Towards a Sustainable Energy-Efficient Future at Universities, Universidad San Francisco de Quito Case Study, Phase I

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***Abstract*—This paper explores the building commissioning process required for improving energy consumption on campus facilities building a dynamic model that considers the principles of energy efficiency proposed by the Intergovernmental Panel for Climate Change. First, the model of the energy efficiency program adopted by the University under study is described. Then, the results obtained from the initial energy evaluation phase are presented; this process consisted on understanding the patterns of energy consumption, obtained by analyzing electrical load profiles from key measurement points around campus facilities during periods of normal operation and holidays, as well as maintenance and behavioral patterns that fit this consumption. Finally, the initial actions taken in equipment and maintenance, the suggested changes in user behavior and the energy savings obtained as result of the changes implemented are also reported and analyzed. Early results obtained indicate that a sustainable energy-efficient policy is feasible.**

***Keywords*—building commissioning, energy consumption, energy efficiency, energy management policy, retrofitting, living lab.**

I. Introduction

The energy sector is the largest contributor to greenhouse gas (GHG) emissions in the world [1] and Ecuador is not the exception, the highest GHG emissions also come from the energy sector, including transportation as well as production and electricity consumption [2]. While Ecuador has already committed to decarbonizing its energy sector as part of its intended nationally determined contributions to the Paris Agreement [3], there are still many areas for improving the efficiency of energy consumption. Energy consumption in universities corresponds to a high level of their carbon footprint [4], presenting therefore a great opportunity for universities to set a model for best practices.

Universidad San Francisco de Quito (USFQ) is one of the first universities in South America certified by the Association for the Advancement of Sustainability in Higher Education [5] and one of the winners of the Environmental Distinction of the Metropolitan District of Quito for three consecutive years (2015, 2016 and 2017). At USFQ, electricity use corresponds to 17% of its total carbon footprint, being second after transportation, for which a carpooling program solution (Autocompartido) has been implemented and is being expanded to other initiatives [6]. The Intergovernmental Panel for Climate Change (IPCC) in its fourth assessment identified key principles for energy efficiency [7], as described in Table I.

In order to understand USFQ's energy demands, its climatic conditions must be considered. USFQ is located in the Cumbayá valley near Quito that has an equatorial climate with an average temperature of 22.6°C at noon [8], and therefore the need for heating is avoided. However, for applying the principles of Table I, the reduction of cooling and lighting loads can be managed through building insulation, equipment shifting to more efficient energy saving technologies, improving operations and maintenance of equipment as well as changing user's behavior [9]. All of these strategies are listed in IPCC's efficiency principles and the approach adopted for USFQ is to implement them by retrofitting its existing facilities. Retrofitting involves a more efficient reuse of existing facilities to improve the energy performance of buildings [10].

Other principles mentioned in IPCC's hierarchy such as con-

TABLE I
Intergovernmental Panel for Climate Change Energy Efficiency Principles from their fourth assessment [7].

	Energy Efficiency Principles
1	Reduce heating, cooling and lighting loads
2	Utilize active solar energy and other environmental heat sources and sinks
3	Increase efficiency of appliances, heating and cooling equipment and ventilation
4	Implement commissioning and improve operations and maintenance
5	Change Behavior
6	Utilize system approaches to building design
7	Consider building form, orientation and related attributes
8	Minimize halocarbon emissions

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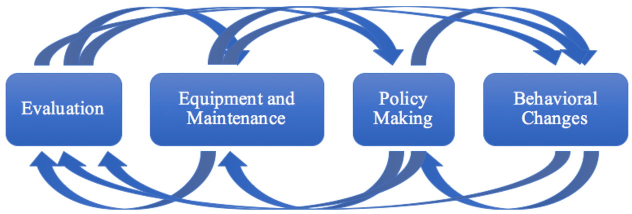

Fig. 1. Dynamic Model for Energy-Efficiency Programming at USFQ.

sidering building shape and design are relevant for planning stages of construction and are also being considered as the University expands. Managing halocarbon emissions, however involves upstream governmental policy, a portion not covered in this study.

A paradigm for an energy efficiency program was developed at USFQ. The design of such program has environmental but also economic motivations, since energy savings can also represent operation cost savings, based on appropriate investments; this was a major factor to consider during this study.

USFQ's model for the energy efficiency program was designed in four phases: evaluation, equipment and maintenance, internal policy-making and user behavioral changes. These four sections are intended to work dynamically, continuously informing each other, as shown in Fig. 1. This paper addresses the initial evaluation that was carried out in a collaboration between the Department of Electrical and Electronic Engineering and the Office of Innovation and Sustainability (OIS), and it reports some of the initial actions implemented both in the equipment and in the maintenance, and some of the changes in user behavior that have been put into effect. Energy savings obtained as a result of the changes implemented are also reported and analyzed. The evaluation of these results will guide the next steps for University policy-making including future equipment procurement, operations and maintenance, as well as nudges for behavioral changes.

II. Methods

The first phase of this study was the "Evaluation phase" which consisted on understanding the patterns of energy consumption at USFQ during the 2015-2016 academic year. The first step was to collect the energy bills for the months under study and characterize them. The second step was to conduct a pilot energy audit to find the most energy consuming equipment, locate possible electrical failures, and to propose initial optimal solutions capable of contributing to energy savings. Moreover, electrical load connections on the distribution panels were also identified for future work.

Results obtained in previous energy studies conducted at USFQ [11]–[13] indicate that 5% of all energy consumption came from the Heating, Ventilating, and Air Conditioning (HVAC) equipment located in the libraries and 8% from the university kitchens. Therefore, these two key areas: Library (Area 1) and Kitchens (Area 2) were selected for the study. Power parameters were collected through the use of an industrial power analyzer (Fluke 1744 three-phase power quality logger), which was provided and installed by Empresa Eléctrica Quito (EEQ).

In the case of the Library (Area 1), it was necessary to map the electrical load connections prior to obtaining the measurements. Despite the specific focus on the 3 HVAC systems available in the Library, it was not possible at this stage to separate or distinguish the energy used by the HVAC systems from the energy used by the printing, scanning & photocopying machines available to students within the library, or by the illumination system. The same was true for the Kitchens (Area 2), where electrical signatures from equipment, cold rooms and lights could not be separated and identified with the equipment available, at this stage. Initial energy measurements were performed in two periods, as shown in Table II. The first one, corresponds to a period in which the University was closed for holidays (Dec 23-Jan 8, 2015), where most of the equipment is not operating at its maximum load, while in the second period (Feb 5-29, 2016) the opposite is true, as the University resumed its normal administrative and student activities during operating hours. A third study period (September 6-25, 2017) was carried out after the initial saving strategies were implemented for comparison in Area 2, as it will be later described in the Results section.

TABLE II
PERIODS OF ENERGY CONSUMPTION EVALUATED DURING THE INITIAL ENERGY AUDIT AT UNIVERSIDAD SAN FRANCISCO DE QUITO.

No.	Period of Evaluation	University Activities
1st	Dec. 23 - Jan. 8, 2015	Holidays (University Closure)
2nd	Feb. 5 - Feb. 29, 2016	Normal operating hours (inclusive on weekends)
3rd	Sep. 6 - Feb. 29, 2016	Normal operating hours (Area 2, inclusive on weekends)

The third step consisted of implementing a manual reporting system within the Maintenance Department to determine the frequency of light bulb changes in specific areas. Finally, the Security Department also developed a system for monitoring light shutdown in offices and common spaces to understand the behavior of administrative and academic personnel.

III. Results

A. First Phase Evaluation

1) Energy Costs: The monthly electricity consumption was about 240.701,00 kWh or $21,507 in electricity bill per month on average for the year 2015. There were not additional charges due to lower power factor since the power factor for all the period was of 0.92 or above. However, there were additional chargers due to peak demand.

2) Energy Audit: The results for the energy audit for USFQ were analyzed for each area evaluated. Fig. 2, for example, shows the peaks of power consumption obtained for the three-phase electric power from monitoring the Library (Area 1) during a full day during normal university opening hours, a regular Monday. Line graph traces L1, L2 and L3 correspond to phases R, S and T, respectively. The peak variations corresponds to the air conditioners, as each of the individual HVAC system controllers was set to different temperatures in the first and third floors, at 19.5°C and 24°C, respectively. This is particularly evident at 21:00h and 23:00h when two of the air conditioners were manually turned off and the third one had to compensate for the other two, generating therefore a 30 kW peak. Furthermore, it was also identified that only 3 out of the 20 air conditioning ducts were properly maintained, obstructing therefore the cold air that would signal the controllers to reduce air flow. During the holiday period evaluated, there weren't significant differences in terms of consumption (data not shown).

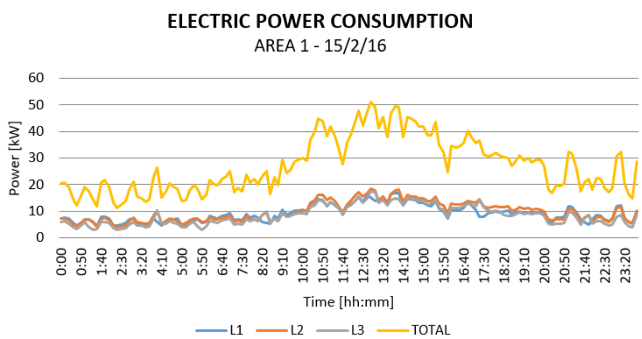

Fig. 2. Three-phase electric power consumption on Monday, February 15, 2016 at full capacity in the Library's area (Area 1) at USFQ. Line graph traces L1, L2 and L3 indicate the power phase L1 (R), L2 (S), L3 (T), respectively.

Fig. 3 shows the base-load consumption in the Kitchen's area (Area 2), during a holiday, December 25, 2015. The energy consumption shows an average Power consumption of 25 kW for all equipment and lighting maintained during that day.

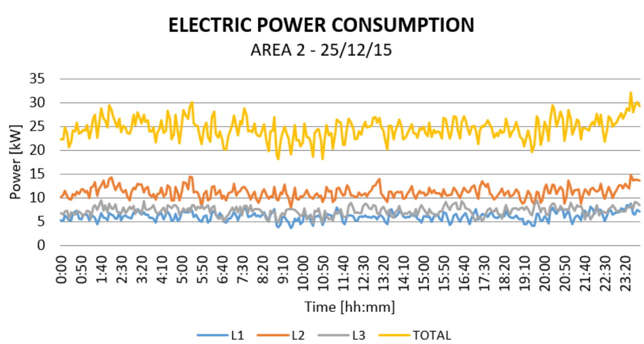

Fig. 3. Base-load three-phase electric power consumption during Friday, December 25, 2015 in the Kitchen's area (Area 2) at USFQ. Line graph traces L1, L2 and L3 indicate the power phase L1 (R), L2 (S)and L3 (T), respectively.

Fig. 4, on the other hand, shows the power consumption in the Kitchen's area during a normal working day. There are major issues of peak consumption related to the Kitchen's operation. The higher peaks observed were between 9:00h and 11:00h corresponding to hours in which the cold rooms are opened. Based on observations of the behavior of the kitchen's occupants, it was seen that the cold room's doors remained open for extended periods of time, despite that this was contraindicated in order to maintain the necessary temperatures inside the cold rooms, generating therefore a lag and increasing peak consumption.

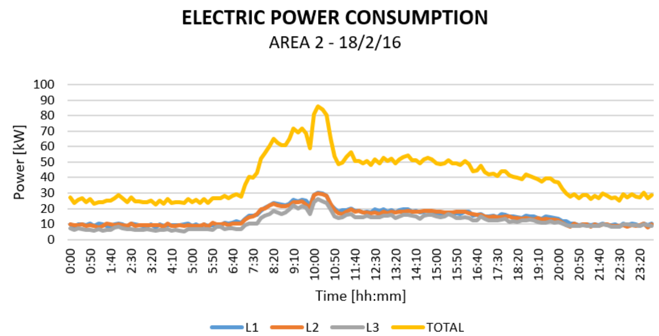

Fig. 4. Three-phase electric power consumption during normal operations on Thursday, February 18, 2016 in the Kitchens at USFQ. Line graph traces L1, L2 and L3 indicate the power phase L1 (R), L2 (S)and L3 (T), respectively.

3) Light Bulb Change Monitoring: Through the monitoring of light bulb changes it was possible to determine the lack of ground connections in some parts of the University's facilities, which makes light bulbs burn more frequently, reducing their lifetime by about 91%. This led to an average expenditure of $1,841 per month in 2016 only in new light bulbs.

4) Light Shutdown in offices and shared spaces: University guards have a policy of turning-off lights in rooms where there is no occupancy and to notify the occupants of offices that have leave their lights-on overnight. It was fortunate to see that this rarely happens and for the only two cases with recurrent scenarios, the administration directly approached the offenders to solve the issue. Furthermore, some areas in the University were identified as problematic; where one switch turned-on many light bulbs that do not necessarily correspond to the same area. Given current USFQ facilities and the exponential growth of the student population, electrical infrastructure has grown without a planned demand and these findings present an opportunity to properly perform the required retrofitting. Complementary to this study, there was an evaluation of the electrical loads wiring that needs to be replaced, separated or redesigned.

B. First Phase Implementation

After the initial energy audit was performed, energy charts and peak demands were obtained, and the daily energy consumption was analyzed. The energy cost during peak hours was also identified as an opportunity to change night operations to only one section of the University and to avoid keeping redundant lights-on around campus.

After these findings were presented to the administration, the stakeholders of the specific areas assessed during the energy audit were also notified, including the managers of the Kitchens (School of Gastronomy/CHAT) and the Maintenance

Department (Planta Física). The results were presented to the stakeholders and they were asked to deploy action plans for their respective areas while the OIS offered its support for planning, deployment and further evaluation. The following are the actions taken so far to reduce energy consumption around campus, including the first steps towards a second phase of equipment replacement and maintenance.

1) Lights: Considering the high usage of electricity in areas identified as with the highest occupancy, the opportunity of using new efficient technologies such LED illumination, and the high load due to illumination, a pilot program was implemented in order to change light bulbs from fluorescent or mercury-based energy saving bulbs to LED-based illumination. After a local market analysis, the highest efficiency savings were offered by the Spanish company AIRIS which offered an average of 84.7% savings in both Library and Kitchen areas according with the efficiency of their patented technology that includes integrated sensors and dimers in each light. They prepare the projections based on hours used currently, power required by each light bulb (previous vs current) and the availability/viability of the use of sensors depending on the area. The projected average savings per month were $2,032 or almost 9.44% of all costs associated with electricity bills at USFQ.

2) Air conditioning: Unnecessary temperature set-points were corrected in all library floors, HVAC system controllers were set to 23-25°C to preserve an adequate temperature for the books. Moreover, a maintenance plan for the air ducts was also implemented for a 4-month interval maintenance to ensure proper functionality over time. An outside contractor with the required expertise for this maintenance was hired to carry out this service.

3) Cold Rooms: An automated locking system was installed in the doors of the cold rooms, thus avoiding therefore that they remain open for continued periods of time and an appropriate training program for all the employees in the kitchens was given to ensure compliance of the new policy.

C. Implementation Evaluation

In order to compare energy consumption from before and after the implementation of the energy saving strategies, a new set of energy consumption measurements were collected through the use of an industrial power analyzer (HT Instruments PQA820 Three-phase Power Quality Analyzer) acquired by the University. The measurements corresponds to a period of evaluation (Sept. 6-25, 2017) during the normal university activities cycle that corresponds to an equivalent period in the semester as the first evaluation in February, within the third and fifth weeks into the semester, when operations have settled. For the second measurement period there were 7766 students in campus, while for the third measurement period there were 8861 students. In order to make a fair comparison between the measurement periods, only a 18 days period were compared among same weekdays.

Figures 5 and 6 show an example of the total power consumption for Area 2 before and after the saving strategies were implemented, respectively. As it can be seen, the power peaks in the last measurement period have decreased in relation to the peaks of the previous measurement periods.

Similarly, Tables III and IV show the maximum, minimum power in kW and the total energy consumption in kWh, obtained for the Kitchens (Area 2) during the measurement periods, before and after the implementation of the saving strategies. The Energy and power consumption values are also detailed in the tables according with their time-of-use pricing, the highest energy cost is from 7:00h to 22:00h, while the lowest energy cost is during off-peak from 20:00h to 7:00h, the peak demand during peak hours is from 18:00h to 22:00h.

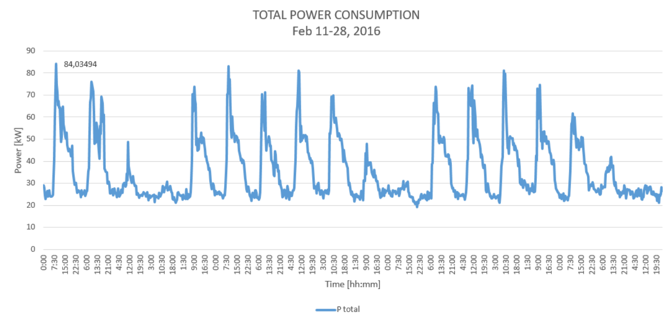

Fig. 5. Total electric power consumption during the measurement period 1 (Feb. 11-28, 2016). The highest power peak demand was 84.03 kW

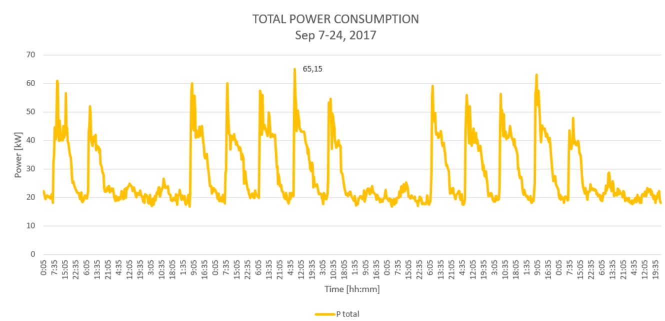

Fig. 6. Total electric power consumption during the measurement 3rd period (Sept. 6-25, 2017). The highest power peak demand was 65.23 kW

TABLE III
TOTAL ELECTRIC POWER CONSUMPTION FOR AREA 2 DURING THE 2ND MEASUREMENT PERIOD (FEB. 11-28, 2016).

Parameter	Power kW	Energy kWh
Max	84.03	14.01
Min	16.54	4.14
Total		5,111.53
Energy Consumption 7:00h-22:00h		3,820.03
Energy Consumption 22:00h-7:00h		1,291.50
Peak Demand 18:00h-22:00h	47.05	
Peak Demand 22:00h-18:00h	84.03	

Table V, on the other hand, shows a comparison for the daily average energy consumption and the peak demand for

TABLE IV
TOTAL ELECTRIC POWER CONSUMPTION FOR AREA 2 DURING THE 3RD MEASUREMENT PERIOD (SEPT. 7-24, 2017).

Parameter	Power kW	Energy kWh
Max	65.15	16.29
Min	16.72	4.18
Total		6,046.92
Energy Consumption 7:00h-22:00h		4,507.57
Energy Consumption 22:00h-7:00h		1,539.35
Peak Demand 18:00h-22:00h	38.61	
Peak Demand 22:00h-18:00h	65.15	

TABLE V
DAILY AVERAGE ENERGY CONSUMPTION FOR THE 2ND AND 3RD MEASUREMENT PERIODS

Parameter	2nd Period	3rd Period
Period of days to compare	Feb 11-28, 2016	Sep 7-24,2017
Peak Power (kW)	84.03	65.15
Daily average Energy (kWh) 7:00h-22:00h	6.85	8.08
Daily average Energy (kWh) 22:00h-7:00h	4.22	5.03

both periods. As it can be seen, although the daily average energy consumption for the second measurement period was less (6.85 and 4.22 kWh) than during the third one (8.08 and 5.03 kWh) for peak and off-peak demand hours, the daily cost of energy for the second period ($196.48) is higher than the cost of energy for the third period ($182.59), since the energy cost also depends of the peak demand consumption during the measurement period.

The maximum peak demand before the implementation of energy saving actions was of 84.03 kW while in the most recent measurement period it was 65.15 kW, proving that a 22.46% of electric power saving was achieved. From the energy cost analysis, a reduction of about 7,07% was obtained in maximum peak hours, which represents about $13,89 of savings per day, taking only the Area 2 into account and only the daily average energy. A reduction in peak consumption has been achieved despite the fact that energy demand has increased. Consequently, it may be concluded that the solutions applied in the Area 2, which correspond to the improvements of the cold room areas, provide positive energy saving results.

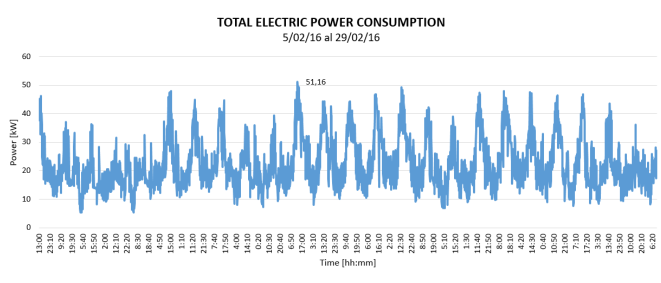

Fig. 7. Total electric power consumption during the measurement period 1 (Feb. 5-29, 2016). The highest power peak demand was 51.16 kW

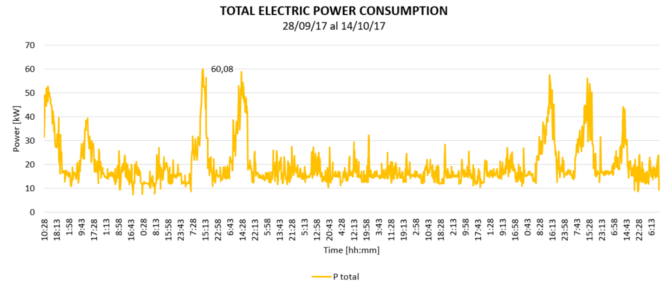

Fig. 8. Total electric power consumption during the measurement period 2 (Sept. 28 to Oct. 14, 2017). The highest power peak demand was 60.08 kW

The analysis of Area 1 is more complex since the operation of the HVAC systems also depends on environmental conditions, the following studies will monitor temperature to assess degree-days for HVAC demand. Moreover, area 1 being a library has to guaranty luminosity that is adequate for reading. The lumens available were increased for the area while identifying that previously the light provided was not suited for continuous reading conditions. Fig.7 shows the total electric power consumption during the initial measurement period 1 (Feb. 5-29, 2016). The power peak demand was 51.16 kW for such period. Fig.8, on the other hand, shows total electric power consumption during the measurement period 2 (Sept. 28 - Oct. 14, 2017). The power peak demand in this case was 60.08 kW. Although, the peak demand has increased for this measurement period, which may be due to HVAC operation as a result of high temperatures for weather conditions, the overall number of power peaks has decreased considerably as it can be observed in the graph of Fig. 8 in contrast to the initial measurement period 1 (Feb. 5-29, 2016) shown in Fig. 7, demonstrating therefore that a reduction in the average energy consumption was also achieved for Area 1.

IV. CONCLUSIONS AND MOVING FORWARD

There are many opportunities to improve the energy efficiency practices at different levels at USFQ Campus. Starting with using IPCC's principles for energy efficiency both in planning and operations but also in deploying an appropriate dynamic model to evaluate all the initiatives being implemented that slowly guide the initial equipment and maintenance changes, start to form the required policies and also measure and guide the best strategies for behavioral changes on campus. The use of retrofitting will turn USFQ into a model for other universities with existing infrastructure to have an energy efficiency program that does not compromise its technological and research development and that could even create savings that generate resources for further research and implementation of future initiatives. It is important to mention that, despite the growth of the university population, considerable savings have been achieved. This also further shows environmental benefits by reducing the environmental footprint of the university by 6893.22Mg CO_2 yearly considering the latest published emission factor for Ecuador with 313g CO_2 per each kWh produced [16]. This energy efficiency benefits complement the decarbonizing initiatives of Ecuador reducing the carbon footprint of the university as the emission factor decreases.

The continuous improvement of these programs is crucial to ensure energy efficient methods. The next opportunities in equipment implementation include the collection of data from the newly installed illumination through monitoring software to start projects on Internet of things and big data. We are also planning to install a Non-Intrusive Load Monitoring (NILM) prototype system [14], [15] for identifying individual loads from energy signature profiles. The deployment of NILM technology could facilitate the energy commissioning process by identifying the consumption of specific equipment generating peaks and informing about it to the users, this has also been recognized as an opportunity as the behavioral change approach to energy efficiency measures rises. It is also crucial to continue the collaboration in energy monitoring with stakeholders to ensure follow-up and to define the metrics of success in energy efficiency. Finally, this is a study that shows the opportunities of using the campus as a living laboratory, involving a multidisciplinary team of faculty and students in experiential learning and implementation on site. This has the potential to further promote sustainability not only with academic theory but with evidence that energy efficiency programs can be applied and scaled on campuses, industry and elsewhere.

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