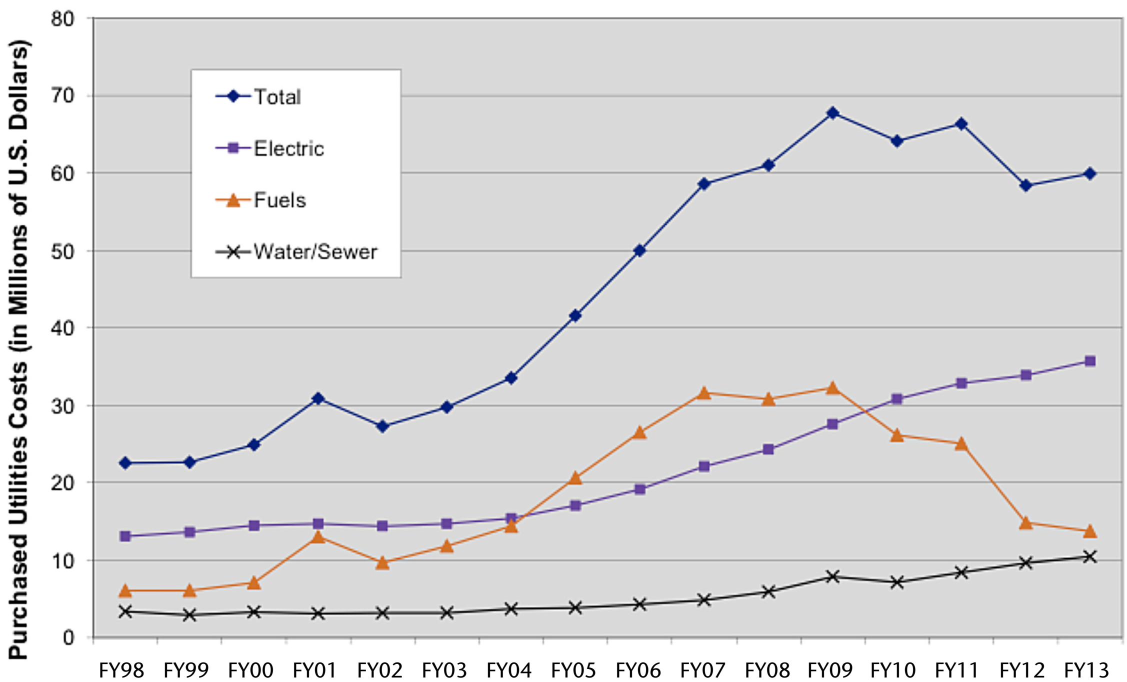
Dougherty (2010) revealed that the annual number of LEED registrations and certifications had sharply increased on campuses from only 200 in 2004 to almost 1,400 in 2009. In other countries such as Australia, green buildings also became popular on university campuses due to various reasons, e.g., enhancing university reputation, meeting the specific needs for education and research, and improving financial conditions of universities (Li et al. 2013). In 2011, the USGBC Center for Green Schools recruited 35 university research teams through its Research to Practice (R2P) Program to study the performance of campus LEED buildings (The Center for Green Schools 2013). Some research findings including lessons learned and new recommendations were generated through the Phase I & Phase II studies. For example, the analysis performed by Driza and Antonini (2013) at the University of Florida revealed a number of trends that impacted LEED building performance and could be improved to lower energy and water consumption as well as waste generation. One of useful measures proposed was to educate students about energy conservation efforts and provide continued incentives for participation.

Early studies indicated that university sustainability/green policies are important to determine the level of efforts a university will make in sustainable initiatives and to ensure the successful implementation of green projects (Wright 2002; Richardson and Lynes 2007). As reported by Dougherty (2010), 91% of 53 surveyed colleges had integrated a LEED certification requirement into their sustainability plan or policy. Harvard University seemed to be in the forefront of institutional LEED policies. Its Green Building Standards not only mandated LEED Gold certification, but also required project teams to use an integrated design approach and turn in closeout documentation including the energy model for future confirmation of energy savings. Cupido et al. (2010) evaluated university green building policies in North America and provided a useful template for policy development.

LEED Buildings on Ohio State Columbus Campus

Ohio State's main campus is located in Columbus, Ohio. A central physical plant provides steam, hot water, and chilled water to academic buildings located on the core of main campus. In the plant, diesel fuel, #2 fuel oil, gas, and electricity are used for boilers, chillers, emergency generators, etc. All the electricity used on campus is supplied by the American Electric Power (FOD 2012). Fig. 1 illustrates the total utilities costs of the main campus for the past 16 years (FY1998-2013). It can be seen that the purchased utilities costs increased rapidly in earlier years and reached the peak at US$67.7 million in FY2009. The costs then became steady or dropped slightly for the last four years due to the implementation of building energy-related sustainability initiatives, including LEED building development, energy audits, and energy retrofits for existing buildings.

Figure 1: Ohio State main campus purchased utilities costs for FY1998-2013 (Source: FOD).



In December 2008, Ohio State issued the Interim Green Build and Energy Policy #3.10 to comply with Ohio House Bill 251, which required the university to reduce its building energy consumption by at least 20% by 2014, using 2004 as the baseline (Ohio State Office of Business and Finance 2008). The interim policy was an 11-page document consisting of two parts: Policy and Procedure. The two-page Policy part was written concisely to cover the objective and policy statement, similar to what was included in the proposed institutional green building policy template by Cupido et al. (2010). However, unlike many previously studied policies, Ohio State's interim policy also included a nine-page Procedure portion to provide detailed information about green building and university design standards, energy efficiency and conservation guidelines, and metrics. Under the Standards subsection, obtaining LEED Silver or higher certification was required for all new construction and major renovation projects equal to or greater than $4 million. In the policy, the following were named as mandatory LEED credits among those that can be pursued under the LEED-NC rating system:

- Optimize energy performance (2 and 4 points for new and renovation projects, respectively);
- Enhanced commissioning;

- Enhanced refrigerant management;
- Low-emitting materials;
- Indoor chemical and pollutant source control; and
- Thermal comfort: design.

This policy became official in November 2011, with an added appendix titled "The Ohio State University Sustainability Programs & Guidelines," which provided tools and resources for university staff, external consultants, and project teams to reference when addressing the policy. The latest revision of the policy was made in August, 2012 to include additional subsections under the Procedure portion, such as Responsibilities and Resources (Ohio State Office of Administration and Planning 2012).

As early as November 2007 before the energy policy was developed, the new 4-H Center, built on undeveloped land, became the first LEED Certified building on Ohio State's Columbus campus. The building features a closed-loop geothermal heating and cooling system, water efficient plumbing fixtures, occupancy-based lighting control, and recycled or environmentally-friendly building materials. In the following years, two new construction projects, the Ohio Union building and the Student Academic Services (SAS) building were constructed and completed in 2010 to replace the demolished old facilities. Both buildings had earned LEED Silver certification. The renovated Kenny Commons Residence Hall and Cunz Hall buildings (both opened in fall 2011) also received the LEED Silver rating in 2012 and 2013, respectively.

While several existing LEED campus buildings have been in use for a number of years and a couple of other buildings (e.g., the $1 Billion Wexner Medical Center Project) are going through their construction and LEED certification processes, it is possible and also necessary to examine the energy performance of the built LEED facilities for the following two reasons:

- LEED buildings are closely related to the university's sustainability goals and its compliance with the state law(s). It is important to understand whether these buildings perform as expected in energy efficiency and environmental impact. It is also necessary to know whether the buildings meet occupants' thermal comfort and health requirements.
- This assessment could further the university community's knowledge and understanding of green building. The best practices and lessons learned from past LEED projects will be extremely helpful for guiding current and future green building practices on campus.

Research Methods

This study investigated three LEED buildings on the Ohio State campus: the 4-H Center, the Ohio Union building, and the SAS building. The researchers first examined these buildings' LEED scorecards (V2.1/2.2) with a focus on the points achieved under the LEED categories of Energy & Atmosphere and Indoor Environmental Quality as well as other credits that had a relationship with building energy use and human comfort. As emphasized by Wang et al. (2012), achieving energy efficiency should not compromise the performance of the building.

The researchers requested the energy simulation data from corresponding engineering firms to determine these buildings' expected energy efficiency levels. For each building, predictions of annual building energy consumption were provided. The simulation results were listed separately for the Baseline Design (baseline energy use) and the Proposed Design (predicted energy use) cases, which had been used by the engineering firms to demonstrate a percentage improvement in energy costs for LEED certification. Since different versions of LEED-NC rating system were used for these projects, energy modeling for the 4-H Center and Ohio Union (certified under V2.1) complied with the Energy Cost Budget Method in Section 11 of ASHRAE/IESNA Standard 90.1-1999 (without amendments) while the Building Performance Rating Method in Appendix G of ASHRAE/IESNA Standard 90.1-2004 was used to model the SAS building (certified under V2.2). As defined in Appendix G, the energy model for the Proposed Design is "a computer representation of the actual proposed building design or portion thereof used as the basis for calculating the design energy cost." The model is then used as the basis to create the Baseline Design, which is a hypothetical design based on the proposed building but with modified component performance values to meet the applicable mandatory and prescriptive requirements of the Standard.

As per the researchers' request, FOD provided the actual energy use data for these three buildings for FY2011-2013 (July 2010 - June 2013 as defined by the university). These were monthly consumption data for each type of site energy used in these buildings. Since none of the buildings installed energy submeters to provide more spatially resolved measurements, actual energy uses in individual areas, systems, or equipment were not available. In response to the limitations in data collection, this study used a whole-building assessment rather than multi-level assessment (Wang et al. 2012) to evaluate the overall building energy performance through comparing these buildings' energy consumption with the simulated results and reference benchmarks. The purpose was to determine if the buildings achieved their designed energy efficiency and how they perform when compared to market buildings of similar types.

During the course of research, the SAS building was found to have its actual energy consumption doubling its predicted energy use in the Proposed Design model. It is also a main office building without instructional spaces and research laboratories to complicate the energy performance analysis and interpretation. Furthermore, the building has regular operating hours and relatively consistent occupancy rates. As a result, it was selected for further investigation to understand what caused its deviation from the predicted energy use level and how the identified problems could be improved in future LEED building development and operations. Considering the breadth of contributing factors that could affect a building's energy performance, qualitative research methods (i.e., face-to-face interviews and focus group studies) were used. Particularly, the researchers interviewed the mechanical engineering firm to gain a better understanding about the simulation data. Internal interviews with the building coordinator and the building automation engineer as well as focus group studies among occupants and operations and maintenance (O&M) staff were conducted to learn about how this building performed from a user's perspective and how it was operated and maintained.

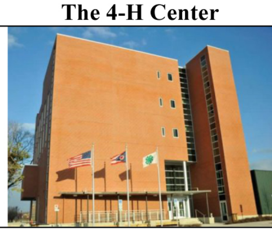
The procedures in Bedford and Burgess (2001) were adopted to perform focus group studies. The snowballing method was used to recruit participants. Specifically, one contact for each focus group was made first. This person then used his/her personal contacts to recruit other members. The recruitment was not publicly done as per the request of the building coordinator, who had received multiple thermal comfort complains from occupants in the SAS building and did not want to cause further anxiety. To help protect the anonymity of the participants, the researchers assigned a number to each of them and notes were taken under their participant number. Each focus group study took approximately one and half an hours and was held in a private conference room to limit distractions and provide confidentiality. Two specific questionnaires (see Appendices B and C) were developed to guide the discussions of these two focus groups, respectively. All the results are presented in the following section.

RESULTS AND DISCUSSION

Demographic Building Information

As mentioned above, three campus LEED buildings were selected for this research. Table 1 lists their demographic information. It can be seen that the 4-H Center and the Ohio Union building are for mixed use while the SAS building is an office building with regular operating hours. The heating, ventilation, and air conditioning (HVAC) systems in these three buildings are run in a similar manner: on schedule according to building hours, same thermostat set points, and temperature setbacks during night and/or weekend, except that the 4-H Center also allows daytime temperature setback for unoccupied meeting spaces. In addition, the site energy sources for heating and cooling as well as related HVAC equipment are different for these buildings based on their accessibility to steam and chilled water campus loops.

Table 1: Demographic Information of the Three LEED Buildings Studied.

Building information	The 4-H Center	The Ohio Union Building	The SAS Building
Image of the building			
Type of building	Mixed use: conference and office spaces	Mixed use: conference, dining, office, and student spaces	Office building
Number of stories	4	3	6
Basement (Yes or No)	Yes	Yes	Yes
Gross floor area (sf)	45,190	338,407	138,095
Time of completion	November 2007	March 2010	April 2010
Certification awarded	December 2008	July 2010	May 2011
Hours of operation	8:00am – 5:00pm on Monday through Friday and closed on weekend (open in early morning, late evening, and weekend for events	7:00am – 12:00am on Monday through Friday, 9:00am – 1:00am on Saturday, and 10:00am – 12:00am on Sunday	8:00am – 5:00pm on Monday through Friday and closed on weekend
Heating and cooling equipment	Geothermal heat pumps	Variable air volume (VAV) with reheat served by the campus steam and chillers	VAV with reheat served by the campus steam and chilled water
HVAC system operation pattern	On schedule but allow daytime temperature setback for unoccupied meeting spaces	On schedule	On schedule
Thermostat set points	Deadband*: 71°F-73°F	Deadband: 71°F-73°F	Deadband: 71°F-73°F
Temperature setbacks	60°F (heating) and 80°F (cooling) during night and weekend	60°F (heating) and 80°F (cooling) during night	60°F (heating) and 80°F (cooling) during night and weekend

*Denotes a neutral zone when neither heating nor cooling occurs.

LEED Scorecard Comparison

The LEED scorecards for these three buildings were compared for consistencies and differences. As shown in Appendix A, the LEED planners had chosen many of the same LEED credits for these buildings, like public transportation access and bicycle storage and changing rooms, water efficient features, recycled and regional materials, etc. This consistency not only benefited the LEED certification process, but also facilitated project procurement, construction management, and achievement of university-wide goals. While the three buildings all had fundamental commissioning performed as it is one of the LEED prerequisites, the Ohio Union and SAS buildings also obtained additional commissioning credit as mandated in the green building policy. Another main difference was that the 4-H Center intended to achieve 25% energy cost savings than the other two buildings that aimed for 20%. This might be attributed to the geothermal heating and cooling system installed in the 4-H Center. Also, the SAS building had not obtained any points for thermal comfort, whereas the other two buildings had.

Whole-Building Assessment: Comparison of Modeled and Actual Energy Use

The comparison of modeled and actual energy consumption was based on site EUI. The EUI is expressed as energy per square foot per year (kBtu/sf/yr) and calculated by dividing the total energy used by the building in one year by the gross floor area of the building. To calculate the total energy use, all types of site energy need to be counted and expressed in Btus. Since they were measured in different units, conversion equations were acquired from FOD and displayed in Table 2. Note that the conversion equations for chilled water and steam were calculated by the FOD personnel based on their measurements on the amounts of chilled water and steam produced and the associated energy use in the central plant.

Table 2: Conversion equations used in the EUI calculation.

Energy type	Unit used in measurement	Conversion equation
Electricity	kWh	1 kWh = 3,412 Btu
Natural gas	Cubic foot	1 cubic foot of gas = 1,027 Btu
Chilled water	Ton-hour	1 ton-hour = 0.9 kWh or 3,071 Btu
Steam	Pound	1 pound of steam = 1,390 Btu

Table 3: 4-H Center Comparison: Predicted versus Actual Energy Use (FY2011-2013).

Energy consumption item	The baseline energy use	Predicted energy use	Actual energy use			
			FY2011	FY2012	FY2013	Average
Electricity (million Btu [mBtu])	n/a	2,095.00	1,327.15	1,241.22	1,533.53	1367.30
Total (mBtu)	n/a	2,095.00	1,327.15	1,241.22	1,533.53	1367.30
EUI (kBtu/sf/yr)	n/a	46.36	29.37	27.47	33.93	30.26

The first comparison was made for the 4-H Center. As shown in Table 3, the building's actual annual energy use in the three FYs was consistently lower (i.e., by 34.7% on average) than the predicted energy use. However, the building was mainly used for university extension programs and external events. Except for general public and office spaces, the utilization rates and occupancy levels for the meeting rooms and conference spaces varied during the year. Based on the estimate from the building coordinator, such spaces were occupied by 30–40% of time; when unoccupied, they were operated on setback temperatures, leading to some energy savings. By taking all the factors into consideration, the researchers estimated that the 4-H Center, if not much more energy efficient than prediction, at least meets the expected energy efficiency level. It was noted that the engineering firm performing the simulation did not establish the baseline energy use.

The researchers also learned that there were issues with the geothermal system not being properly integrated into the 4-H Center's building automation system (BAS) during the first two years of occupancy. This was due to the lack of compatibility between the BAS provided by the KMC Controls and the Johnson controllers used for the geothermal heat pump system. Since the building was operated by the control manufacturer who wanted to maintain the building's energy efficiency level under the two-year warranty, this problem went unnoticed by the university until the third year. The malfunction was finally fixed by replacing the entire control system with products from Delta Controls at the cost of the university. This correction increased the building's energy use by 15.5-19.0% but solved some building performance problems.

Table 4 displays the comparison results for the Ohio Union building. The building consumed on average 161.15 kBtu/sf/yr for the three years, close to the baseline energy use of 166.24 kBtu/sf/yr but 22.5% higher than the predicted energy use of 131.58 kBtu/sf/yr. Note that in the EUI calculation, the gas used for the two restaurants and kitchens in the building was not included since both the Baseline and the Proposed Design models did not consider this end-use either. This research did not pick this building for further investigation due to two reasons. First, although the building seemed not to reach the expected energy efficiency level, this inference could not be verified without knowing all the major modeling parameters and detailed building operation and usage information. In reality, the building was used for various student activities and the occupancy levels associated with different functional spaces were fluctuated and not tracked during building operation to provide needed information for further analysis. Second, even if the gap in energy performance did exist, it could be moderate or small and the potential problems might be harder to identify.

Table 4: Ohio Union Building Comparison: Predicted versus Actual Energy Use (FY2011-2013).

Energy consumption item	The baseline energy use	Predicted energy use	Actual energy use			
			FY2011	FY2012	FY2013	Average
Electricity (mBtu)	29,595.70	28,613.90	11,598.42	24,624.71	22,484.87	19,569.33
Purchased steam (mBtu)	26,661.60	15,913.20	39,110.15	34,648.39	31,135.03	34,964.52
Total (mBtu)	56,257.30	44,527.10	50,708.57	59,273.10	53,619.90	54,533.86
EUI (**kBtu/sf/yr)**	166.24	131.58	149.84	175.15	158.45	161.15

The last set of energy performance data examined was for the SAS building. As shown in Table 5, SAS was predicted to consume 67.78 kBtu/sf/yr, a 22.9% reduction when compared to the baseline energy use. However, its actual performance was vastly different at a consumption level of 135.76 kBtu/sf/yr on average in the three years. In essence, the SAS building consumed 100.3% more energy than predicted. As explained in the Research Methods section, this building was considered the most ideal case for a further study to identify problematic areas in energy-related building development and operations. A thorough investigation is presented later.

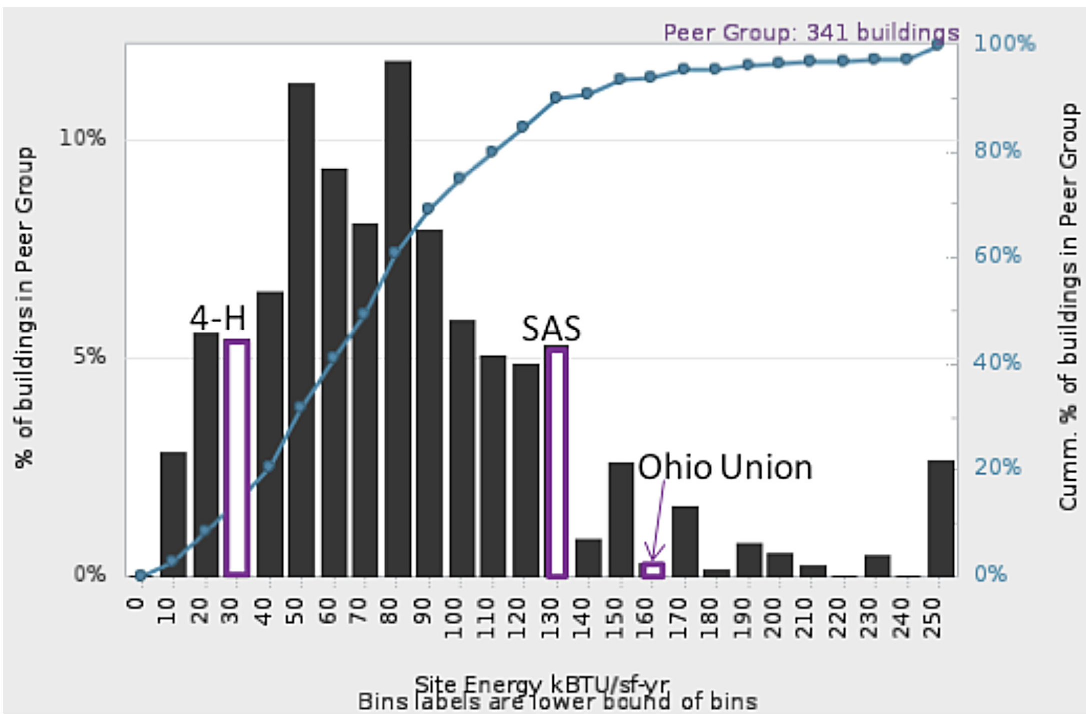
Table 5: SAS Building Comparison: Predicted versus Actual Energy Use (FY2011-2013).

Energy consumption item	The baseline energy use	Predicted energy use	Actual energy use			
			FY2011	FY2012	FY2013	Average
Electricity (mBtu)	8,432.60	7,309.10	7,371.06	7,178.11	6,561.35	7,036.84
Purchased steam (mBtu)	209.10	209.10	11,739.16	8,555.52	9,703.08	9,999.25
Gas (mBtu)	3,497.50	1,841.30	-	-	-	-
Chilled Water (mBtu)	-	-	1,573.94	1,706.36	1,854.18	1,711.49
Total (mBtu)	12,139.20	9,359.50	20,684.16	17,439.99	18,118.61	18,747.59
EUI (kBtu/sf/yr)	87.90	67.78	149.78	126.29	131.20	135.76

Benchmarking

The Commercial Buildings Energy Consumption Survey (CBECS) is a national survey that records the energy consumption and expenditures data on commercial buildings. To better understand the energy performance level of the three studied buildings, this research compared their EUI with a peer group of 341 buildings in 2003 CBECS. The selected peer group included all the school buildings, office buildings, and buildings used for social/meeting in Climate Zone 2 (a cold climate with 5,500-7,000 heating degree-days and less than 2,000 cooling degree-days) where Columbus, Ohio was assigned in the survey. As shown in Fig. 2, the 4-H Center, Ohio Union, and SAS fall into the 14th, 93rd, and 90th percentiles, respectively; i.e., the EUIs of these three buildings are higher than 14%, 93%, and 90% of comparison buildings, respectively.

Figure 2: Benchmarking with 2003 CBECS (Performed using EnergyIQ developed by the Lawrence Berkeley National Laboratory).



Additional benchmarking was performed to compare SAS with a peer group of 183 office buildings in 2003 CBECS. The SAS building falls into the 92nd percentile and its EUI is 72.1% higher than the group's median value, 78.9 kBtu/sf/yr, showing very poor energy performance. The researchers also attempted to compare this building with a similar non-LEED campus office building to determine whether the poor energy performance of SAS is symptomatic of a larger operational issue on campus. It was found that SAS was the only individually metered office building on campus at the time of this study; the closest comparison would be the Parks Hall, a metered building that houses the College of Medicine. Parks Hall comprises mainly offices, classrooms, and a few lab spaces (including both computer and research laboratories). Its size, 95,000 square feet, is comparable to the SAS building. Further, there is a similar mix of energy types used for Parks Hall. The analysis result showed that the EUI of the SAS building is only 14.5% lower than Parks, which had an EUI of 158.80 kBtu/sf/yr for FY2011. Considering that Parks Hall was constructed in 1962 without energy efficient design, contains energy-intensive laboratories, and does not implement night and weekend temperature setbacks, such a performance level seems reasonable, though far from the true energy efficiency.

It is important to point out although benchmarking is a useful tool to assess a building's energy efficiency, the interpretation can be complicated by other energy influencing variables, including operating hours, occupancy, behavior and maintenance factors, energy systems used, etc. (Monts and Blissett 1982; Chung et al. 2006). The investigation of such variables for the SAS building is presented in the following subsections.

Interview with the Engineering Firm

In addition to the problem that the actual energy use of SAS was significantly higher than the predicted, several other questions were generated after reviewing the energy simulation data in detail. These include:

- Why was the purchased steam consumption identical in the Baseline Design and Proposed Design cases? Why were these numbers so low compared to the actual usage?
- Why was gas included in the model but actually not utilized in the SAS building?
- Why did the model not include chilled water even though SAS did utilize it for cooling?

These questions led to an interview with a project engineer from the firm that designed the building's energy system and performed the energy simulation for LEED energy credit. It was found that the energy simulation models were created in Trane TRACE® 700, a professional energy and economic analysis program (Trane 2013). The interviewed project engineer provided researchers with major parameters and assumptions used in modeling (see Fig. 3), and pointed out that these variables, if different from reality, could throw the model off. The engineer also answered the questions researchers had in the following ways:

- The gas line item shows the amount of natural gas used to produce steam for space heating. An efficiency of 67% means that, whatever the quantity of natural gas (in kBtus) goes into the steam plant, 67% of that energy quantity will come out as steam.
- The purchased steam line item shows the amount of steam used for domestic hot water only, which remains the same for both the Baseline and Proposed Design cases. The gas used for domestic water heating can be calculated by dividing that number by 67%.
- The electricity line item in the model contains the building's electricity use in lighting, plug loads, fans, etc., as well as the energy associated with the chilled water production.

This information ensured the researchers that the initial EUI comparison presented in Table 5 was appropriate. Although the energy associated with the purchased steam (209.10 mBtu) needed to be converted back to gas (312.09 mBtu), the influence on total EUI was only about 1%. Also, the efficiencies of steam and chilled water production defined in modeling were reasonably consistent with the measurement results provided by FOD. After verifying the modeling results, researchers noted that the actual energy use associated with steam for space heating and hot water (9,999.25 mBtus, 53.3% of total energy use) was still

Figure 3: An illustration of modeling parameters and assumptions provided by the engineer.

- The facility is served by the OSU central steam and chilled water plants, which are modeled with an efficiency of 67% for steam and 0.893 kW/ton for chilled water production.
- The building setpoints are 75 in cooling and 72 in heating.
- The building setbacks are 78 in cooling and 69 in heating.
- Three variable air volume units with reheat boxes are served by the campus chilled water and steam.
- Wall insulation results in U-values of U-0.0437 and U-0.0506.
- The window characteristics are U-0.50, SC-0.43.
- The roof insulation results in a U-value of U-0.033.
- The whole building lighting power density average is 0.965 W/sf.
- The building schedule is as follows with the right column representing the percentage of the building that is occupied.

Jan-Dec Weekday		
Midnight	7 a.m.	0
7 a.m.	8 a.m.	50
8 a.m.	11 a.m.	100
11 a.m.	1 p.m.	80
1 p.m.	4 p.m.	100
4 p.m.	5 p.m.	50
5 p.m.	6 p.m.	20
6 p.m.	9 p.m.	5
9 p.m.	Midnight	0

Jan-Dec Weekday		
Midnight	8 a.m.	0
8 a.m.	4 p.m.	10
4 p.m.	Midnight	0

significantly higher than the Baseline (3,809.59 mBtus, 31.12% of total energy use) and Proposed Design (2,153.39 mBtus, 22.76% of total energy use). According to the 2011 Building Energy Data Book (U.S. Department of Energy, 2012), the site energy consumed in space and water heating accounts for an average of 33.3% of total energy use in commercial buildings. For the SAS building located in a cold climate, the end-use distribution of space and water heating in the model, especially for the Proposed Design (22.76%), was relatively low, suggesting potential inaccuracies in energy modeling, which could partially contribute to the big deviation.

When reviewing the building's actual operating parameters (setback temperatures, occupancy, etc.), researchers found that they were different from what were modeled. But their impacts on the total building energy use were not consistent. For example, the HVAC system operating on schedule not on occupancy could lead to higher energy use during the periods when the building's actual occupancy levels were low. However, the real setback temperatures (80°F in cooling and 60°F in heating) having a bigger range than what was modeled (78°F in cooling and 69°F in heating) actually saved some energy. These impacts have to be quantified by first calibrating the energy model for its accuracy and then adjusting the related parameters to generate new energy use predictions, which will be performed in future research. Since researchers did not obtain the inspection and testing information for the building envelope, its thermal properties and air tightness could not be verified. The properties of building envelope could have a great impact on space heating energy use.

Although the interview results did not fully answer the big puzzle the researchers had, the obvious discrepancies between the modeling parameters and actual operating parameters show that the modeling results were not true representations of energy uses in the actual building and communication and coordination issues might be involved with energy modeling. Denzer and Hedges (2011) categorized energy modeling as one of the numerous third-party documentation problems in LEED, and indicated that LEED added significant additional coordination and communication challenges for the project team versus a non-LEED project. Since the energy puzzle was not fully resolved, it was necessary to perform a deep investigation into how the building was operated and whether human behavior also contributed to the elevated energy use.

Interview with the Building Automation Engineer

To fully understand how the SAS building's HVAC system was operated, the researchers interviewed the building automation engineer. The engineer not only provided information about the operating schedule for SAS (presented in Table 1), but also indicated the following four major contributing factors that likely elevated the building's actual energy use:

1) Reduced Deadband: For the SAS building, the HVAC control was originally set to allow 8°F (68°F -76°F) deadband for energy efficiency. Deadbands are applicable on newer thermostats that automatically switch between heating and cooling. The operating scenario can be described as: When room temperature falls below 68°F, the heating system operates. When room temperature exceeds 76°F, the cooling system turns on. With a deadband in between, no control action takes place. This neutral zone prevents frequent cycling of the HVAC system to save energy. However, to mitigate discomfort complains from occupants, the engineer had to reduce the deadband to 2°F (i.e., 71°F-73°F), which increased the energy use, especially during the heating season.
2) Humidity Problems: The lack of a humidity control system caused fluctuated indoor humidity levels throughout the year. In the heating season, the indoor relative humidity (RH) could be lower than 15% (e.g., 10-11% recorded in February), causing severe discomfort to occupants. As a result, the engineer tried to pull in extra outside air when its humidity level was greater than indoor air. According to American Technical Publishers (2008), the effect of this remedy might be very limited since RH of cold outside air decreases as it is warmed up. On the other hand, having the economizer mode on sometimes caused high indoor humidity levels in summer. The decision was then made to stop pulling in outside air and just run the cooling system. All of these measures consumed more energy. The energy impact could be quantified in future research.
3) Ventilation Control: The building utilized CQ_2 sensors to measure the quality of return air. A reading exceeding 1000 parts per million (ppm) would trigger the control to bring in more outside air. Since this was done automatically, the engineer did not have an idea about how much extra outside air was pulled in and the associated energy use for conditioning such air. Multiple occasions were observed by reviewing the recorded data.

4) Server on the Sixth Floor: A computer server room added an extra cooling load, even during the winter time. Also, the chilled water had to be pumped up to the sixth floor all year round, which consumed extra electricity. By revisiting the monthly chilled water usage data provided by FOD and examining the different cooling loads between the summer and winter months, the researchers estimated that the server room might contribute 5-10 kBtu/sf/yr to the building's EUI.

The engineer also indicated that the university had replaced the BAS in SAS just like what had been done for the 4-H Center. The network structure of the original BAS from Siemens—Multiple Spanning Tree Protocol with one Ethernet Panel—had high potential for traffic bottlenecks. But the type of Delta's variable-air-volume (VAV) controllers installed did not have control logic (the portion of controller software that makes decisions based on the inputs) at the VAV control level. The large amount of VAV traffic to the Siemens PXCM controller caused network failures. Also the original BAS only offered application specific controls, which did not allow custom logic written by the engineer for implementing different HVAC control strategies (i.e., non-programmable). According to the engineer, the BAS manufacturer has more capable products and network design. But to increase its chance of winning the bid, the manufacturer might have chosen the cheaper model and design if that could meet the university's project specifications.

The interview findings provided some explanations about the elevated energy use of the SAS building. It also seemed that the adopted specifications failed to address the complexity of building automation and HVAC controls for high performance green buildings, which caused the project quality problem when used with the low-bid project procurement system.

Interview with SAS Building Coordinator

A survey among building occupants was originally planned to learn their energy-related behaviors and their satisfaction scale for thermal comfort, daylighting and views, acoustics, and air quality. However, during the communication with the SAS building coordinator, who serves as a resource on facilities service matters, the researchers were requested to drop the occupant survey. An interview with this person revealed the rationale behind the request.

It turned out that SAS had been receiving complaints on thermal comfort commencing the first day of occupancy. At first glance, the operating temperatures seemed to fit the building energy management requirements—heating and cooling temperatures at 70°F and 76°F respectively when occupied and allowing temperature setbacks at 60°F and 80°F during heating/cooling unoccupied periods—defined in the Procedure II. Energy and Sustainability, Section B(2)(a) of the Green Build and Energy Policy. The building coordinator hypothesized that the problem was not the set temperatures but rather the humidity. Because SAS is an office-only building, there is no humidity control system installed as the university only requires humidity control for laboratory and medical buildings. The low humidity level in the winter caused occupants to feel colder than the actual room temperature. During the summer time, the operating staff had utilized the economizer mode to pull outside air into the building for free cooling (e.g., during the night or early morning). This sometimes caused high indoor humidity levels, which negatively affect thermal comfort.

After gaining the above insights from the building coordinator, the researchers revised the original research plan and suggested conducting small focus group studies to learn occupants' perspectives about this building. This suggestion was approved by the coordinator.

Focus Group Studies

Five building participants with varied backgrounds and exposure to other campus or non-campus buildings were recruited for the first focus group study, which led to the following consistent findings:

- All participants were aware of SAS being a green building prior to their occupancy.
- All participants rated SAS as an improvement in overall indoor environmental quality over the previous building they had worked in.
- All participants had positive comments about natural daylighting and views provided.
- The most common complaints were with the acoustics and layout of the office cubicles. Specifically, the use of metal furniture, the lack of noise-absorbing finishing materials, and the open floor plan caused some acoustic problems for building occupants.

During the meeting, thermal comfort was discussed at great length. It seemed that the building occupants had limited controllability over the building's temperature setting, which was monitored and controlled by the BAS. Occupants were also informed that they could not use electric space heaters without prior authorization. The discussions revealed that the layout of the building might contribute to the thermal comfort problem, as well as the automated HVAC system that was built for SAS. Given that the building functions primarily as one large open room on each floor, adjusting temperatures for certain areas became difficult. One participant specifically said that since she is located on the south side of the building, the temperature at where she sits was relatively warm in comparison to other cool areas of the building.

It was also interesting to hear that although more than half of the participants felt that the facilities staff did not have the right type of training to operate this green building, they were satisfied with their issues being resolved to the extent that they could be resolved. This testimony is consistent with what the researchers learned in this study: The building automation staff had done extensive work on the building to get all the controls and zones to work correctly and provide a good thermal environment for SAS occupants.

The participants of the second focus group were a mix of ten Ohio State employees providing the following services to campus LEED buildings: maintenance (e.g., maintaining and repairing low-flow plumbing fixtures and lighting fixtures), automation (zone controls for HVAC and lighting systems), and custodial services (regular building clean-up). The goal of this focus group study was to identify if LEED buildings were maintained and managed differently than other campus buildings and if the training provided for facility/maintenance was specific and adequate. The following understanding was garnered through the focus group discussions:

- Training was provided often by the vendors that supplied the systems and components installed in the building. The training was sometimes not effective.
- While there are positive aspects to utilizing contract employees for custodial or facility services, the downfall is the loss of institutional memory due to high turnover rates of contractors' employees.
- Employees noted an improvement with "being included in the conversation," especially for building renovations.
- A need exists for more consistent products and systems throughout campus buildings.
- There is a gap in education of occupants in campus green buildings.
- The Green Build and Energy Policy is too broad, leaving too much room for interpretation.

Discussions were also focused on the SAS building. One of the staff members from the building automation team spoke directly to the temperature problem within the building: The automated HVAC system was custom built based on the Green Build and Energy Policy temperature requirements on a range of 70°F to 76°F. The range of temperature in a given day in combination with inappropriate humidity levels in the building resulted in a very uncomfortable indoor environment for occupants. Further, since the system did not have the recode option, the automation team had to override the entire system (i.e., suspending the automatic function) to change the temperature range. It seemed that the broad nature of the policy (e.g., just providing a temperature range for thermal control) became an initial reason that SAS failed to achieve its expected thermal comfort.

However, a further discussion with FOD staff outside of the focus group study revealed that the Green Build and Energy Policy intends to provide a temperature set point guideline for building O&M. It should not be mistakenly used as a design standard to design a BAS that only offered application specific controls without flexibility for custom logic. Misunderstanding the policy or lacking a good explanation of the policy to avoid interpretation errors partially contributed to the thermal comfort and control problems.

Recommendations for Policy Improvement

Although Ohio State's Green Build and Energy Policy has enabled the university to take great strides in green building and sustainable development and ensured the LEED certification being pursued and obtained for qualified projects, the above discussions exposed various problems in LEED building development and operations that impaired the building performance. The results of this research shed light on areas in which the policy, strictly speaking, the Procedure portion of this policy, could be improved.

First, the policy does not require post-occupancy measurement and verification of building energy savings. This could be improved by mandating the LEED Measurement and Verification points under the Procedure, or at a minimum requiring an energy performance assessment for each LEED building after one year of occupancy. It would also be useful to develop an appropriate methodology for measurement and prediction of energy use in such a way that it establishes a reliable standard. The assessment result should then be presented at the University Energy Committee or a similar campus energy working group. If necessary, a more in-depth investigation should be performed, followed by corrective action if problems are identified. To perform such an energy performance assessment, whole building energy simulation and calibration would become a critical task. Note that although building commissioning can help identify many system/component failures or malfunctions, it may not be able to detect all energy-related problems.

As we know, LEED certification usually requires a whole building energy simulation to demonstrate energy cost savings from the proposed design. Energy modeling is also an important design tool for comparing design alternatives. One important priority for evaluating vendors is to ensure that the engineering firm hired has extensive expertise and properly trained personnel to perform modeling. The university should also provide the modeler with adequate information about building schedule, operating conditions, occupancy, demand, specific Btu conversions for certain energy sources like steam and chilled water, etc. It will be helpful to hire a third party or let building commissioning agent to review and verify the accuracy of the model if the university's in-house personnel do not have the expertise or time. The same party can work with the engineering firm after one year of occupancy to perform model calibration and performance assessment. The related processes, standards, responsibilities, and quality assurance need to be clearly defined by additional procedures and/or guidelines.

Second, the LEED credit on Thermal Comfort: Design is mandatory for university LEED projects in the existing policy. However, the SAS building did not intend or failed to earn this point. Also, the Thermal Comfort—Verification point is neither required nor recommended by the policy. How could the university ensure that the expected thermal comfort is achieved in a LEED building? Responding to service calls or occupant complaints is not a preferred approach. Similar to the energy issue discussed above, the policy could mandate the LEED verification point, or require a thermal comfort survey of building occupants within 6 to 18 months after occupancy. The survey will be able to capture potential problems and collect valuable insights on what causes these problems. This will also increase the involvement of university community in campus-wide green building and sustainability initiatives.

Third, institutional green building policies are usually very concise documents with the typical size of one to two pages (Cupido et al. 2010). To ensure successful implementation and positive outcomes, such policies will need to be well supported by clearly defined procedures, standards, and/or guidelines that provide sufficient details to guide project planning, design, construction, and O&M. Ohio State's Green Build and Energy Policy already self-contains a procedure section and also provides links to other standards, guidelines, resources, and tools. However, problems still arose in the implementation process, e.g., the accuracy of energy modeling, the compatibility issue on the BAS components, the quality of project specifications, issues on building operations, and training for O&M staff (e.g., how to deal with humidity issues or run the economizer mode). These problems will need to be addressed since pursuing LEED is not the ultimate goal of the policy, but only a procedure leading to building energy conservation.

To address these issues, corresponding university offices should regularly review the policy and supporting documents for correctness and completeness; also, the best practices and lessons learned can be incorporated during the review and revision process. Since its inception in 2008, a thorough review and revision of this policy occurred only once in August 2012. This pattern complies with the University Policy Process, which does not mandate an annual review but leaving responsible offices/executives to review, update, and decommission their policies on a regular basis. However, considering the rapidly evolving nature of the sustainability field, an annual review of the policy and supporting documents would be appropriate. Cupido et al. (2010) also found that 18 out of 49 studied schools had their policies reviewed annually. Additionally, a proper feedback channel should be built for university employees, external consultants, and vendors/contractors to make recommendations for policy improvement.

Lastly, the policy could be further improved by encouraging the use of an Integrated Project Delivery process and Best Value Contracting (alternative to the low-bid method) to improve LEED building design, system integration, and overall project quality. The policy could also allow some flexibility in building operations (e.g., how to reach thermal comfort in individual buildings), occupant behavior, and other areas. For example, the open floor plan of SAS may be more suitable for having local thermal comfort controls, including a proper level of individual temperature control, operable windows, shading devices, or even space heaters. Education and training can be provided to help occupants use these measures wisely and responsibly.

CONCLUSIONS AND FUTURE RESEARCH

This research shed light on an issue that has so far not been adequately addressed: ensuring that the LEED buildings perform up to their design expectations, especially in energy efficiency and thermal comfort. The whole-building energy assessment results revealed that of the three LEED campus buildings studied the 4-H Center seemed to be able to meet the expected energy efficiency level. While it is subject to further investigation to determine whether the Ohio Union building performed as expected, it is obvious that the SAS building had poor energy performance and thermal comfort problems. Further interviews and focus group studies identified multiple contributing factors to the said problems, including the accuracy of energy modeling, the compatibility issue on the BAS components, the quality of project specifications, building design problems (e.g., due to misinterpretation of information), issues on building operations, and training for O&M staff. Many of these factors and associated complications could be addressed by improving the Procedure portion of the university's Green Build and Energy Policy and other supporting documents, including related design standards, specifications, and guidelines.

As we know, LEED could be a very useful tool to guide green building practices. However, it is important to understand that LEED is simply a roadmap not the ultimate goal. Earning LEED certification is also not the only measurement for the success of an institution's green building policy. Universities should closely monitor the performance of their built LEED facilities and refine their policies, procedures and supporting documents to address any identified problems. The study presented in this paper will provide insights to other institutions to enhance their green building and sustainable practices. Future research will be focused on calibrating energy models and disaggregating energy consumption data to diagnose the performance of campus LEED buildings based on end-use categories and to offer energy-saving control strategies. One of the key research tasks is to better understand the steam use related to space heating and hot water in the SAS building. In addition, the construction quality of building envelope related to thermal properties and air tightness will also be investigated to see whether it contributed to building energy use issues.

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APPENDIX A: LEED Scorecard Comparison (LEED for New Construction V2.1/2.2).

LEED credits	4-H	Ohio Union	SAS
Sustainable Sites (SS)	**6**	**7**	**9**
Prerequisite 1: erosion & sedimentation control	Y	Y	Y
Site selection	1	1	1
Development density			1
Brownfield redevelopment			
Alternative transportation - public transportation access	1	1	1
Alternative transportation - bicycle storage & changing rooms	1	1	1
Alternative transportation - alternative fuel vehicles			1
Alternative transportation - parking capacity & carpooling	1		
Reduced site disturbance - protect or restore open space			1
Reduced site disturbance - development footprint	1	1	
Stormwater management - rate & quantity		1	1
Stormwater management - treatment		1	1
Landscape & exterior design to reduce heat islands - non-roof		1	
Landscape & exterior design to reduce heat islands - roof	1		1
Light pollution reduction			
Water Efficiency (WE)	**4**	**4**	**4**
Water efficiency landscaping - reduce by 50%	1	1	1
Water efficiency landscaping - no potable water use or no irrigation	1	1	1
Innovative wastewater technologies			
Water use reduction - 20%	1	1	1
Water use reduction - 30%	1	1	1
Energy and Atmosphere (EA)	**3**	**4**	**4**
Prerequisite 1: fundamental building systems commissioning	Y	Y	Y
Prerequisite 2: minimum energy performance	Y	Y	Y
Prerequisite 3: CFC reduction in HVAC&R equipment	Y	Y	Y
Optimize energy performance, 15% new / 5% existing	1	1	1
Optimize energy performance, 20% new / 10% existing	1	1	1
Optimize energy performance, 25% new / 15% existing	1		
Renewable energy			
Additional commissioning		1	1
Ozone depletion/Enhanced refrigerant management		1	1
Measurement & verification			
Green power			
Materials and Resources (MR)	**4**	**5**	**7**
Prerequisite 1: storage & collection of recyclables	Y	Y	Y
Building reuse, maintain 75% of existing shell			
Building reuse, maintain 100% of shell			
Building reuse, maintain 100% shell & 50% non-shell			

Construction waste management - divert 50%			1
Construction waste management - divert 75%			1
Resource reuse - 5%			
Resource reuse - 10%			
Recycled content - 5%	1	1	1
Recycled content - 10%	1	1	1
Local/regional materials - 20% manufactured locally	1	1	1
Local/regional materials - 20% above, 50% harvested locally	1	1	1
Rapidly renewable materials			
Certified wood		1	1
Indoor Environmental Quality (IEQ)	**8**	**10**	**9**
Prerequisite 1: Minimum IAQ performance	Y	Y	Y
Prerequisite 2: Environmental tobacco smoke (ETS) control	Y	Y	Y
Carbon dioxide monitoring/Outdoor air delivery monitoring	1	1	1
Ventilation effectiveness	1		
Construction IAQ management plan, during construction		1	1
Construction IAQ management plan, before occupancy		1	
Low-emitting materials, adhesives & sealants		1	1
Low-emitting materials, paints		1	1
Low-emitting materials, carpet	1	1	1
Low-emitting materials, composite wood & agrifiber products		1	1
Indoor chemical & pollutant source control	1	1	
Controllability of systems, perimeter/lighting			1
Controllability of systems, non-perimeter/thermal comfort			
Thermal comfort, comply with ASHRAE 55-1992	1	1	
Thermal comfort, permanent monitoring system	1	1	
Daylight & views, daylight 75% of spaces	1		1
Daylight & views, views for 90% of spaces	1		1
Innovation & Design Process	**5**	**5**	**2**
Innovation in design, green building education	1	1	1
Innovation in design, WEc3	1	1	
Innovation in design, SSc5.2	1	1	
Innovation in design, green housekeeping	1	1	
LEED Accredited Professional	1	1	1
Total points	**30**	**35**	**35**

Note: LEED-NC V2.1 was used for the 4-H Center and Ohio Union projects while LEED-NC V2.2 was used for the SAS building project.

APPENDIX B: SAS Occupant Focus Group Study Procedures and Questions.

Welcome and Background Information (10 minutes)

Check the participants in, assign them a number, and retrieve the following background information:

1. How many years have you worked at The Ohio State University?
2. How long have you been working in the SAS building?
3. If applicable, what building did you work in prior to the SAS building?
4. In a typical week, how many hours do you spend in your office within the SAS building?
5. Please describe your work environment according to the following factors:
    - individual office
    - shared office space
    - cubicle

- window nearby
- operable window (able to open or close)
- control over temperature

Focus Group

Once the group members are assigned with numbers, the following questions are asked as a group:

1st Priority Group Questions:

1. How many of you know what LEED is?
2. How many of you know that the SAS building is LEED certified?
   - If yes, how did you find out?
3. How does the SAS building compare with other buildings on campus and/or other buildings you have worked in that are not on campus?
4. Do you feel that the following factors have improved or decreased your efficiency at work?
   - Air Quality
   - Daylighting and Views
   - Acoustics
   - Thermal Comfort
5. Let's discuss your satisfaction level with:
   - Air Quality
   - Daylighting and Views
   - Acoustics
   - Thermal Comfort
6. How have issues with any of the above (fill in the blank) been dealt with in the past?
7. What was the final outcome of the mentioned issue(s)?
8. Does the comfort level change by season?
9. Does the comfort level change by time of day?
10. Do you know how to change the heat/light in your location?
11. Does anyone ever change the heat/light in your location?
12. Do you feel like that it is your responsibility to change the heat/light in your location?
13. Are there ever any funny/toxic/bad smells?
    - Cleaning products
    - Paint
    - Adhesives
    - Office equipment
14. If you could change three things, what would they be?

2nd Priority Group Questions if Time Allows:

15. How do you get to work?
16. What does it a LEED certified building mean to you?
17. Does the school make an effort to let occupants know that the SAS building is a LEED building?
18. Do you feel like that the operators of the building care about your comfort?

APPENDIX C: SAS Maintenance Focus Group Study Questions.

General Questions:

1. What training is provided for facilities staff/maintenance staff/automation staff?
2. What policy/policies are used to manage the SAS building?
3. How does a complaint or work request get prioritized and resolved?
4. If you could change one thing about your organization/process/resources, what would it be?

Questions Specific to the SAS building:

5. How do complaints/work requests get routed and addressed in SAS?
6. What makes SAS a good building to maintain?
7. Conversely, what makes SAS a challenge to maintain?
8. How does it compare to other green buildings on campus (or from previous work experiences)?
9. Have you ever considered offering educational programs to the occupants in the building who may be unfamiliar with the different features in a green building such as SAS?