Positively Net Zero: Case Study of Performance Simulation and Hitting the Targets

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ABSTRACT

The actual energy performance of three mixed-mode net zero energy (NZE) classrooms aligned closely to the predictive building simulation models used to estimate classroom performance in two different microclimates in Hawaii. Energy consumption by circuits, energy generation, temperature, relative humidity, CO_2 concentration, and interior light levels were monitored for over two years to determine the relationships among physical building characteristics, environmental factors, and energy consumption.

EnergyPlus™ and other computational tools were utilized to predict energy loads and photovoltaic (PV) generation. After completing data collection in 2015, the structures met the NZE design expectation, with two notably net positive on an annualized basis. During design, three simulated energy prediction scenarios were created to bracket a range of performance possibilities: “High Estimate”, “Anticipated Performance”, and “Optimal Performance”. Each of the energy efficient, grid-tied structures featured a 5 kW photovoltaic renewable energy system.

The structure in the hotter microclimate on the island of Oahu used air conditioning throughout the year and performed slightly over the “High Estimate” yielding an actual site energy use intensity (EUI) of 7.7 kWh/sf/yr (26.3 kBTU/sf/yr). The two structures on the more temperate island of Kauai realized average site EUIs of about 3.8 and 5.6 kWh/sf/yr (13.0 and 19.1 kBTU/sf/yr) due to less mechanical cooling. The two Kauai structures exceeded net zero energy goals, while the Oahu fell slightly short. These differences in both energy consumption and PV generation are due to differences in microclimates, operational policies, and user awareness and response to the internal environment.

Introduction

Project FROG (Flexible Response to Ongoing Growth) began a collaboration with the Office of Naval Research (ONR) in 2008 to provide a high performance, quickly-deployed, cost-effective, energy-neutral building concept that integrates modular component prefabrication and is tailored to the Pacific region with potential to mass-deployment. Initial stages of research in materials and systems performance, manufacturing, installation cost-effectiveness and logistical efficiency of shipping, resulted in a pre-engineered “kit-of-parts” design. In 2009, Project FROG and ONR then collaborated with University of Hawaii’s Hawaii Natural Energy Institute (HNEI) to pilot-test the effectiveness of the net zero energy design, building technologies and alternate energy systems as adapted for different tropical climatic conditions of the Pacific region. The project team selected two sites for the installation of three FROG research platforms to be used as school classrooms: one at Ilima Intermediate School on the island of Oahu and two at Kawaikini School New Century Public School on the island of Kauai. Construction took place between 2009 and 2013 followed by two years of monitoring and data collection (March 2013-June 2015). An image of the Ilima FROG is shown in Figure 1.

In this case study, the authors compare the results of predictive energy modeling to actual recorded data for three net zero energy buildings in Hawaii. While two years of data were collected, due to sensor and equipment performance issues, only the 12-month period from July 2014 through June 2015 is used as the evaluation period. This paper identifies the sources and magnitude of uncertainty that can go unaccounted for in a simulation model. The NZE modeling suggests that physical characteristics and operational assumptions can be modeled to represent boundary conditions for a range of expected performance. However, up to 50% of the annual energy consumed can be attributed to user-response to the environment which can be driven by routine, habits, knowledge of equipment and their use.

Using a predictive model, three levels of performance were defined: “high estimate”, “anticipated estimate” and “optimal performance estimate”, each based on varying assumptions for the heating, ventilating, and air conditioning (HVAC) set point, daylighting, ceiling fans, and natural ventilation. A target energy use intensity (EUI) is derived from the “anticipated” performance simulation, 4.7 kWh/sf/yr (16.0 kBTU/sf/yr) for the Kawaikini structures (on Kauai) and 5.2 kWh/sf/yr (17.7 kBTU/sf/yr) for the Ilima structure (on Oahu).

Project Description

Test Platform Design Features and Building Elements

These platforms utilize prefabricated components, easily shipped in standard 40-foot shipping containers and assembled onsite. The design is modular-like, consisting of a central high volume, the spine, and wings located on either side of the spine. Figure 1 shows the completed building as well as examples of modular components. The platforms use both passive and active cooling and ventilation systems to ensure thermal comfort while using energy efficiently. The envelope features a cool roof and low-e glazing, high values of thermal insulation, high and low operable windows and clerestories, large roof overhangs and architectural sun shades, louvered air inlet wall apertures for natural ventilation and cooling, enhanced by a roof exhaust fan when conditions call for it.

Figure 1. Project Frog Ilima Int. School, Ewa Beach, Hawaii. Finished bldg. (left), wall panels (center), window components (right).

The FROG test platform was designed to maximize daylight autonomy such that electric lighting is not required. The daylighting studies indicated that daylight autonomy is expected to occur over 95% of the time during occupied hours at each project location. To support natural daylight the other 5% of the time, high efficiency direct/indirect lighting is used. Each light fixture is outfitted with a Lutron EcoSystem® ballast that works in conjunction with daylight and occupancy sensors to automatically adjust lighting levels. FROG platform characteristics are summarized in Table 1.

Table 1. Project FROG key building features summary

Building name	Kawaikini East	Kawaikini West	Ilima
School name	Kawaikini New Century Public Charter School	Kawaikini New Century Public Charter School	Ilima Intermediate School
Building type	Component/Modular project FROG		
Use type	Classroom		
Grade level	7-12	7-12	7-8
Orientation	North-facing		
Tropical Microclimate	Warm (<75°F avg.) Humid (>70% RH avg.) Cloudy (<260 W/m^2/mo.)	Warm (<75°F avg.) Humid (>70% RH avg.) Cloudy (<260 W/m^2/mo.)	Hot (>75°F avg.) Dry (<70% RH avg.) Sunny (>260 W/m^2/mo.)
Year built	2013	2013	2010
Building area	1,280 ft^2		
Glazing / wall ft^2	750 ft^2 / 1,785 ft^2 = 42%		
Electricity Costs	Energy Charge: ~$0.35/kWh	Energy Charge: ~$0.35/kWh	Energy Charge: ~$0.28/kWh

The energy features of the FROG research platforms include:

- R-24 walls; R-22 and R-30 roof decks.
- Operable louvers at the base of the solid wall panels for natural ventilation.
- High and low operable windows for natural ventilation.
- Low-e, PPG Solarban 70XL glazing (SHGC=0.27; U=0.24; VLT=64%).
- Roof mounted exhaust fan at high point of the roof for fan induced ventilation.
- Direct/Indirect fluorescent T8 lighting with photosensor daylight control.
- Nine variable speed ceiling fans.
- High efficiency split system fan coil and condensing unit (EER/SEER: 11.0/13.5).
- PV systems: 5.24 kW per structure.

The purposes of the field tests were: 1) to study how the FROG platforms perform with respect to daylighting, energy efficiency, thermal comfort, indoor air quality (IAQ), material durability, and energy consumption; 2) to test the ability to self-generate energy to offset consumption as net zero site energy buildings (Torcellini et al. 2006). Nominal five kW photovoltaic systems were installed on each platform in mid-2013. Monitoring started in October 2013.

The platforms themselves serve as the "control" as the envelope, structure and mechanical specifications are identical across the test platforms. The single difference is that low, operable side-louvers used for natural ventilation are motor driven in the Kawaikini platforms. These latter automatically close when the HVAC is ON. The motorized louvers in the Ilima structure are manually opened and closed from a standard on/off wall switch.

Predictive Modeling and Assumptions

During the design conceptualization phase, modelers used the EnergyPlus™ program to run multi-dimensional parametric analyses that optimize varying combinations of design factors including mass, natural ventilation, window effects, multi-zone airflow, and renewable energy. The lighting simulation program Radiance was used to simulate daylighting impact of the glazing designs. Local weather files were used in separate simulations for the two sites. Together the simulation results were used to fine tune overall building and lighting design (Project Frog 2010).

Upon completion of the design analyses, to account for potential uncertainty due to real world vs theoretical operation and behavior, and to provide bounded high, anticipated and optimal annual energy estimates, three different mixed-mode control configurations were modeled to reflect a range of conditions from 100% natural ventilation and daylighting to 100% mechanical cooling (Table 2).

Table 2. Summary of the control configurations for predictive modeling assumptions

High estimate	Anticipated performance estimate	Optimal performance estimate
-No natural ventilation	-No natural ventilation	-Natural ventilation protocols
-Lights on 100% school hours	-Daylighting sensors active	-Daylighting sensors active
-HVAC set point = 77°F	-HVAC set point = 77°F	-HVAC set point for nat.vent. = 82°F
-Ceiling fans ON	-Ceiling fans ON	-Ceiling fans ON

- The *high estimate* assumptions: natural ventilation is not used at all and the air conditioner thermostat set point is 77°F; the ceiling fans are used; daylighting advantage is not used, thus internal lighting is ON during 100% of occupied hours.
- The *anticipated performance estimate* assumptions: daylighting is maximized using integrated photosensors that dim the lights in 3% incremental steps to OFF; natural ventilation is not used and air conditioner is set to 77°F; this represents a middle value between high and optimal estimates.
- The *optimal performance estimate* is achieved when operating in one of three distinct operating modes. In all cases daylighting is maximized and lights are OFF during daylight hours. Mode one, featuring natural ventilation, is the least energy intensive, cooled by natural ventilation with open wall louvers, room-level and clerestory windows. Ceiling fans augment comfort. In the second mode, the buildings switch from passive to active mode when natural ventilation is complemented by a roof-mounted exhaust fan. In the third mode, all ventilation louvers and windows are closed and the air conditioning system is turned ON with a thermostat set point of 82°F.

Other assumptions:

- Plug loads are assumed to be the same in all cases.
- Exterior lighting was not included in the model.
- Occupancy schedule: the buildings remain open for five days a week and closed during weekends and winter and summer school holiday periods. The study considers one school year (07/01/2014 – 06/30/2015) based on the Hawaii Department of Education official 365-day 2014-15 calendar (185 school days, 180 non-school days). Days were classified as either:

- School days: days when class is in session. Hours 8:00 a.m. to 2:00 p.m.
- Non-school days: days that include holidays, weekends, and summer, winter and spring breaks.

Building Performance Monitoring

Both interior and exterior conditions were monitored for over two years at the sites beginning March 2013. Weather stations installed in Ewa Beach (Oahu for the Ilima site), and at Kawaikini School in Lihue (Kauai), provide temperature, relative humidity, solar radiation, wind speed, gust speed, wind direction, rain, dew point, and air pressure values. Table 3 presents the sensor type and locations used to collect the internal environmental and energy data (MKThink 2016).

Table 3. Summary of the sensing points for the environmental and energy data

Electrical circuits	Indoor	Weather
Circuits: 10 current transformers -HVAC condenser -HVAC fan coil -Lighting (internal and external) -Ceiling fans -Solar PV -Exhaust fan -Panel feed	-Room air temperature -Wall surface temperature -Supply and return air temp. -Relative humidity (room, supply and return duct) -CO_2 concentration -Illumination (wall and ceiling) -Air speed	-Ambient temperature -Relative humidity -Solar radiation -Wind speed -Wind direction

Results and Findings

Predictive Modeling and Actual Observed Results

The results from the design optimization and predictive modeling are presented in Table 4 and the observed results are presented in Table 5.

Table 4. Design energy use intensity (EUI)

	High estimate		Anticipated estimate		Optimal estimate	
	Kawaikini	Ilima	Kawaikini	Ilima	Kawaikini	Ilima
Total annual energy (kWh)	8,124	8,389	5,984	6,641	3,806	4,684
Predicted EUI (kWh/sf /yr and kBTU/sf/yr)	6.3 / 21.7	6.6 / 22.4	4.7 / 16.0	5.2 / 17.7	3.0 / 10.1	3.7 / 12.5

Table 5. Actual energy use intensity (EUI)

	Kawaikini East	Kawaikini West	Ilima
Total annual energy (kWh/yr)	7,183	4,840	9,881
Actual EUI (kWh/sf/yr and kBTU/sf/yr)	5.6 / 19.1	3.8 / 13.0	7.7 / 26.3

Energy Use Disaggregation

Figure 2 is a graphic representation of annual energy disaggregates across end-uses for both the predicted energy as well as the actual one. Predicting whole-building energy use with modeling simulation may not reflect real-world variability introduced by occupant behavior and systems. Lack of strong operational instructions or effective institutional memory of those instructions, inconsistent operation by different users, modification of energy features by the users, and equipment failure each can skew the operation of an otherwise well-defined building.

A mixed-mode building is particularly sensitive to occupant involvement. Windows are to be opened and closed according to specific operating protocols; ceiling fans should operate during natural ventilation modes but not during mechanical cooling; and HVAC temperature set points should be set consistent with the design intent. These factors combined with institutional factors such as attitudinal inertia (energy device weariness), routines and habits, lack of accountability for space usage such as might be found in classrooms with multiple instructors and courses, level of engagement (Gram-Hanssen 2014), unexpected operating hours (e.g., after-hours and spillover usage), occupancy schedule (Lenoir 2013, 25) and adaptive thermal comfort (Carlucci et al. 2015) can affect energy consumption by a factor of two or more (Haldi and Robinson 2011; Gram-Hanssen 2010; Santin, Itard, and Visscher 2009).

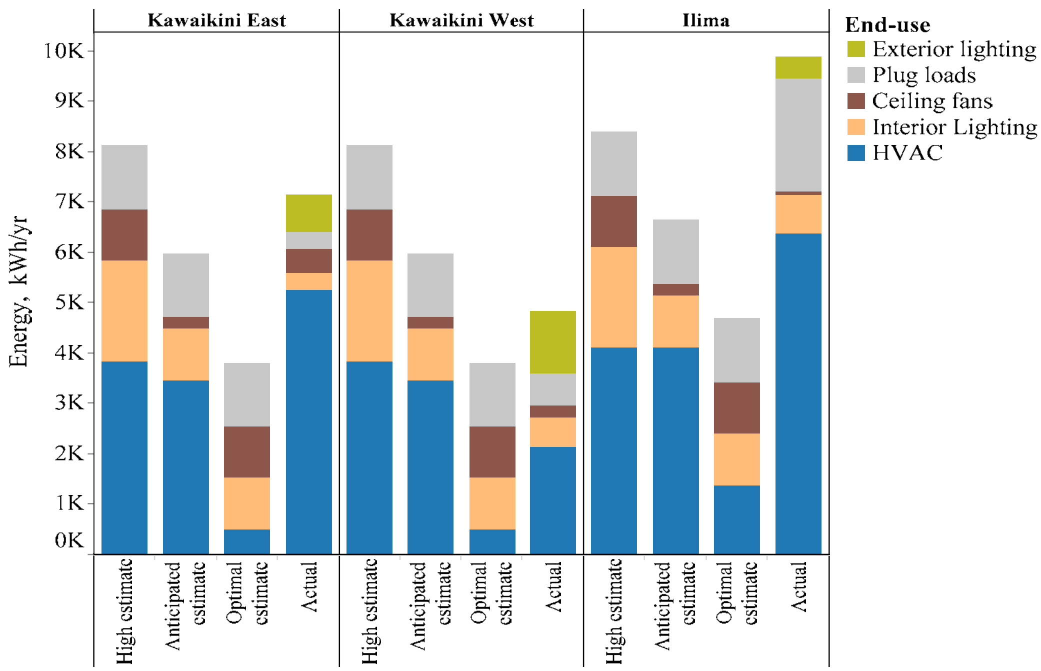

Figure 2. Energy disaggregation: actual compared to predicted (exterior lighting not included in predictive model).

School Day vs. Non-School Day Energy Consumption

Chief among the energy drivers in a net zero building is the ability to manage energy consumption during unoccupied periods. Figures 3a-d compare average annual energy utilization during the school and non-school day by total energy (Figure 3a) and three primary end-uses, interior lighting (Figure 3b), ceiling fans (Figure 3c) and HVAC (Figure 3d). Overall, Kawaikini East used 71% as much energy on the average non-school day as it did during the school day. By contrast, Kawaikini West only used 28% of the school day average on a non-school day. Ilima used 46% of its school day energy during the average non-school day.

Detailed evaluation of the data highlighted the building use that had not been accounted for in the predictive modeling. As one of the flagship buildings on campus, the Kawaikini East structure became the preferred venue for extracurricular gatherings such as parent groups, school board meetings, faculty meetings and other events that would occur after school hours and on weekends.

Interior lighting (Figure 3b) appears to be well managed with total non-school energy use from 2% to 24% of school day energy. The higher values in Kawaikini are due to the use of the facilities as a school community resource during non-school days as compared to Ilima's more traditional public school calendar-based schedule. The same pattern holds true for ceiling fans and HVAC consumption, Figures 3c and 3d, respectively.

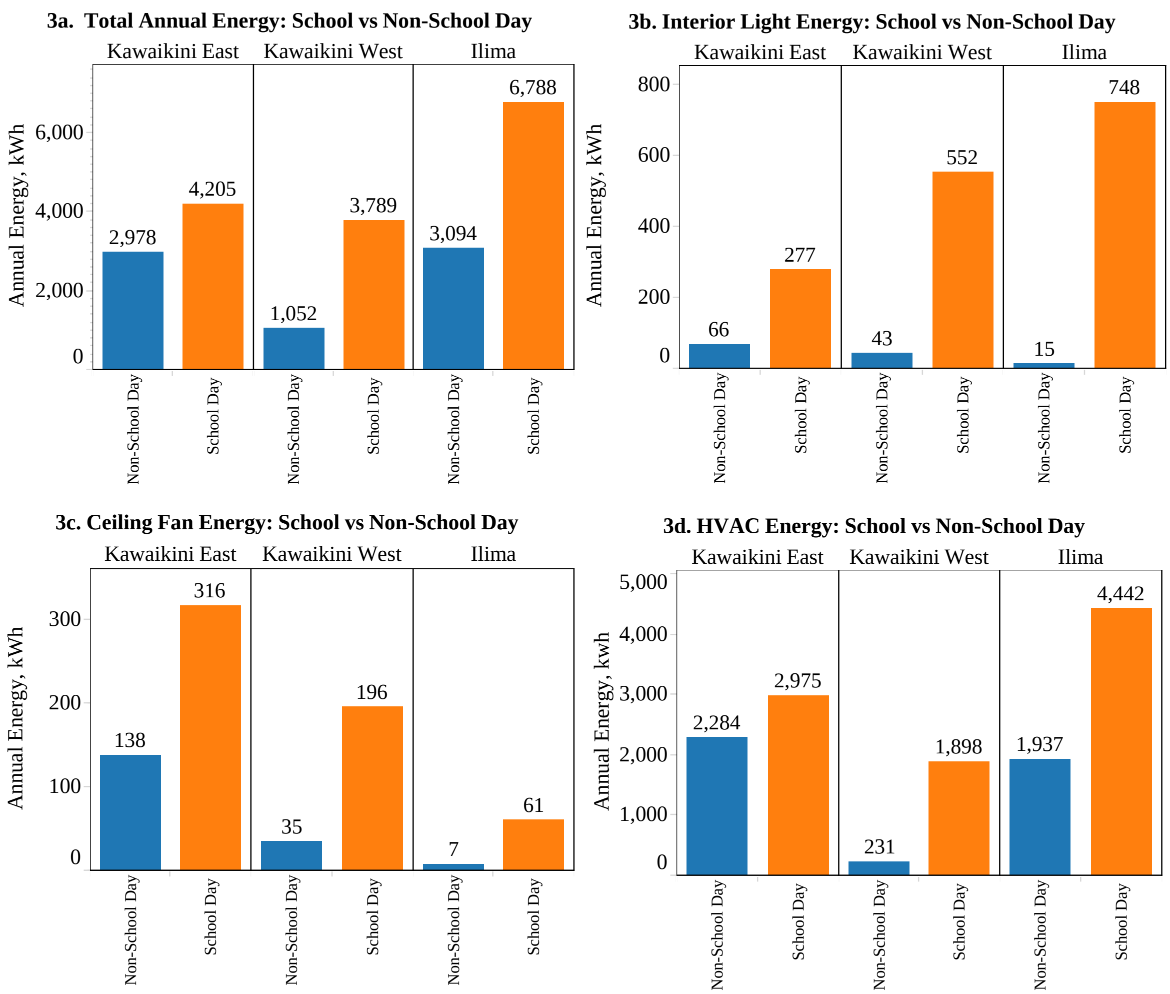

Figure 3a-d. Daily end-use energy per school day type, July 2014-June 2015 (185 school days and 180 non-school days).

Total Energy Consumption vs Generation - Net Zero Analysis

Designed to meet net zero energy goals, generation for the two Kawaikini structures exceeded consumption, one by over 4% (Kawaikini East) and one by more than 37% (Kawaikini

West), see Table 6. The Ilima structure fell nearly 7% short of the NZE goal, due to 24/7 HVAC operation in June 2015 when the system was unintentionally left ON after school was out-of-session. More than 4 times the average monthly HVAC energy of the previous 11 months was consumed in this month. Should HVAC consumption for June been at the average of the previous 11 months, Ilima would have been over 9% net positive, generating over 800 more kWh than consumed.

Table 6. Total annual energy consumption versus total annual PV generation

	Total annual consumption (kWh/yr)	Total annual PV generation (kWh/yr)	Equivalent annual hours of peak rated PV production (kWh/yr/W_p)	Net energy generation (kWh/yr)	Net energy balance (Total annual PV generation – Total annual consumption) / Total annual PV generation
Kawaikini East	7,183	7,500	1.43	317	4.23% (net generation)
Kawaikini West	4,840	7,792	1.48	2,952	37.89% (net generation)
Ilima	9,881	9,247	1.76	-634	-6.86% (net consumption)

Average daily solar radiation at the Ilima site is approximately 63% higher than the Kawaikini site for a six month period covering the months of April through October. The difference in annual incident solar radiation is responsible for the difference in total annual generation for similar sized PV systems as well as the greater need for air conditioning use at the Ilima site (Figure 4).

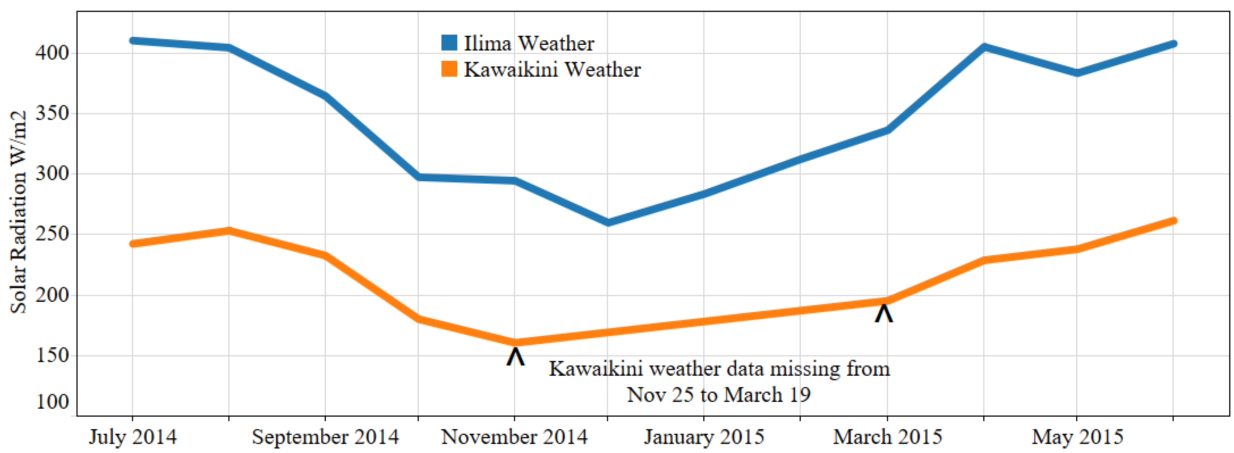

Figure 4. Monthly average solar radiation for monitoring period.

Discussion

By definition, performance modeling can, at best, predict energy based on precise representations of the structure's physical construction, mechanical and electrical systems and operating schedules to reflect how the envelope and systems function, as well as capturing occupant behavior. Specific sources of uncertainty result from physical properties of materials, design variations that occur during the planning process, and scenario parameters such as uncertainty in boundary conditions. External scenario uncertainties would include actual microclimatic conditions (Ding et al. 2015; Hopfe and Hensen 2011). Internal scenario uncertainties include differences in building operation, occupant response to the environmental conditions, and equipment malfunction. Examples of the internal scenario uncertainties are discussed below.

Interior lighting. The structures are designed for natural daylighting, incorporating photosensors into the fixtures and using occupancy sensors for overall interior lighting control. The use of daylighting is discretionary based on user habits, expectations or need. For Ilima, the classroom was used for science and was equipped with expensive devices and equipment. Opaque paper was applied to the inside window surface for security to prevent visibility from outside, thus reducing most of the daylighting opportunity. The two Kawaikini platforms took advantage of daylight to differing degrees. As is evident in Figure 3b, Ilima used 763 kWh, over two times the 343 kWh annual lighting energy of Kawaikini East. Kawaikini West used 595 kWh, higher than its counterpart.

Because these two structures are identically built on the same site and Kawaikini East is the venue for after hours and weekend events, the impact of behavior, habits, and expectations is evident. Figure 5 illustrates a typical day, showing average hourly values for the month of September 2014, overlaying illuminance with the power. The power curve for Kawaikini West indicates that the lights are turned ON approximately at 7:00 a.m. and OFF at 5:00 p.m. Next door in Kawaikini East, the lights are on a very low level most of the day, spiking for the evening meeting. The illuminance plots in Figure 5 indicate only a small difference in observed lighting levels between day lit (non-school day) and artificially illuminated (school-day) conditions. Data collection on behavior was outside of the scope of this research. Without speculating on the specific drivers within this classroom, the data shows user preference for using natural daylight provided by windows and clerestories in the east building, and for using artificial light in the west.

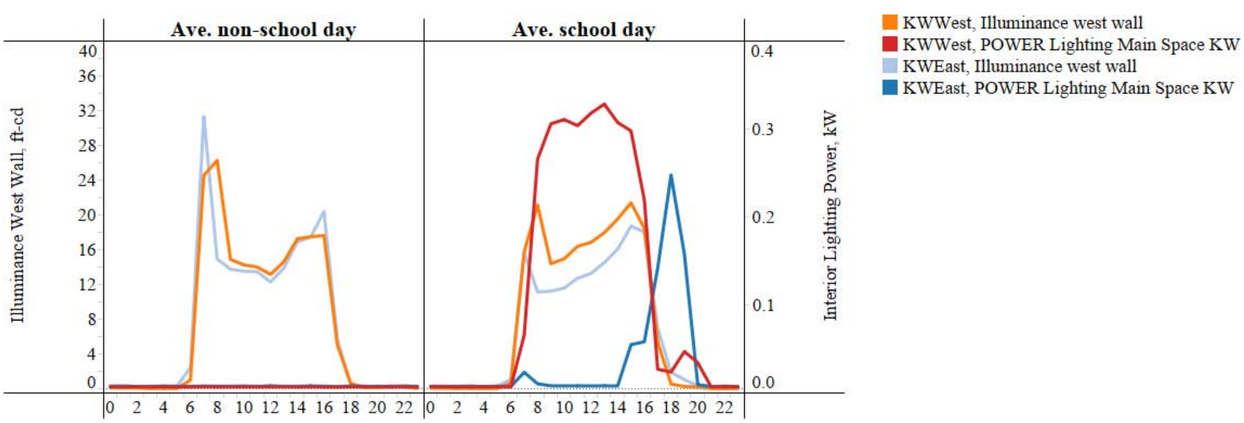

Figure 5. Average daily illuminance and energy profiles for September 2014 illustrating user preference for natural daylighting.

Ceiling fans. Ceiling fans were intended to be used in naturally ventilated conditions, that is, when the HVAC system is not being utilized. In practice, the data shows ceiling fans were frequently used in parallel with the HVAC systems in both Kawaikini buildings. In Ilima, the fans were indeed OFF while the HVAC was running, but their use occasionally appeared during the warmer hours of the day. Figure 6 illustrates very little coincidental ceiling fan and HVAC energy in Ilima.

While Ilima tends to operate the HVAC system on a consistent daily basis, the Kawaikini platforms were truly mixed-mode, relying on natural ventilation, but activating the HVAC when needed. In these instances, the ceiling fans were complementary to the HVAC system, allowing comfort to be achieved with the combination of airflow and mechanically cooled air. The monthly data analysis showed that fans, for both Kawaikini buildings, were operating in July, when school was not in session. The monthly total fan energy showed a positive relationship to ambient temperature. Daily patterns indicate that teachers were consistent in turning fans ON in morning and OFF upon leaving and manually controlling the fans based on need. Data indicates that both fans and HVAC systems are turned ON after hours, evenings and weekend events, complicating efforts to predict future energy use in the building.

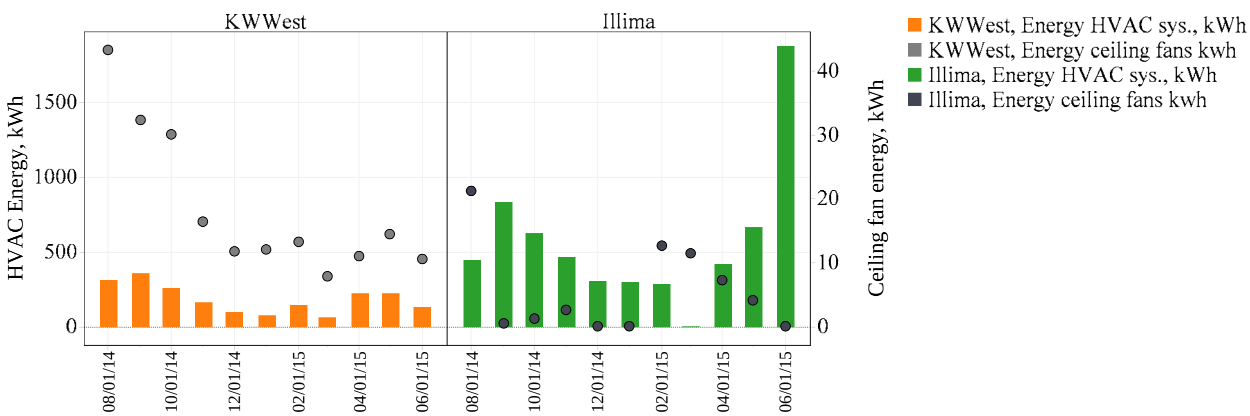

Figure 6. Ceiling Fan energy plotted against HVAC energy, Kawaikini West and Ilima.

HVAC. The use of mechanical cooling in a mixed-mode building is based upon operational protocols intended to balance energy with comfort. Without mechanical lockouts to prevent overuse, small single-zone spaces may be subject to user behavior for much of the year, driven by both microclimatic conditions as well as expectations of the users. The two identical facilities at Kawaikini exhibit significantly different operating profiles from each other. The east platform used about ten times more HVAC energy during non-school days and about 50% more during school days than the west platform (Figure 3d). These profiles are also quite distinct from Ilima partly due the warmer Ilima microclimate as well as the use of the classroom as primarily a science/electronics/robotics room compared to general classroom.

The data collected during the one year period shows inconsistent and sporadic use of HVAC in the Kawaikini East structure, as might be expected from mixed-mode structures. A subset of time, March – June 2015, is plotted in Figure 7 to illustrate HVAC use during more moderate months, for school and non-school days, and to show an anomalous operating profile at Ilima in June. In this illustration, Ilima and Kawaikini West show a consistent and regular use. The higher Ilima HVAC energy profile, averaging from between 2.0 to 4.5 kWh per hour reflects the warmer microclimate at the site. The monthly data analysis for both Ilima and Kawaikini

West showed that HVAC was used year-round, exhibiting a higher power demand during the warmest months (not shown). The data also indicates longer operating hours during the warmer months, with earlier ON times of 5:00 a.m. (Ilima) and 7:00-8:00 a.m. (Kawaikini West). The measured demand rose with an increase in outdoor temperature and reduction of thermostat set point by the occupants. During the cooler months, AC was turned ON approximately one or two hours later. In all cases, HVAC was turned OFF when occupants leave the building at 6:00 p.m.

The impact on unaccounted-for HVAC energy is observed in Figure 8, showing significant non-school day use in Kawaikini East due to the HVAC running continuously. In September 2014, non-school days used 35% of the school day energy there. Figure 8 also shows higher power usage during the school day for Kawaikini East which likely was not accounted for in the predictive modeling. This is a result of the use of the HVAC system at night for school and community-based meetings. The other buildings show very little non-school day use.

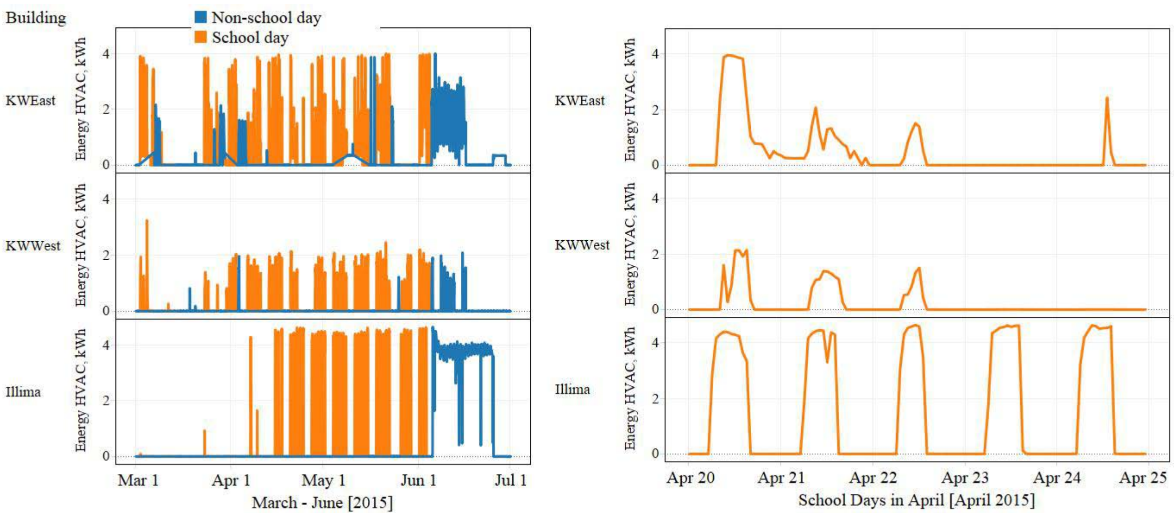

Figure 7. HVAC energy profile Mar.-Jun. 2015 (left); Example daily HVAC profiles: school days (right).

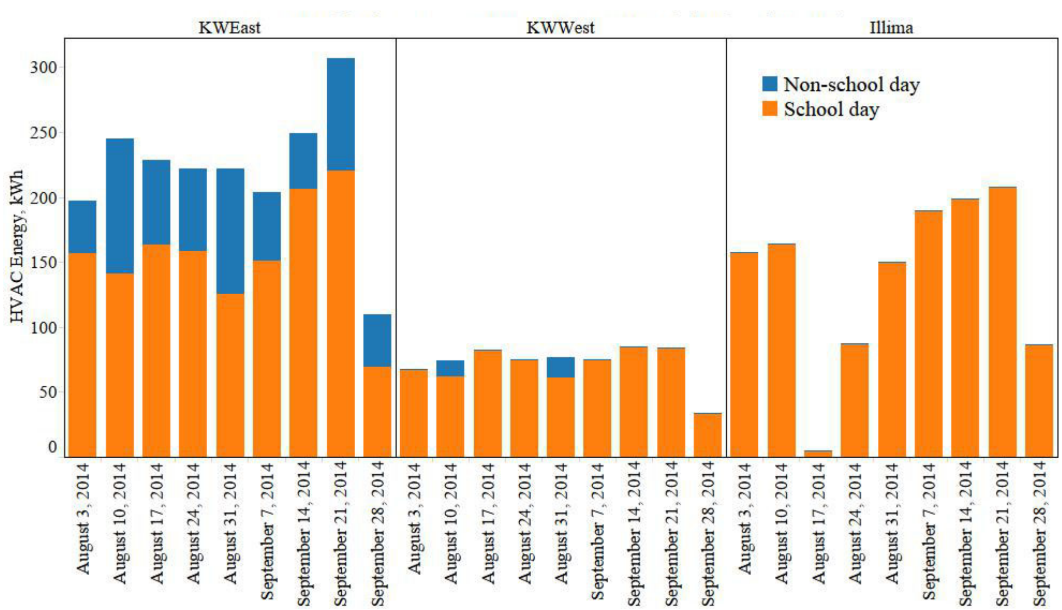

Figure 8. Weekly HVAC energy: school vs. non-school day (August-September 2014).

Exterior lighting. The structures are equipped with exterior lighting that was not anticipated in the predictive modeling. However, on an annualized basis exterior lighting accounted for between 4% and 25% of the annual energy, see Table 7. Accurate predictive modeling programs have the capability to model exterior lighting, therefore, precise determination of fixture type, operating schedule and a good forecast of motion-sensing activity will improve the accuracy of the forecast.

Table 7. Exterior lighting energy

	Total energy used (kWh)	Exterior lighting energy (kWh)	Percent of total energy (%)
Kawaikini East	7,183	737	10%
Kawaikini West	4,840	1,231	25%
Ilima	9,881	418	4%

Plug loads. In the FROG study, plug loads accounted for 0.28 to 1.76 kWh/sf/yr (Figure 9). The significant difference between Kawaikini and Ilima is the after-hour computer/monitor/printer protocols, e.g. shutdown and standby modes to reduce unneeded consumption and reduce phantom energy. In building simulation, it is recommended that one estimates plug loads by projecting the potential inventory of devices and their power consumption profiles to predict annual energy consumption. In implementation, user education and awareness, policies, protocols and best management practices are encouraged to optimize consumption.

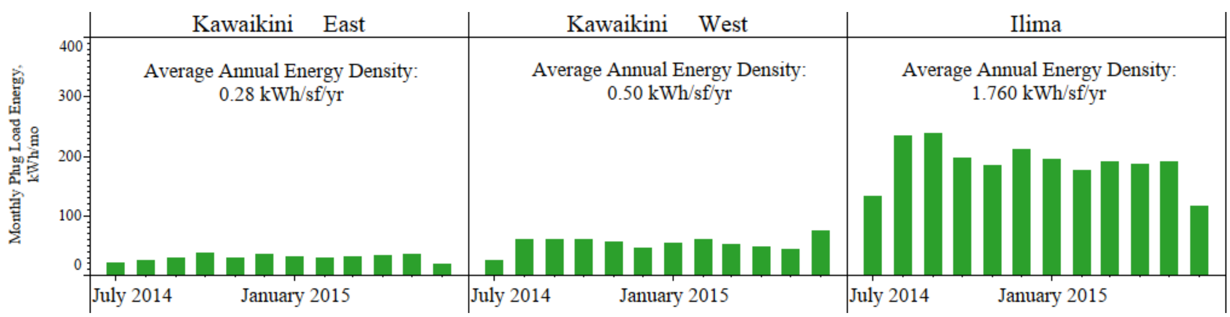

Figure 9. Comparison of plug load energy.

Equipment failure. Equipment failure, operational disruption, controls calibration, and sensor problems can contribute to unpredicted energy consumption. Specific anomalies observed in the data are subject to deeper investigation, but anecdotal reports of equipment failure such as a several months fan coil problem and thermostat re-programming issues would result in inconsistent performance and control over the systems.

PV Generation. The sizing of PV systems was based on the High Estimate of the three conditions modeled in two different microclimates.

Conclusions and Recommendations

The design of a net zero energy structure requires detailed planning that begins early in the design process. Once the most energy efficient elements have been incorporated into the final design, skilled modelers will generate very accurate theoretical estimates. Some field-based sources of simulation inaccuracy remain either in control of building users, or are completely unavoidable, such as weather. With the certainty of uncertainty, designers can hedge their estimates by bracketing their modeling assumptions using a range of parameters to represent low, medium and high use estimates. Although a PV system may be sized to the high estimate, operational vigilance is required to ensure consumption remains as low as is practical.

Beyond addition of more automation and controls, user training on the operation of the building will encourage appropriate use of equipment as designed. For example, windows and skylights help ventilate the space, but they must be opened and closed to do so. The most successful buildings are supported by a culture of efficiency that encourages a conscious and integrated approach toward maintaining comfort while minimizing demand on energy resources. This may be achieved by training, awareness and cultivating a context of the nature and intent of the building design. An in-class dashboard would offer immediate feedback on interior comfort conditions and energy disaggregation and consumption relative to power generation and annual NZE goals.

Anticipated schedules of operation will never be 100% predictable and unforeseen use of the facilities is expected. When net zero energy is the target, consider possible extended hours of operation and factor them into the model as a variable parameter. When gathering operation profiles, inquire about extracurricular activities such as after-hours and weekend meetings (school interest groups, clubs, activities etc.).

Significant differences in usage patterns were observed between the Kawaikini and Ilima buildings. Documentation of personal preference and adaptive conditions were not part of this study, specific conclusions regarding behavioral and preference have not been drawn or quantified from the energy data alone. However, consideration should be given to the economic drivers. Ilima is a public school, where energy costs are paid for by the State (not the school) and therefore far removed from the user. Kawaikini is a charter school, responsible for their own utility bills. With Kauai’s electricity costs in excess of $0.35/kWh, budget management is important to most members of the school’s constituency.

Future work in this area will examine behavioral, social, and economic drivers to help manage many of the uncertainties observed in the operation of net zero energy buildings. The impact of user behavior and motivation will be studied in future research with the construction of two new FROGs on the University of Hawaii at Manoa campus. Visual feedback via a dashboard will be provided to users showing the current building operation, generation and consumption with the intent to create a culture of sustainability to drive responsible stewardship of the building.

Acknowledgements

The construction and monitoring of these NZE structures was supported and funded by the Office of Naval Research in grant awards: N00014-10-0310, N00014-11-0391 and N00014-12-0496.

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