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The Business of High Performance:
The USC Darla Moore School of Business

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Energy Technologies Area

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Disclaimer

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U.S. DEPARTMENT OF **ENERGY** | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES OFFICE

The Business of High Performance:

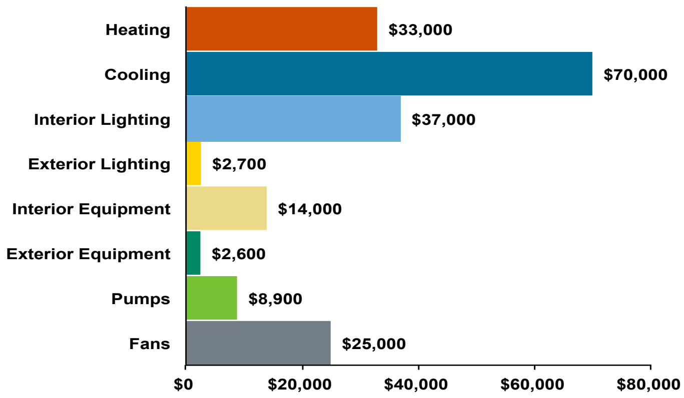
The USC Darla Moore School of Business

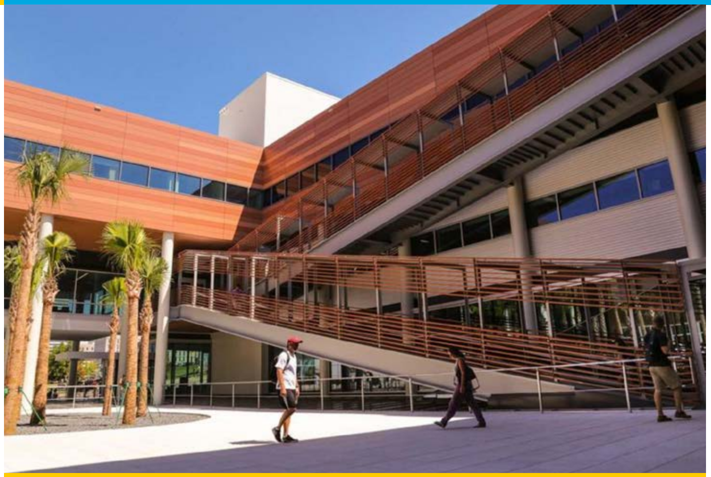
Overview

The University of South Carolina (USC), a public university in Columbia, South Carolina, partnered with the U.S. Department of Energy (DOE) to develop and implement solutions to build a new, low-energy educational building. The new Darla Moore School of Business (DMSB) will consume about 50% less energy than requirements set by Energy Standard 90.1-2007 of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the American National Standards Institute (ANSI), and the Illuminating Engineering Society of North America (IESNA) as part of DOE's Commercial Building Partnerships (CBP) program.[4] Lawrence Berkeley National Laboratory (LBNL) provided technical expertise in support of this DOE program.

The new ~250,000-square foot (ft^2), four-story facility will house classrooms, offices, two auditoriums, a computer lab, a library, and a small cafeteria. Additionally, the building will have both a walk-out basement and functional spaces on the roof, with multiple areas of green roofs. The project team is pursuing Platinum Certification under the U.S. Green Building Council's (USGBC) LEED-NC version 3 rating system while also targeting zero-net energy usage. The DMSB building is currently on track to exceed the ASHRAE baseline by approximately 48%, demonstrating many energy efficient opportunities in mixed-use educational construction.

Expected Energy Cost Reductions





Darla Moore School of Business

Photo credit: Andrew Shain, *The State/News/Education*/Sept 6, 2014.

Project Type	Educational, New Construction
Climate Zone	ASHRAE Zone 3A, Warm-Humid
Ownership	Owner occupied
Barriers Addressed	• Aligning business school values and energy efficiency • Integrating energy management data platform into operations • Aligning operational staff resources between business school and campus facilities • Occupant behavior transitioning from an existing building to a new building • Long-term zero-net energy goal
Square Footage of Project	~250,000
Energy Savings (vs. ASHRAE 90.1-2007)	~48%
Expected Energy Savings	~1,00,000 kWh/year ~10,000 MMBtu of CHW ~2,600 MMBtu of Steam
Expected Cost Reductions (vs. ASHRAE 90.1-2007)	~$190,000/year[1]
Project Simple Payback	N/A[2]
Expected Carbon Dioxide Emissions Avoided	~140 metric tons per year[3]
Construction Completion Date	September 2014

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1. Cost reductions based on utility rates for USC of $0.0815/kWh, $6.94 MMBtu of CHW and $11.79 MMBtu of Campus Steam.
2. Budget estimates were not provided by USC for all measures, specifically windows, exterior lighting, and equipment/plug loads.
3. Calculated using the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Equivalencies Calculator.
4. The Commercial Building Partnerships (CBP) program is a public-private, cost-shared initiative that demonstrates cost-effective, replicable ways to achieve dramatic energy savings in commercial buildings. Through the program, companies and organizations are selected through a competitive process and team with DOE and national laboratory staff, who provide technical expertise to explore energy-saving ideas and strategies that are applied to specific building project(s) and that can be replicated across the market.

Additional energy savings in terms of reduced internal electricity consumption (such as those from equipment) are anticipated based on the DMSB's efforts to incorporate additional plug load savings measures that developed from the review of existing plug load use monitored in the Business School's former building on campus. Those savings will assist in reaching the 50% savings target.

The design process was a collaborative effort involving USC, its design team, and the DOE Technical Expert Team (TET). Led by LBNL, the TET also included subcontractors Steven Winter Associates, Inc. (SWA) as the TET Lead and LHB Inc. /The Weidt Group, Inc. (TWGI) as the Measurement and Verification (M&V) Contractor. The team proposed efficiency measures based on computer simulations of the building in full compliance with ASHRAE 90.1-2007. The energy modeling, completed in EnergyPlus, showed that for this cooling-dominated climate the main energy consumption drivers were cooling (both waterside and airside), lighting, and equipment loads. Promising measures were modeled to estimate their energy performance, and each measure was evaluated for its feasibility in terms of campus goals for performance, return on investment, and sustainability.

Through the course of the project, the project team has learned lessons that can assist in replicating the successes from this project for other classroom building and campus building projects. These include how a project can be a catalyst for developing campus standards, and the importance and influence of cultural change on energy savings associated with the business school's day-to-day activities.

Decision Criteria

The tone for the decision criteria was set by then Dean Hildy Teegen of DMSB when she expressed the need for DMSB to focus on the vision of energy efficiency and sustainability, and challenged the faculty and staff to take on this new vision. Since the DMSB building also is to be the gateway to USC's developing Innovation District, called Innovista, a high-bar energy-efficiency target of 50% better than ASHRAE 90.1 2007 was established for the design. The long-term goal is for DMSB to be a zero-net energy building with the implementation of a PV system and additional EEMs.

The identification of the energy efficiency measures (EEMs) for the DMSB building was a collaborative effort among the project design team, the DMSB team, and the TET. Through the course of developing the energy analysis, the TET identified EEMs that then went to the project design and DMSB teams for evaluation and feedback. Ideally the analysis would be complete prior to the milestone decision discussions. However in some cases, the very tight design schedule necessitated the design team to begin incorporating EEMs while the TET evaluated them in parallel and then reported on their influences. In each case, the EEMs were modeled based on the available inputs provided by the design team, to assess the impact they had on overall building performance. Verification of savings from EEMs was also a high priority, so an M&V Plan and a Monitoring Plan were drafted to provide the basis for the methods and process used for EEM performance assessment once the building becomes operational.

Economic

The $107 million facility resulted in the creation of approximately 1,640 jobs, and more than 65% of project spending has been local[5]. The project relied on funding from a wide range of sources, including revenue bonds, state institution bonds, donor gifts, and various USC foundations. Being a publically funded project, there is strong interest in seeing high-impact EEMs incorporated into the building design. In addition, the economics of the EEMs played a key role since the DMSB is one of the premiere business schools in the nation. The initial EEM target of a 5-year payback period served as a preliminary evaluation filter. This target was extended to a 10-year payback, and in some cases longer, when a strong case for EEM benefit could be made for how a measure could positively influence the culture and/or building operations.

Operational

In addition to first cost and the targeted payback period, EEMs were evaluated based on their role in:

- Enhancing operations and maintaining, or improving upon, design energy consumption.
- Informing the occupant behavior of faculty, students, and visitors for key performance drivers, such as internal loads.
- Enabling facility managers to meet and maintain performance targets over time.
- Effectively utilizing controls during operations to maintain and improve upon energy consumption levels.
- Facilitating the availability of information for use in future research studies.
- Providing opportunities to integrate curriculum within the DMSB and across departments.

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[5] Source: Darla Moore Business School website (http://moore.sc.edu).

Design

The list of design criteria started with Columbia's warm, humid climate, which poses challenges for certain EEMs that are typically associated with high-performance design. The architectural aesthetic was also a primary decision criterion throughout the design process, and the overall team had to work collaboratively and diligently with the architect to integrate EEMs into this vision. As part of this integrated approach, the TET team looked for EEMs that made contributions to aspects of the design beyond energy savings and aesthetics, such as:

- Influencing the culture of the building occupants.
- Promoting a shift in occupant behavior necessary for achieving performance goals.
- Supporting related performance goals, such as the LEED Platinum certification.
- Providing ongoing awareness of energy efficiency through a variety of visual and interactive components.

Policy

The DMSB's participation in the DOE CBP program helped establish the project's energy savings target (50% better than ASHRAE 90.1-2007), and the stretch goal of zero-net energy. It also helped them achieve high points in the LEED rating system's Energy & Atmosphere category, setting the course to achieving LEED Platinum. Decision criteria were established and informed by USC-developed policy guidelines that the project touched upon. These ranged from the Innovista campus area, to the campus as a whole, to all the other USC campuses. Decisions were also informed by USC's relationships with the local utility companies and the incentive program requirements they set forth.

Energy Efficiency Measures Snapshot

The following table lists the EEMs proposed for this project. Measures that were adopted but were not regarded as EEMs included:

- An internal load-monitoring program for the existing Business School building. This has been put in place to raise awareness for the current occupants (who will later occupy the new building), as well as to start a dialog with operations staff about what performance data can be captured in the new building and how that information can be leveraged.
- The fourth floor will have more granular metering and monitoring of the offices and classrooms, which will allow operations personnel a "closer look" at key areas of the building, to inform operational decisions.
- The development of M&V and Metering Plans, in conjunction with USC's sole controls vendor, placed an emphasis on bringing the right set of performance data together, with a focus on quality, not quantity, of data.
- Performance Data Visualization Design for the DMSB is a key effort currently under way. The intent is to put performance data on key resource-conserving features of the building at the fingertips of the major audiences—operations staff, DMSB faculty, student occupants, student/faculty research, and visitors—to enable the ongoing maintenance and improvements needed to ensure optimal energy performance of the facility.
- Water-efficient fixtures were installed in all restrooms, and a rainwater reclamation system will capture rainwater for use in irrigation and toilet flushing.

Energy Efficiency Measures

Energy Efficiency Measure Description	Implementing in this Project	Will Consider for Future Projects	Expected Annual Savings		Expected Improvement Cost[6] $	Simple Payback Years	Cost of Conserved Energy (CCE)[7] $/kWh
			kWh/year	$/year			
Final Design Measure Set (~48% Whole-Building Savings)							
Envelope[8]			4,900,000	$194,000	$2,400,000	12	0.035
Install high-performance glazing and a 30% decrease in window area on floors 3 and 4.	Yes	Yes					
Interior Lighting							
Reduce interior lighting loads by installing T5 linear fluorescents and LEDs, and install occupancy and daylight sensors.	Yes	Yes					
Exterior Lighting							
Reduce exterior lighting loads by installing LED and other low-wattage exterior lighting fixtures.	Yes	Yes					
HVAC							
Provide two 100% outdoor air units, each with an enthalpy wheel for heat recovery. Install a combination of variable air volume (VAV) units, chilled beams, an under floor air distribution (UFAD) system, and secondary desiccant wheels in each of the six primary air handling units (AHUs). Also, install demand-controlled ventilation coupled with carbon dioxide monitoring in many spaces, including classrooms.	Yes	Yes					
Utilize a cooling tower or waterside economizer to provide free cooling for the chilled beam chilled water loop and offset the need for purchased campus chilled water.	No	Yes					
Reduce pump head by upsizing the piping, allowing for smaller-horsepower pumps.	No	Yes					
Use variable-speed fan-array technology in conjunction with the total energy recovery wheel located upstream of the cooling coil in each of the two dedicated outdoor air system (DOAS) units. By eliminating the sound attenuator, the overall system pressure drop would be reduced, potentially allowing for a smaller fan and reducing fan energy consumption.	No	Yes					

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6. Does not include annual operation and maintenance cost; this is included in the expected annual cost savings.
7. CCE is calculated using a 5% discount rate for 25 years (Meier 1984).
8. Since the envelope decisions were not a large energy driver for the project, USC did not analyze pricing for various insulation strategies.

Energy Efficiency Measures

Energy Efficiency Measure Description	Implementing in this Project	Will Consider for Future Projects	Expected Annual Savings		Expected Improvement Cost[6] $	Simple Payback Years	Cost of Conserved Energy (CCE)[7] $/kWh
			kWh/year	$/year			
Plug Load							
Reduce plug load and equipment power density by purchasing ENERGY STAR appliances and computers, employing centralized printers, aligning procurement policies to continue to keep plug loads low over the long-term, adopt restrictions to prevent occupants from adding personal equipment, and add controls to shut down equipment during unoccupied periods.[9]	Yes	Yes					
Equipment							
Replace standard elevators with high-efficiency, machine room-less, geared-traction elevators with 10–12 horsepower motors	Yes	Yes					

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[9] The last round of modeling had plug load inputs that were the same in both energy models, since decisions were still being made regarding the FFE package and the best approach to estimating these savings.

Energy Use Intensities by End Use

The evaluation of the final design energy consumption was conducted using three versions of energy models created to compare the proposed energy efficient design to the baseline building determined by ASHRAE 90.1-2007-compliant design. The DOE's EnergyPlus software, an energy analysis and thermal load simulation program, was used to model the versions of the building. Model 1 is the ASHRAE 90.1 2007 baseline model, Model 2 represents the DMSB building with the proposed EEMs in the initial design, and Model 3 represents the DMSB building with the proposed EEMs in the final as-built design. Heating, ventilation, and air-conditioning (HVAC) efficiency measures represented a major portion of the savings due to USC's location in a cooling-dominated climate.

The building is in the form of an inverted pyramid, with an interior courtyard. The form posed a unique set of challenges in terms of finding an appropriate balance for shading, daylight admittance, glare reduction, daylighting controls, and aesthetics. Numerous exterior shading configurations were presented and analyzed during the process to optimize different facades. The final design implemented both interior and exterior balconies (which varied per floor but were of the same depth on all four facades) and a shading structure at the upper level. This exterior shading design addressed a portion of the climate challenges; however, it was difficult to make a strong case for alternative exterior shading design, since the envelope's impact on the overall energy consumption was minor for this internal load-driven building.

The interior lighting consumption in the baseline model accounts for almost 12% of the total building energy consumption. Installing T5 linear lamps and LED lamps, along with occupancy and daylight dimming sensors, reduced the interior lighting consumption by almost 40%. Although these measures do not have a positive net present value (NPV) after five years, the longer service life of LED lamps (30,000 hours or more compared to the CFL service life of 6,000–15,000 hours) resulted in an acceptable NPV for DMSB, even when considering costs for the maintenance of occupancy and daylight dimming sensors and higher lamp replacement costs.

The exterior lighting consumption for the proposed building is about 17% less than the baseline model. This reduction was achieved by installing LED and other low-wattage fixtures. The additional costs were minimal due to the size of the site relative to the building footprint.

The code-compliant baseline was modeled with a standard variable air volume (VAV) system with reheat. The proposed design utilized a similar type of HVAC system, but incorporated two dedicated outdoor air system (DOAS) units supplying fresh air for the entire building during targeted occupancy periods, advanced controls and higher performance equipment. In addition, the proposed building receives chilled water from a central plant on campus, which supplies the active chilled beams, the coils in the air handling units (AHUs), the underfloor air distribution (UFAD) system, and the fan coil units (FCUs). The chilled beams are fed by upstream air handling units with additional heat recovery wheels and VAV boxes. The high-occupancy spaces utilize demand-controlled ventilation and controls logic to reduce energy use during unoccupied periods. Traditional VAV units are dedicated to serve the two auditoriums, while fan coil units and VAV systems serve common areas, corridors, and mechanical spaces. The two added roof pavilions are to be served by FCUs. The proposed buiding consumes about 52% less energy for cooling and 63% less energy for heating than the ASHRAE 90.1-compliant baseline model, resulting in significant whole-building savings related to the HVAC system. The annual maintenance costs for the proposed HVAC design are comparable to the standard systems.

Model 1 – Code Compliant Baseline

Model 1 represents the program-defined ASHRAE Standard 90.1-2007, Appendix G and ASHRAE 62.1 2007 code-referenced baseline. The envelope of the baseline model aligns with ASHRAE 90.1 requirements for climate zone 3A. For lighting, the baseline model assumes a lighting load density per the ASHRAE Building Area Method.. The baseline building is conditioned by ASHRAE System 7—package rooftop VAV systems with reheat serving each floor. For the chilled and hot water distribution, the baseline is modeled with a primary/secondary pumping configuration (22 Watts/gallon per minute). Domestic hot water is provided by a stand-alone natural gas system. The DMSB baseline building has annual energy use intensity (EUI) of about 130 kBtu/ft^2.

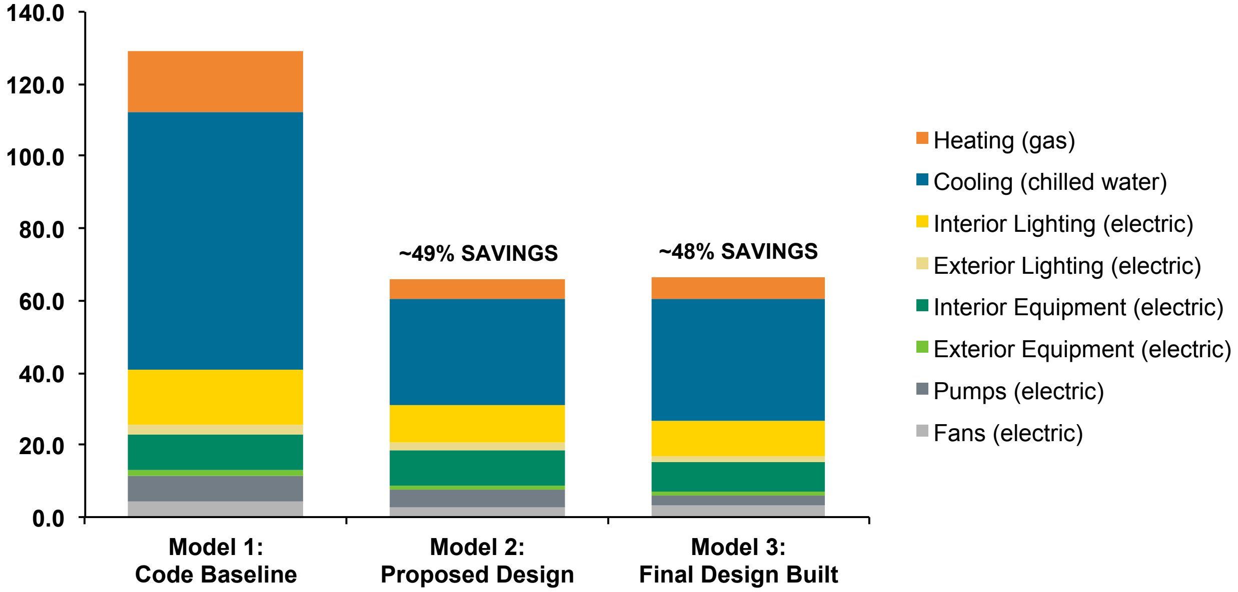
Model 2 – Proposed Design

Model 2 incorporates the EEMs that were selected from the recommendations for the DMSB building (see table above). The EEMs include high-performance windows, reduced lighting loads with T5 lamps indoors and LEDs indoors and outdoors, reduced plug loads, and a combined HVAC system consisting of VAV units, chilled beams, and an UFAD system that also contains heat recovery and specific controls strategies for demand control ventilation (DCV). The chilled beams utilize water, rather than air, for space conditioning. This shifts some of the energy related to distribution from fans to pumps. While this is more efficient overall, the result is larger pumping energy in the proposed building as compared to the baseline. This building model has an estimated annual EUI of 67 kBtu/ft^2, which is approximately 49% better than the Model 1 baseline.

Model 3 – Final Design

Model 3 incorporates the final EEMs that were implemented on the project. The EEM set was very similar to the EEM set incorporated into Model 2, and demonstrates that the EEM set did not vary significantly overall through the final stages of design and construction. This model update resulted in an estimated annual EUI of ~68 kBtu/ft^2, which is approximately 48% better than the Model 1 baseline, and shows slight improvement from Model 2. Some of the key end use category differences from Model 2 were cooling, interior equiprement and pumps.

Comparing EUI of Code Baseline and Proposed Design Models



Expected Annual Energy Use and Percentage Savings by End Use

End Use Category	Model 1: Code Baseline	Model 2: Proposed Design	Model 3: Final Design Built	
	Annual EUI (kBtu/ft²)	Annual EUI (kBtu/ft²)	Annual EUI (kBtu/ft²)	Percent Savings Over Baseline
Heating (gas)	17	5.8	6.1	63%
Cooling (chilled water)	72	29	34	52%
Interior Lighting (electric)	15	10	9.3	38%
Exterior Lighting (electric)	2.5	2.1	2.1	17%
Interior Equipment (electric)	10	10	7.9	22%
Exterior Equipment (electric)	1.5	1.1	1.1	26%
Pumps (electric)	6.9	4.5	2.9	57%
Fans (electric)	4.5	2.8	3.1	31%
Total	**129**	**66**	**67**	**~48%**

Expected Building Energy Savings from Implemented EEMs by End Use

Electricity End Use Category	Expected Energy Savings (kWh)
Cooling	3,000,000
Interior Lighting	450,000
Exterior Lighting	33,000
Interior Equipment	~180,000
Exterior Equipment	31,000
Pumps	~310,000
Fans	110,000
Electricity Total	**~4,100,000**

Natural Gas End Use Category	Energy Savings (therms)
Heating	28,000
Natural Gas Total	**28,000**

Note: All savings shown in this case study are estimated. These tables and figures illustrate the expected savings resulting from the various mechanical schemes. Totals may not add up due to rounding.

Lessons Learned

> “The new facility will be a living experiment of its own, as we implement and monitor the design features and energy initiatives that will contribute to the Moore School being one of the healthiest, most efficient buildings in our region, and perhaps the world.”
>
> — Debbie Brumbaugh
>
> Chief Financial Officer and Director of Administrative Services, Darla Moore School of Business

The contractual relationships of the design team members can play a significant role

Team chemistry, team size, the number of decision makers, and other group dynamics all play a key role in an integrated design process. This is especially true for projects that are targeting energy goals of 50% better performance than the ASHRAE 90.1-2007 standard, because of the required level of integration to achieve the goal. Another dimension to the team dynamics can be added for University projects when a financial donor makes a substantial monetary contribution to a project, which can include the compensation of a key design team member’s services. To successfully bring the team together, each team needs to accept and support the project’s goals, strategies, and approaches. Inevitably, building projects focused on achieving low-energy design reach critical points in the decision-making process when the ‘collective will’ to achieve the performance goals can significantly benefit the direction of the project and the design.

Cultural change with an emphasis on energy efficiency can take a while

Since the initial design of the new DMSB building began, the faculty, staff, and students have started a journey down the path of awareness and understanding of energy efficiency. It is one thing to have a high-performance building designed and built; it is another to occupy that building and meet or exceed those design energy targets. In initial workshops and discussions there was resistance against the idea of “doing things differently,” which would allow energy savings through better control of heating, cooling, and internal loads. As the various stakeholders began to understand more about the strategies and how they would be implemented, they began to embrace the concepts. The Internal Loads Monitoring program for both the existing and new buildings, described below, is another interesting part of this journey that will assist shifting the mindset and influencing the DMSB culture.

Internal loads are a driver, and steps to inform occupant behavior can pay significant dividends

Through the course of the design process and the energy modeling analysis, it became apparent that to reach the performance targets, the internal loads—particularly the plug loads—were going to be a major driver. The DOE and DMSB teams launched an internal loads monitoring program to gather data on energy consumption and use trends at the existing building. The results of this assessment will be a part of an occupant training program for the new DMSB building’s occupants, who also occupied the old building. In the new building, internal loads will be monitored in the same way, and will be compared to the existing building. This monitoring effort will provide a dataset to evaluate and raise awareness on the role of occupant behavior, improving the potential for the building to meet the design energy-performance goals.

Start metering discussions early in the design phase to minimize cost and maximize systems

The old saying goes that “the devil is in the details.” This statement could not be any truer in the realm of metering, monitoring, and performance metrics. There is a perception that this should be straightforward and easy: a meter measures things, and these measurements can be evaluated. The reality is that many pitfalls can impede the effort to gather the desired measured data in a format that can be effectively utilized. In addition, when implementing low-energy strategies, such as chilled beams, it can be helpful to initiate regular discussions early on to coordinate monitoring of the different components of the system in the most cost effective and useful way.

Establish timeline for integration of meter data

DMSB made the decision to be the first building on campus to utilize an Energy Management Data Platform to inform and assist optimizing operations. Although a powerful tool for commissioning and operations, it can add complexity to the process. Until the data from the meters and sub-meters is flowing effectively into the platform, the data platform is not useful for the critical task items of the commissioning agent, and the building energy manager. Since a clear timeline for data integration was not communicated by the data platform provider and locked into the schedule, the majority of data was not flowing for this project until well after occupancy.

Future project teams should provide progress updates, so that key stakeholders are made aware of the constraints associated with data access for equipment completion, commissioning, and finalization of the building management system. In addition, energy management data platform use cases and end-user interfaces should be defined during the planning, pre-design, and design phases.

Clearly define who the University Owner is for commissioning

Third-party Commissioning for the project is a key criterion for both the CBP program and the LEED program. For the CBP program, Commissioning is a quality control process to assist in optimizing the systems in preparation for the M&V phase. While Commissioning was performed for the project, based on schedule delays it largely occurred after occupancy, and the Construction team did not actively engage the Owner (DMSB and/or Facilities). The "Owner" was often interpreted as being USC (via Facilities), rather than the Purchaser/Client/End User (DMSB), which made it difficult to monitor activities that affected both DMSB's daily operations and the CBP process. For University projects, initial discussions between the end user, campus facilities and the commissioning agent should be conducted early, so that communication protocols necessary to meet the Owner's needs can be clearly expressed to the commissioning agent.

References and Additional Information

Advanced Energy Design Guide for Small to Medium Office Buildings: 50% Energy Savings can be downloaded for free at: https://www.ashrae.org/standards-research--technology/advanced-energy-design-guides/50-percent-aedg-free-download.

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