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Achieving a Net Zero Energy Retrofit – in a humid, temperate climate – lessons from the University of Hawai’i at Mānoa:

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Energy Technologies Area

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Achieving a Net Zero Energy Retrofit —

in a humid, temperate climate — lessons from the University of Hawai'i at Mānoa

Architectural rendering of the Kuykendall Hall retrofit, classroom wing in the foreground, office tower in the background.

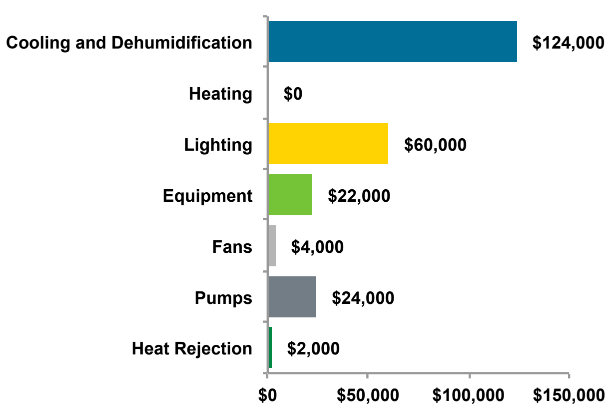
Source: Ben Woo Architects

Overview

The University of Hawai'i at Mānoa (UHM) partnered with the US Department of Energy (DOE) and the Hawai`i Clean Energy Initiative to develop and implement solutions to retrofit exiting buildings to reduce energy consumption by at least 30% as part of DOE's Commercial Building Partnerships (CBP) Program[1]. Kuykendall Hall, located on the UHM campus in Honolulu, was the focus of a CBP analysis and design collaboration among the University of Hawai'i, their consultants, and Lawrence Berkeley National Laboratory (LBNL). Kuykendall Hall consists of two 1960s-era wings – a four-story wing containing classrooms, and a seven-story tower containing offices – with a total floor area of approximately 76,000 square feet (ft^2).

The retrofit design, which uses local prevailing winds to aid ventilation and cooling and incorporates envelope and lighting elements that reduce the need for cooling, is on track to use about 76% less energy than the current building, exceeding the CBP's 30% savings goal. With the addition of building-mounted solar electric panels, the retrofitted building is expected to achieve net-zero annual energy use. Achieving net-zero energy addresses an emerging challenge to the university – how to lower energy usage and reduce dependence on imported fossil fuel in the face of already-high energy prices that are forecast to double by 2040.

Expected Energy Cost Reductions



Project Type	Higher Education, Classrooms and Offices, Retrofit
Climate Zone	ASHRAE Zone 1C, Warm and Humid
Ownership	Public
Barriers Addressed	• Conventional design practice; focus on air conditioning • Existing energy management practices • Campus policies on thermal comfort, interior and exterior noise
Square Footage of Project	76,000
Expected Energy Savings (vs. existing energy use)	~76%
Expected Energy Savings (vs. average energy use)	Not Available
Expected Energy Savings (vs. ASHRAE 90.1-2007)	547,159 kWh/Yr
Projected Energy Savings (vs. existing)	686,137 kWh/Yr
Expected Cost Savings[2]	~$234,000 (Yr. 1) ~$758,000 (Yr 30)
Project Simple Payback	24 years[2,3]
Expected Carbon Dioxide Emissions Avoided	~589 Metric Tons per Year[4]
Construction Completion	TBD

1. 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, selected through a competitive process, team with U.S. Department of Energy (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.
2. Cost savings are based on average commercial electricity rate for Hawaii. First year is based on $0.344 / kWh annual average for 2013, U.S. DOE, EIA (SEDS), Year 30 is based on 4% per year escalation.
3. Includes cost of acoustic attenuation equipment, estimated at $2,700,000. The need for this additional level of acoustic attenuation may not be typical of a need on other projects. Without this cost the simple payback would be 19 years.
4. Assuming electricity carbon factor for Hawai'i of 0.858 metric tons / Mega-Watt hour (EIA).

Not only will the retrofit dramatically reduce Kuykendall Hall's annual energy costs, but the project lays the groundwork for new campus policies, processes, and low-energy design approaches and contributes to a campus knowledge base on low-energy practices. As such this project is an important step towards the UHM goals of 50% energy reduction by 2015, and energy self-sufficiency by 2050. This project is a model of integrated design and building delivery that will be replicated in future projects on the campus.

This first "deep energy retrofit" project at the University of Hawai'i engaged the university in defining new retrofit objectives and processes, enacting policies to help realize the project's low-energy goals, and helped disseminate these innovations across the organization. This project also aimed for a climate-appropriate, cost-effective, integrated low-energy design that provides a comfortable, healthy working environment. A key concomitant of the retrofit design process was creating a new campus thermal comfort standard, which defined thermal comfort ranges for different conditioning strategies such as natural ventilation and air conditioning. For example, a wider interior temperature range is considered comfortable when occupants are connected to the outdoors, as in a naturally ventilated building. The new standard allows higher temperature setpoints to be used in warmer months, translating into energy savings. A campus thermal comfort standard was also useful for campus decision makers and facilities personnel to understand the benefits of different strategies, such as the comfort benefits of ceiling fans, and to set quantifiable comfort parameters to help aid in the design and operations phases. From this process DOE has lessons learned about how similar projects can achieve deep substantial energy savings in humid, temperate climates.

The figure on the first page illustrates that the design selected for UHM's Kuykendall Hall reduces consumption within all major energy end uses. The reduction in cooling and interior lighting energy use resulted primarily from meeting energy needs through passive design.

Decision Criteria

UHM decided early in the project to evaluate several whole-build-ing approaches. These ranged from a low-energy, sealed, fully mechanically conditioned option to a mixed-mode conditioning strategy and an overall design that emphasized natural ventilation and ceiling fans for cooling and comfort control. The naturally ventilated design included a nighttime dehumidification cycle to control moisture and mold. For UHM, the criteria for selecting the preferred design were cost effectively ensuring occupant comfort while meeting energy savings goals and contributing to the university's longer-term energy self-sufficiency targets. Acoustic comfort was also a key factor for all designs, particu-larly for naturally ventilated modes of operation.

Occupant Comfort

The design that UHM selected had to provide a comfortable environment. Thermal comfort, acoustics, indoor air quality, and lighting were all problem areas in the existing building, and UHM wanted high performance in the new design. The design and analysis team was asked to provide quantified performance results for these areas in each design.

- Thermal comfort – For each design option, hourly interior thermal comfort information, such as interior dry-bulb temperature, was provided from the building's energy model and compared to the campus's thermal comfort standard, which allowed a small number of hours in which the criteria could be exceeded (typically fewer than 40 hours per year during occupied periods). This information was also used to identify areas where the design could be improved and retested. Thermal comfort criteria were developed specifically for this project to provide clear guidance on other items such as the cooling degree benefits of ceiling fans.
- Visual comfort – To demonstrate effective, comfortable daylighting for various envelope designs as well as the quality of interior lighting, key spaces were modeled using RADIANCE. Over the course of a year, lighting metrics were assessed for each design. Because direct solar gain has a huge impact on occupant comfort, shading designs were assessed for their ability to prevent direct solar gain, with the aim of allowing solar gain during only a few winter hours.
- Indoor air quality – The existing building experienced significant issues in mold and airborne particulates. Each new design needed to demonstrate effective means to mitigate and manage these conditions. Interior humidity levels and areas of potential condensation were reviewed in detail, as were materials selections and air filtration methods.
- Acoustic comfort – Acoustic performance was a high priority for the project stakeholders, so the team worked to establish interior acoustical criteria sensitive to the needs of each stakeholder group. For the natural ventilation condition, interior acoustical standards of Noise Criterion (NC) 45-50/50-55 decibels (dBA) were set for classrooms and offices respectively, adjusting standards for acoustics readings taken for sealed buildings, to take into account occupant acceptance of and adaptation to exterior background noise in a naturally ventilated building. This adjustment took into account industry research on situations in which occupants expect background noise and accept it because they enjoy the non-acoustic benefits of natural ventilation. For the sealed condition, acoustic standards of NC 30/40dBA and NC 35/40dBA were set for classrooms and private offices, respectively. The team took acoustic measurements of the existing exterior environment to use in acoustic evaluations of the building interior spaces for each design option. Feedback on acoustic performance was also used to improve on the design. UHM also identified campus policies that could reduce exterior noise sources, such as mandating electric leaf blowers instead of gas-powered devices, designing landscapes to discourage skateboarding near the building, and rescheduling or eliminating other noise sources, e.g., by creating a pedestrian zone to replace an adjacent street and thus eliminate car and moped noise.

Economic

UHM evaluated the packages of energy-efficiency measures for each proposed whole-building strategy based on capital cost, annual operating cost, and annual energy savings.

- The cost-effectiveness assessment was based on comparison to the alternative strategies, using the overall reduced energy costs resulting from the combination of efficiency measures rather than each individual measure. Once a preferred whole-building strategy was selected, further detailed design of that option included additional analysis of individual energy-efficiency measures on a line item basis. This approach allowed the campus to assess different whole-building strategies from several perspectives – energy savings, thermal comfort, acoustic comfort and cost – prior to selecting a strategy to be optimized in a design.
- The overall capital cost of the project was compared with the cost of a complete demolition and replacement of the building. The project needed to be cost sensible as an investment in re-using the building structure rather than starting over from scratch.
- Because the State of Hawai'i faces uniquely high electricity costs and a high rate of projected energy cost escalation during the next few decades, UHM placed great value on energy-saving strategies in the analysis. Escalating energy pricing was taken into account in evaluating the paybacks of the building design options.
- Utility rebates were not available for this project during its design phase but are being investigated in later phases of the project.

Operations

UHM targeted operational elements that would ensure a healthy, manageable, and sustainable transition to low-energy practices on campus:

- Simplicity of design and control strategies – These elements were scrutinized in all options because they affect the cost of training staff and operating and maintaining the building. Although UHM expects that staff will need to learn some new controls and systems, these project elements were chosen strategically to maximize overall value and impact.
- Replicability/potential for application elsewhere – UHM targeted design solutions that are applicable to other facilities on campus and could be considered for incorporation in other projects. Replicating design features maximizes the value of training staff to operate and maintain them. Applying solutions from this retrofit to other campus projects will help to institutionalize, among UHM's design and operations professionals, the CBP project's investment in expertise on low-energy retrofits.

Policy

UHM is the university's largest campus and is charting the path towards sustainability for the University of Hawai'i's entire building portfolio. The university's energy reduction commitments are:

- 30% site energy reduction by 2012.
- 50% site energy reduction by 2015.
- self-sufficient in energy (and water) by 2050.

The State of Hawai'i's Clean Energy Initiative focuses on improving energy efficiency and producing more of the state's electricity from renewable sources with a target of 70% clean energy by 2030. Of that, 40% is to come from renewable energy production and 30% from energy-efficiency improvements. These goals were not set simply for the branding benefit of sustainability but in acknowledgment of real economic repercussions from rapidly escalating prices for imported fossil fuel based energy.

Energy Efficiency Measures Snapshot

The conceptual energy modeling and analysis for this project focused on selecting a whole-building design strategy from among several options based on the relative energy, cost, and overall performance of each option, as summarized in the table below.

- Energy savings are shown for packages of measures rather than for individual measures to capture the overall impact of the measures on the whole-building design option.
- Escalated energy rates consistent with projections from the Energy Information Administration (EIA) were used in this analysis, ranging from $0.340/kWh for year-1 operations to $1.104/kWh for year-30 operations and beyond.
- Options to reduce life-cycle costs, such as rebates from the local utility provider or maintenance savings, were not assessed and are not included in the results.
- Further development of the selected whole-building design strategy will involve more detailed analysis of the individual energy efficiency measures and their cost and energy savings impacts.
- All EEMs included in this project would be considered for future projects.

Energy Efficiency Measures

	Cost of Energy Efficiency Measures	Expected Annual Savings		Cost of Conserved Energy (CCE[5]) ($/kWh)	Simple Payback (years)
		kWh/year	$/year		
Lighting	$9,261,680[6]	686,137	~$236,000[7]	0.96[5]	24[5]
Classrooms – lighting power density (LPD) reduced to 0.48 watts per square foot (W/ft^2) using T5 direct/indirect pendant light fixtures					
Office Tower – LPD reduced to 0.40 W/ft2 using sidewall strip T5 and overhead light- emitting diode (LED) wall washer					
Office Tower – lighting energy use reduced by emphasizing task lighting, LED task lamp, lower ambient lighting levels at 15 foot-candles					
Classroom – daylight dimming controls					
Office Tower – lighting wall switch controls with occupancy sensor, manual on / auto off configuration, daylight dimming controls					
Envelope					
Classroom — new double-pane low-emissivity (low-e) glazing (U-value=0.25, solar heat gain coefficient (SHGC)=0.39, visual transmittance (VT)=0.72)*					
Classroom – operable windows with actuators (manually controlled except for automated closure before dehumidification cycle)*					
Classroom – exterior glazing area and shading optimized to almost eliminate direct solar gain into the space over the course of the year*					
Classroom – automated louvers and sound attenuated natural ventilation intake boxes*					
Office tower – new double-pane, low-e glazing (U-Value=0.25, SHGC=0.39, VT=0.72)* Classroom – operable windows with actuators (manually controlled except for automated					
Office tower – operable windows with actuators (manually controlled except for automated closure before dehumidification cycle)*					
Office – exterior glazing area and shading optimized to nearly eliminate direct solar gain into the space over the course of the year*					
Office Tower – sound attenuated natural ventilation intake boxes*					
HVAC					
Classrooms – natural ventilation, cross-flow through classrooms over double-loaded corridor through low-pressure duct distribution to relief on opposite side of building*					
Classrooms – manually controlled ceiling fans for increased airflow and comfort*					
Offices – manually controlled ceiling fans for increased airflow and comfort as needed					
Classrooms – central mechanical fan assist for increased airflow when natural ventilation and ceiling fans are insufficient for comfort					
Classrooms – nighttime dehumidification					
Classroom corridors – higher air velocity and a higher set point (approx. 82F) to create a comfortable transition environment for occupants prior to their settling in classrooms for sedentary activity					
Offices – natural ventilation through operable window, relief over corridor via low-pressure drop duct system with acoustic attenuation					
Classrooms – 590-kilowatt (kW) direct-expansion (DX) roof-top unit (RTU) with efficiency of 1.17 kW/ton; unit provides daytime fan assist ventilation (no cooling) or nighttime dehumidification					
Offices – 80-kW DX RTU with efficiency of 1.17 kW/ton for nighttime dehumidification*					
Classrooms – chilled water system with 0.72 kW/ton efficiency, including cooling tower with 2-speed fans, 195-kW chiller, fan coils, 2-way control valves to supply high-internal- load spaces such as auditorium and server room					

* EEM is climate dependent.

5. CCE calculated with 5% discount rate for 25 years (Meier, 1984).

6. Includes cost of acoustic attenuation equipment, estimated at $2,700,000. The need for this additional level of acoustic attenuation may not be typical of a need on other projects. Without this cost the simple payback would be 19 years and CCE would be 0.68.

7. Calculated at 2012 energy cost.

Energy Use Intensities by End Use

Energy modeling was a vital part of the decision-making process for the Kuykendall retrofit. UHM was committed to not only meeting the CBP's 30% energy savings goal for retrofits but also meeting or exceeding the university's goal of 50% savings. Each design was assessed with regard to these targets. The energy performance of the three alternatives proposed by the project team was modeled using EnergyPlus simulation software.

The energy models were created during the project's conceptual design stage using inputs from construction drawings. Metered energy and weather data collected from the site were used both to calibrate the existing building model and to help assess natural ventilation strategies. These pre-retrofit data were immensely valuable in refining the design and building a level of confidence in system performance, especially for the naturally ventilated option. For data collection, UHM made an investment in a wireless metering system that will be used in developing future retrofit designs and assessing building performance.

Four different energy models were created to compare each of the designs. The first was the baseline, representing the existing building, against which the alternatives were compared to estimate energy savings. The three proposed alternatives were a natural ventilation and dehumidification system, a mixed-mode system, and a fully sealed, air-conditioned system.

Energy savings from the fully sealed, air-conditioned building fell substantially short of the CBP 30% target. The mixed-mode system met the 30% CBP target but was significantly less than the university's 50% target, as well as being the most expensive option. With a design reduction in energy use of around 76%, the natural ventilation and dehumidification design substantially exceeded the targets of both the CBP and the University. UHM chose the natural ventilation and dehumidification design for the final design.

Pre-retrofit Design

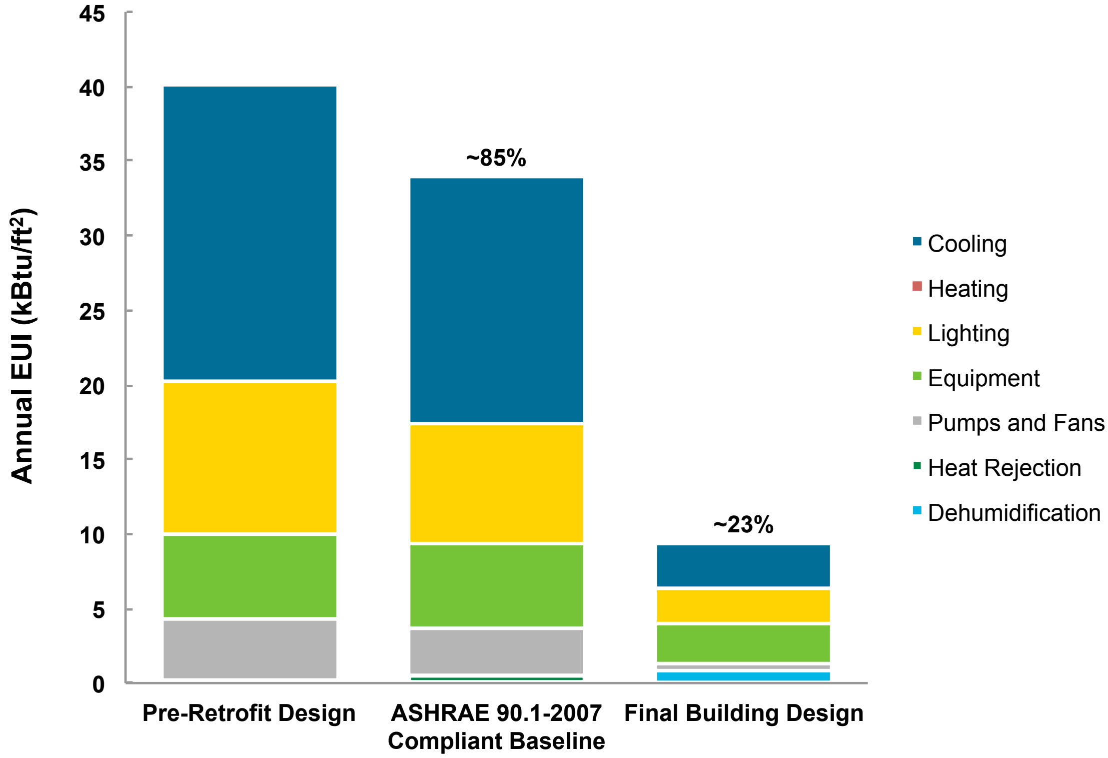
The existing building has an annual site energy use intensity (EUI) of about 40.1 kBtu/ft2.

Retrofit Design

The retrofit design relies heavily on natural local air currents to meet the building's cooling and ventilation needs, with a nighttime mechanical dehumidification process to keep interior moisture levels in check. The mechanical ventilation system provides backup ventilation when natural ventilation and ceiling fans are not sufficient to maintain interior comfort. Energy savings results from the minimal use of the building's heating, ventilation, and air-conditioning (HVAC) system. The minimal HVAC requirements also result from the design's emphasis on daylighting and lowered lighting power density (LPD). This design has an annual EUI of approximately 9.4 kBtu/ft^2.

The energy demand of the pre-retrofit building illustrates that the largest energy reduction potential is from cooling and interior lighting. Of the proposed design alternatives, the natural ventilation and dehumidification design was best able to reduce energy demand while meeting occupant requirements. It achieves these two goals by capitalizing on the local prevailing winds, using ceiling fans to reduce demand for mechanical cooling, and relying on daylighting to reduce demand for electric lighting energy. Two new end uses, tempering of the classroom building hallways and nighttime dehumidification introduced to improve comfort and improve indoor air quality, have modest energy consumptions.

Comparing EUI of Pre-retrofit Design and Proposed Designs for Kuykendall Hall



Expected Annual Energy Use and Percentage Savings by End Use

End-Use Category (electricity)	Existing Building Baseline	ASHRAE 90.1-2007 Compliant Baseline	Final Building Design	
	Annual EUI (kBtu /ft²)	Annual EUI (kBtu /ft²)	Annual EUI (kBtu /ft²)	Percent Savings Over Existing
Cooling	20.0	16.5	2.9	85%
Heating	0.0	0.0	0.0	N/A
Lighting	10.3	8.1	2.4	77%
Equipment	5.6	5.6	2.7	51%
Pumps and Fans	4.1	3.2	0.4	90%
Heat Rejection	0.3	0.5	0.0	100%
Dehumidification	0.0	0.0	0.9	N/A
Total Savings	**40.2**	**33.9**	**9.4**	**77%**

Expected Building Energy Savings from Implemented EEMs by End Use

Electricity End Use Category	Energy Savings
Cooling and dehumidification	359,500 kWh
Heating	0 kWh
Lighting	175,300 kWh
Equipment	63,900 kWh
Pumps / Fans	81,200 kWh
Heat Rejection	6,300 kWh
Total Electricity Savings	**~686,100 kWh**

Lessons Learned

As part of the CBP work in on the UHM campus, UHM and DOE learned lessons that can assist in the design of naturally ventilated buildings in temperate, humid climates.

"The new thermal comfort criteria adopted by UHM, guides the synthesized design and long-term operational considerations that are embedded in this innovative project. The Kuykendall renovation is a fully integrative design approach that is based on building science metrics and collaboration. The design and analysis process, as well as the final building product, will provide positive, transferable lessons for other campus buildings. This zero net fossil fuel building renovation is a game changing commitment that we hope will be emulated and surpassed throughout the university, the state and region long into the future."

— Steve Meder

Assistant Vice Chancellor for Physical, Environmental, and Long-Range Planning, University of Hawai'i at Mānoa

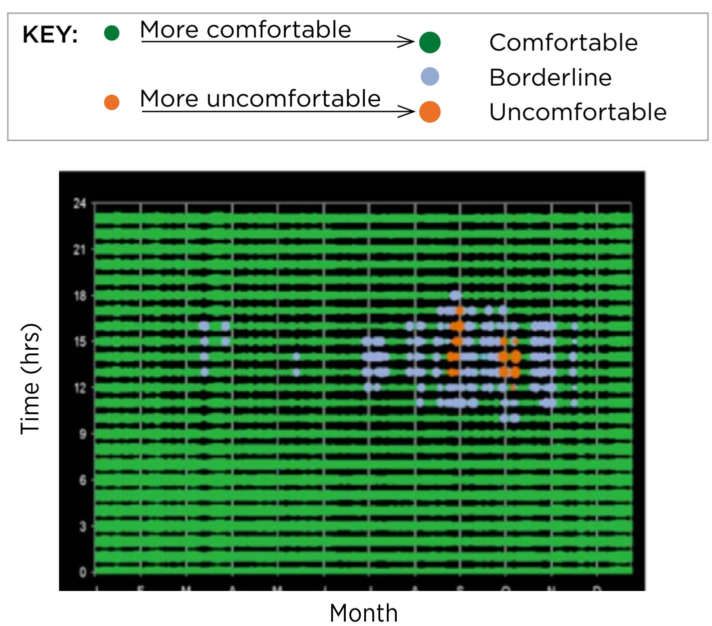
Campus Policies Can Enable Greater Energy Savings

Several energy saving measures in this project were made possible by the campus's flexibility in enacting supportive policy. One example is the campus's creativity in seeking solutions to address exterior noise to ensure optimum acoustic comfort for occupants of the naturally ventilated building chosen as the preferred design. As mentioned earlier, several measures that have been considered included changes in landscape practices and use of an adjacent street.

Set Thermal Comfort Criteria Early for All Modes of Operation

A collective discussion and agreement about how thermal comfort should be delivered is key to making design decisions and selecting HVAC systems based on clear, measurable parameters; this is especially true in climates such as Hawai'i's where natural ventilation is a viable alternative. A pre-retrofit occupant survey help identify existing thermal comfort issues, such as the one administered at UHM by the University of California Berkeley's Center for the Built Environment (CBE). The thermal comfort criteria developed for UHM were based on American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) Standard 55-2010 – Thermal Environmental Conditions for Human Occupancy as well as on CBE's research. Criteria were set for acceptable interior conditions for each type of use in the building. The criteria included quantified comfort benefits for devices such as ceiling fans and, as described earlier, specified a small number of hours per year when the building could exceed the criteria.

Having an open discussion about thermal comfort delivery serves other purposes. It allows all stakeholders to become educated regarding how thermal comfort is provided, which can facilitate effective long-term operations for the building. In this case, as noted above, the criteria established quantifiable parameters against which design options could be assessed. The inset graphic shows an annual thermal comfort output for building design that was selected, indicating the degree of comfort for each hour of the year. The team determined that interior conditions up to 1 degree F outside of the thermal comfort range would qualify as a "borderline" comfort condition, and conditions that varied more than 1 degree F outside of the comfort range would qualify as uncomfortable. The graphic indicates that uncomfortable periods are relatively few, occurring in the late summer and fall. Using this guidance, further design development can be undertaken to target the key periods when comfort falls outside the specified zone to improve the building's thermal comfort performance.



Annual thermal comfort results — A visual tool used to assess hourly thermal comfort performance over the course of a year.

Source: Loisos and Ubbelohde

Pilot Projects Are Opportunities for Capacity Building

With the launch of this flagship deep energy savings project at UHM came a need to quickly educate all campus stakeholders and project participants about low-energy design strategies and benefits. UHM took this project as an opportunity to initiate ground-breaking changes in project delivery and execution. Among the changes was the development of new campus lighting standards for offices and classrooms, new acoustic criteria, new thermal comfort criteria, new decision-making criteria that weighed project decisions in the context of larger energy savings and sustainability goals, and initiation of an integrated design delivery method for campus projects. UHM took an additional step to build capacity for low-energy projects locally by including on-site staff and architecture students in the project. These participants helped perform baseline metering of the existing building and conduct a pre- and post-retrofit survey of the building occupants. The importance of pre-retrofit energy use and environmental data for a project cannot be overstated. These data inform energy savings and economic designs and guide the improvement of elements that are problematic in the pre-retrofit building. UHM invested in a robust wireless metering system that can be used in other buildings to understand existing energy use and thereby guide future retrofits. UHM also made use of technical expertise brought to the project, energy and architecture consultants Loisos and Ubbelohde, who were invited to give an on-site workshop on low-energy lighting design for the local architecture and engineering community. Flagship projects can be learning experiences for all stakeholders, laying the groundwork for the success of future projects.

References and Additional Resources

179D DOE Federal Tax Deduction Calculator
http://apps1.eere.energy.gov/buildings/commercial/179d/

Advanced Energy Retrofit Guide for Office Buildings
http://apps1.eere.energy.gov/buildings/commercial/resource_database/

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