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NET ZERO ENERGY TEST PLATFORM PERFORMANCE COMPARATIVE ANALYSIS

Task 7

Prepared by:

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Prepared for:

University of Hawaii at Manoa, Hawaii Natural Energy Institute

March 2016

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

TEST PLATFORM PERFORMANCE ANALYSIS P2: EXECUTIVE SUMMARY

March 2016 | FINAL INTEGRATED REPORT | Researching the performance of 4 potentially Net-Zero Energy Test Platforms and 2 "traditional" Hawaiian classrooms

Prepared for:

HNEI
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University of Hawaii's Asia-Pacific Research Initiative for Sustainable Energy Systems (APRISES)

Task 7 - Energy Efficiency

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Introduction

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In support of the University of Hawaii's Project "Asia Pacific Research Initiative for Sustainable Energy Systems" and under contract No.N00014-12-1-0496, MKThink instrumented six classrooms (4 high-performance "Test Platforms" and 2 "Traditional" classrooms) with energy use, indoor environmental quality, and system operation sensors to compare their respective performances to each other, to predictive models (where applicable), and to established guidelines for building performance. The study's stated goal is to increase the knowledge-base around key environmental and building (architectural) factors relevant to achieve energy neutral (net-zero) operations. This Part Two contract supports and expands on the Part One Project Frog Test Platform Study at Kawaikini NCPS in Līhu'e, Kaua'i (Contract No.N00014-11-1-0391). In total, this Final Integrated Report analyzes data collected from a one (1) year period 7/01/2014 - 6/30/2015, taken from a larger sample period from 7/16/2013- 7/16/2015, for all six classrooms located at three schools in two different climate zones. The classrooms are as follows:

NAME	aka	CLASSROOM TYPE	SCHOOL	LOCATION	NET ZERO ENERGY (NZE) DESIGN INTENT
Kawaikini West	KW West	Modular Portable FROG	Kawaikini New Century Public Charter	Līhu'e, Kaua'i	Yes
Kawaikini East	KW East	Modular Portable FROG	Kawaikini New Century Public Charter	Līhu'e, Kaua'i	Yes
Ilima FROG	Ilima	Modular Portable FROG	Ilima Intermediate	Ewa Beach, O'ahu	Yes
Ewa P6	P6	Modular ZNE Portable	Ewa Elementary	Ewa Beach, O'ahu	Yes
Ewa P1	P1	Standard Portable	Ewa Elementary	Ewa Beach, O'ahu	No
Ewa D36	D36	Standard Masonry	Ewa Elementary	Ewa Beach, O'ahu	No

The report is organized into the following content sections:

Dashboards: Summarizes answers the key questions of the report
Classroom Asset Information: Details the classroom physical characteristics
Environmental Summary: Details the local climate and weather characteristics
Group Behavior Summary: Details the occupant planned and actual behaviors within the classrooms
Performance Summary: Details the performance of the six classrooms across study criteria
Discussion & Recommendations: Discusses the results through insight, interpretation, and recommendations
Methodology & References: Details the calculations, references, and assumptions used in the report
Appendix: Includes additional charts and data related to the two year study

To conduct the study, MKThink established three (3) key questions to be answered with criteria and sub-criteria developed as the measurable components of each criterion. The three key questions are:

1. How do Test Platform performances compare to Traditional classrooms and each other?
   (Task 1- Planning: 1.1.4.1.1 - "compare...one platform to another")
2. Do Test Platforms perform as predicted by models?
   (Task 1- Planning: 1.1.4.1.2 - "compare...to model predictions in Phase II ONR")
3. Do all classrooms perform within established guidelines?
   (Task 1- Planning: 1.1.4.1.1 - "compare...to established guidelines for building performance")

The criteria and sub-criteria are as follows:

CRITERIA	SUB-CRITERIA	UNIT	DESCRIPTION
Energy Use	Total Loads	kWh	All electrical loads measured at the electrical panel
	Mechanical Cooling	kWh	Condensing Unit, Fan Coil Unit, and Exhaust Fan
	Ceiling Fans	kWh	Electrical energy use of ceiling fans
	Interior Lighting	kWh	Electrical energy use of primary classroom lighting
	Exterior Lighting	kWh	Outdoor lighting electrical energy use (where applicable)
	Plug Loads	kWh	Plug loads from in-classroom devices
Indoor Environmental Quality (IEQ)	Thermal Comfort	PMV	ASHRAE Adaptive Comfort Model
	Air Quality	ppm	CO_2 concentrations
	Lighting Quality	ft-cd	Luminosity and glare ratio at work surface
Building System Performance	Air Supply	°F	Rise in temperature between supply and distribution
	Natural Daylighting	ft-cd	Available daylight utilized without artificial lighting

Additionally, four more Exploratory Questions are asked and evaluated in the report. These questions are as follows:

1. How well did Test Platforms achieve "energy-neutrality"?
2. How do the classrooms compare in use of natural daylighting?
3. How do local weather and differences in microclimates impact building operations and performance?
4. How do the classrooms compare against national averages for Energy Use Intensity?

DESCRIPTION
This section summarizes the major findings of the 2-year study in a series of executive summary dashboards organized to support the study's primary and exploratory research questions. These dashboards compare energy consumption, indoor environmental quality, and system performance for a selected 1-year period.

WHY IMPORTANT
Provides quick access to the most interesting results from the report

2

Dashboards

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Key Findings

Contracted Questions (CQs)

To conduct the study, MKThink established three (3) key questions to be answered. Each question was dissected into measurable metrics with criteria and sub-criteria developed for comparison. The four (4) Test Platforms (TP) were KW East, KW West, Ilima and P6. The Traditional classrooms (TC) were P1 and D36. The questions and results are summarized below and in the following report pages:

(Task 1- Planning: 1.1.4.1.1 - "compare...one platform to another")

CQ1

1. How do Test Platform performances compare to Traditional classrooms and to each other?

On average, Test Platforms (TP) used 40% less energy per square foot, had 6% more time with comfortable interior conditions and delivered 15% more comfort per energy consumed than Traditional classrooms.

- EUI: **TP Avg 1.8 kWh/ft²** [KW East 1.2 EUI, KW West 1.5 EUI, Ilima 3.4 EUI, P6 0.9 EUI], **TC Avg 3 kWh/ft²** [P1 3.4 EUI, D36 2.6 EUI]
- IEQ (% time all 3 envir. criteria simult. met): **TP Avg 39%** [KW East 37%, KW West 75%, Ilima 24%, P6 18%], **TC Avg 33%** [P1 8%, D36 57%]
- COMF/EUI[1] (Comfort delivered (IEQ) per kWh/sf): **TP Avg 27** [KW East 31, KW West 50, Ilima 7, P6 20], **TC Avg 12** [P1 2, D36 22]

(Task 1- Planning: 1.1.4.1.2 - "compare...to model predictions in Phase II ONR")

CQ2

2. Do Test Platforms perform as predicted by models [based on anticipated operating modes]?

Compared to the "Anticipated" model scenario, FROG Test Platforms' total energy consumption varied from +20% to -19% overall, and by individual system from +77% to -72%. Additionally, 40% or less of Active Mode HVAC operations occurred during times recommended in the high-performance building operations guides.

- Total Energy Use: Compared to "anticipated": KW East 20% more, KW West 19% less, Ilima 18% more
- By System: Compared to "anticipated" predictions, systems varied by: KW East (Plugs) -72%, KW West (AC) -38%, Ilima (Plugs) 77%
- By Operating Mode: When "On", Active Mode (Cooling) was used above 82deg F (% time): KW East 40%, KW West 0%, Ilima 15%

(Task 1- Planning: 1.1.4.1.1 - "compare...to established guidelines for building performance")

CQ3

3. Do all classrooms perform within established guidelines (as per ASHRAE Standard 55 and 62.1)?

On average, Test Platforms (TP) had 15% less time within the thermal comfort zone, had 41% more time with acceptable air quality and 2% more time with acceptable lighting conditions compared to Traditional classrooms (TC).

- Thermal Comfort (% time in comfort zone): **TP Avg 41%** [KW East 39%, KW West 77%, Ilima 27%, P6 21%], **TC Avg 56%** [P1 44%, D36 68%]
- Air Quality (% time below 1100ppm): **TP Avg 100%** [KW East 100%, KW West 100%, Ilima 100%], **TC Avg 59%** [P6 100%, P1 21%, D36 96%]
- Lighting Quality (% time illum. met): **TP Avg 92%** [KW East 95%, KW West 97%, Ilima 84%, P6 92%], **TC Avg 90%** [P1 94%, D36 86%]

1: This performance metric was created during this study to link Indoor Environmental Quality (IEQ) to energy used

Exploratory Questions (EQs)

In addition to the contracted research questions, MKThink studied four (4) additional exploratory questions that were relevant to the intent of the research. The questions and results are summarized below and further detailed in the subsequent report pages:

EQ1

1. How well did Test Platforms achieve "energy-neutrality"?

3 of 4 Test Platforms achieved energy neutrality or better on an annual basis.

- Annual Energy (Net Generator (+), Net Consumer (-)): KW East +327 kWh, KW West +2,962 kWh, Ilima -632 kWh, P6 +11,591 kWh
- Daily (% days Net Generator / % days Net Consumer): KW East 59/41, KW West 74/26, Ilima 53/47, P6 99/1

EQ2

2. How do the classrooms compare in use of natural daylighting?

3 of 6 Classrooms showed daylighting capacity above 90% during school hours but only 1 classroom achieved >50% utilization of that daylighting potential.

- Empirical Daylighting Capacity (measured % time daylight can be used): KW East 95%, KW West 96%, Ilima 71%, P6 99%, P1 77%, D36 0%
- Actual Daylighting Achieved (measured % time daylight was used): KW East 85%, KW West 28%, Ilima 20%, P6 38%, P1 10%, D36 n/a

EQ3

3. How do local weather and differences in microclimates impact classroom operations and performance?

Differences in microclimates did not reveal statistically significant linear relationships (p-value < 0.05) with classroom performance; however, individual classrooms did exhibit moderate-strong (R^2 >= 0.60-0.80; p-value < 0.05) weather-performance relationships.

- Microclimate Impacts (Ewa Beach vs. Lihu'e): AC Energy R^2=0.02, Light Energy R^2=0.03, PMV R^2=0.06; p-value not sig.
- Weather vs. AC Energy Use: KW East R^2=0.50/yes, KW West R^2=0.69/yes, Ilima R^2=0.08/no
- Weather vs. PMV: KW East R^2=0.89/yes, KW West R^2=0.81/yes, Ilima R^2=0.27/yes,P6 R^2=0.91/yes, P1 R^2=0.14/yes, D36 R^2=0.53/yes
- Weather vs. Light Use: KW East R^2=0.21/yes, KW West R^2=0.06/no, Ilima R^2=0.02/no, P6 R^2=0.15/yes, P1 R^2=0.14/yes, D36 R^2=0.14/yes

(statistical significance=yes/no; weather/microclimate based on Air Temperature, Relative Humidity, Wind Speed, and Solar Radiation)

EQ4

4. How do the classrooms compare against national averages for Energy Use Intensity (EUI)?

5 of 6 Classrooms had lower EUIs (Energy Use Intensity) than the top quartile of national schools. Kawaikini West and Ewa P6 had EUIs 37% and 58% lower, respectively.

- Annual Average EUI (compared to US Top Quartile): KW East 7% less, KW West 37% less, Ilima 28% more, P6 58% less, P1 8% less, D36 18% less

CQ1, CQ3

Annual Energy and IEQ Classroom Comparison

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

ENERGY USE INTENSITY (EUI)[4]:
- energy end use and the classroom total per net square feet

INDOOR ENVIRONMENTAL QUALITY (IEQ)[5]:

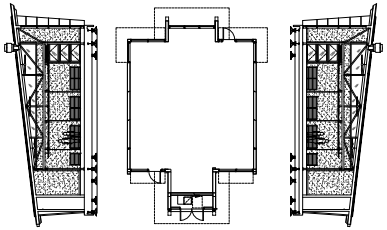
Thermal Comfort: % of time PMV score w/ in ASHRAE Comfort Zone

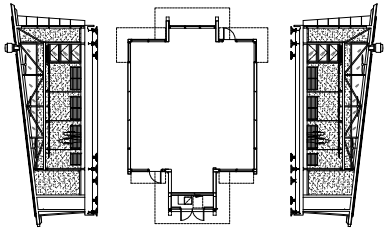
Air Quality: % of time CO_2 concentration below ASHRAE threshold (1100 ppm)

Lighting Quality: % of time wall illuminance >5 ft-c & illuminance ratio (wall illuminance/surface illuminance) <5

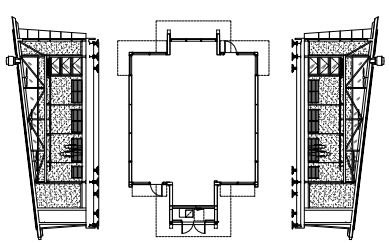
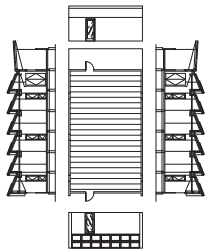
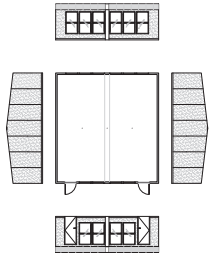
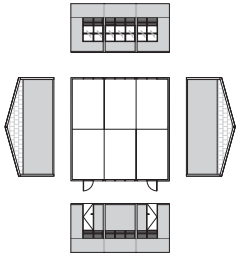
COMF/EUI[5]:
- working metric describing the amount of comfort delivered per unit of energy consumed

1: Classrooms had accompanying operating procedures that occupants were unaware of or did not use.
2: AC unit energy is included in Plugs
3: AC energy use is extrapolated for a year based on energy use from one week in November
4: Calculated using Net Square Feet (NSF)
5: Discussed further in the Methodology section





	KW EAST[1]	KW WEST[1]
EUI (kwh/ft²)	**1.2**	**1.5**
AC	0.9	0.9
FANS	0.2	0.1
PLUGS	0.04	0.2
INT. LIGHTING	0.1	0.3
IEQ (%)	**37%**	**75%**
THERMAL	39	77
AIR QUALITY	100	100
LIGHTING	95	97
COMF/EUI	**31**	**50**

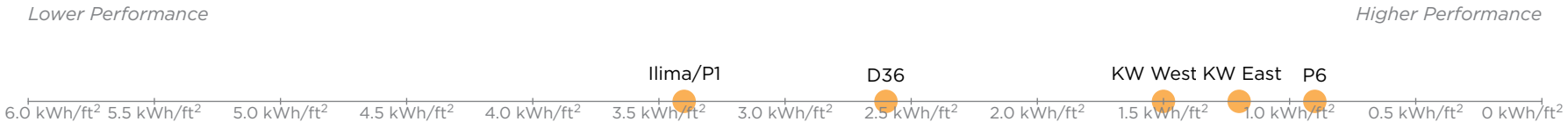
	ILIMA[1]	P6[1]	P1	D36
				
	3.4	**0.9**	**3.4**	**2.6**
	2.6	--	X[2]	2.4[3,5]
	0.04	0.1	0.7	0.0
	0.4	0.3	2.0	0.01
	0.4	0.5	0.7	0.2
	24%	**18**%	**8**%	**57**%
	27	21	44	68
	100	100	21	96
	84	92	94	86
	7	**20**	**2**	**22**

CQ1, CQ3

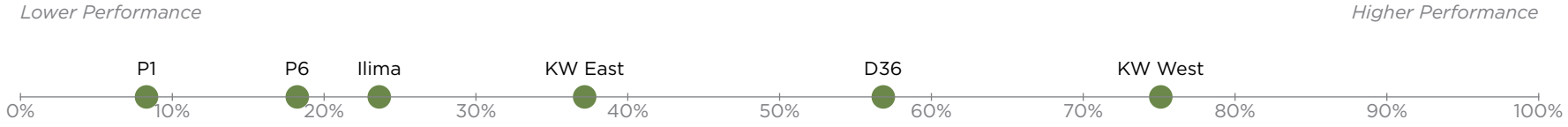
Annual COMF/EUI Classroom Comparison

Description: Classrooms are compared by annual energy use intensity, indoor environmental quality and amount of delivered comfort per unit of energy. Values of indoor environmental quality and energy use intensity are seen on page 12 and 13.

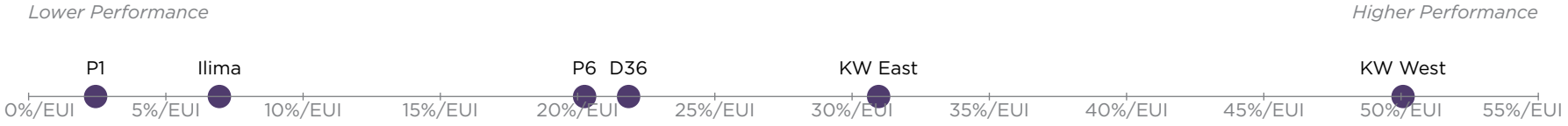
Energy Use Intensity[1] [total annual energy use consumed per square foot]



Indoor Environmental Quality [percentage of time thermal comfort, air quality and illuminance criteria are all met]



Comfort/Energy Use Intensity[2] [percentage of time all environmental criteria are met per kWh/sf²]

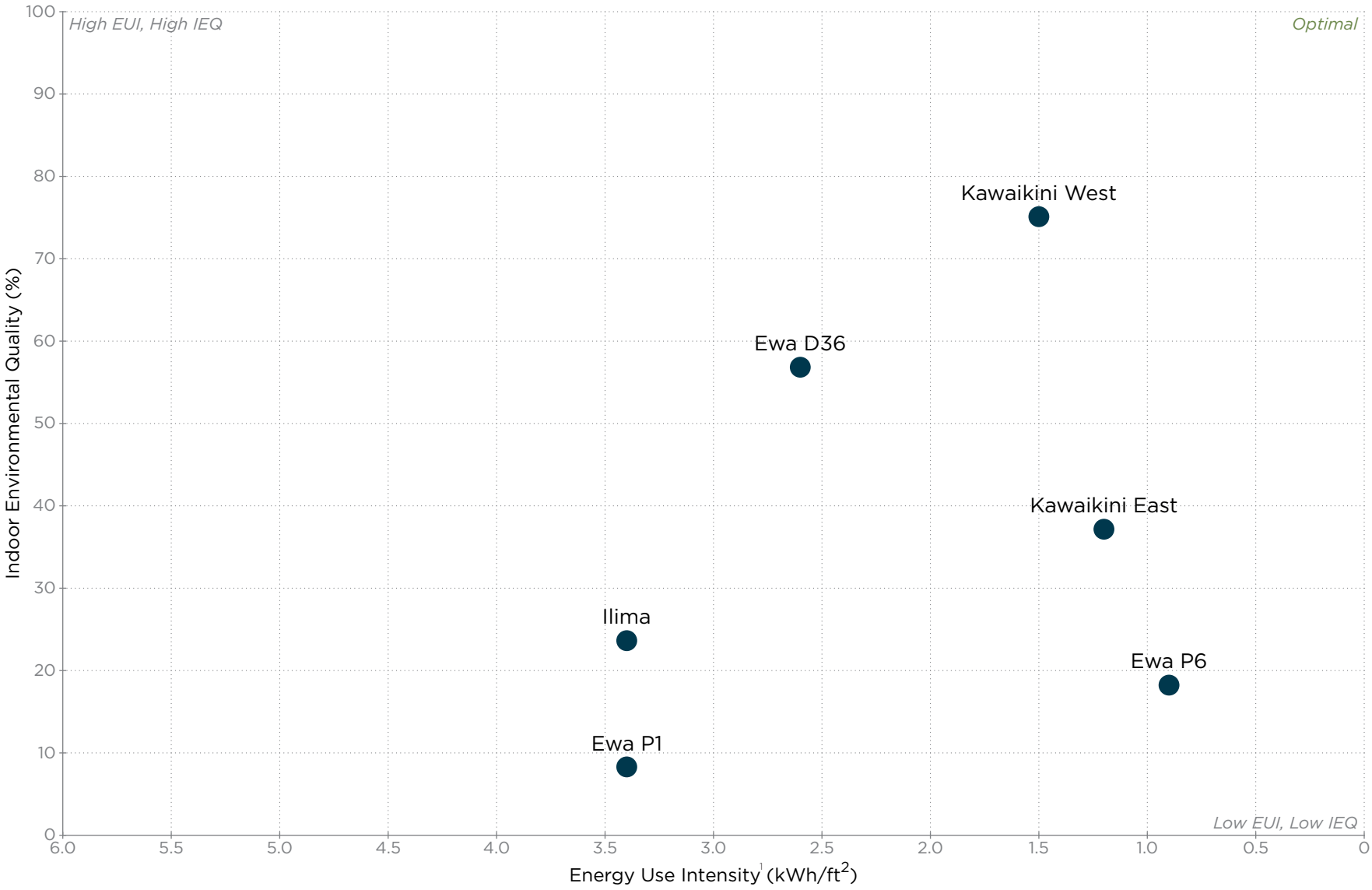


1: EUI axis ranges from 0 kwh/ft² to 6 kwh/ft² based on US Energy Consumption Data for Top Quartile US K-12 Schools electricity reported by Touchstone and US EPA Energy Star Building Manual 10

2: The Comfort/EUI axis will vary depending on the building. The Comfort/EUI upper bound of 55%/EUI was chosen to see variation in classroom performance.

Findings: On average, the Test Platforms used 40% less energy per square foot, provided 6% more time within IEQ thresholds and delivered 15% more comfort per unit of energy consumed than the Traditional classrooms.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

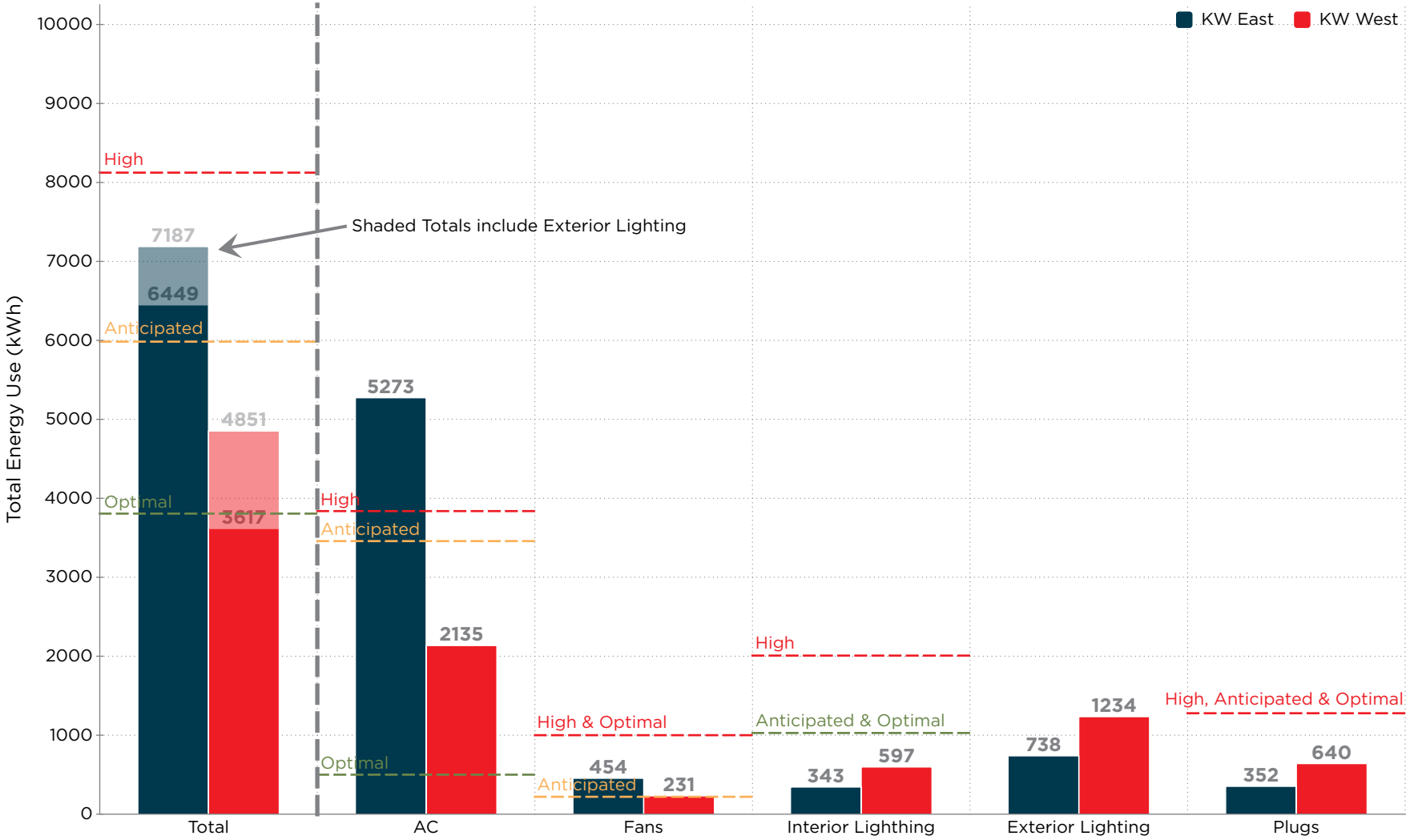


Annual Total Energy Use Actual vs. Modeled: Kawaikini East and West

Description: Kawaikini energy models from the Phase II ONR Report are compared to measured values across energy end uses. Exterior lighting was included in the energy modeling but estimated as "0." Model scenarios are optimal (low), anticipated (medium) and high. More information on model scenarios can be found in the Methodology section.

Findings: Overall, Kawaikini East consumed 20% more than "Anticipated" while Kawaikini West consumed 19% less than "Anticipated." Kawaikini East used 37% more AC energy than the "High" modeling scenario.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



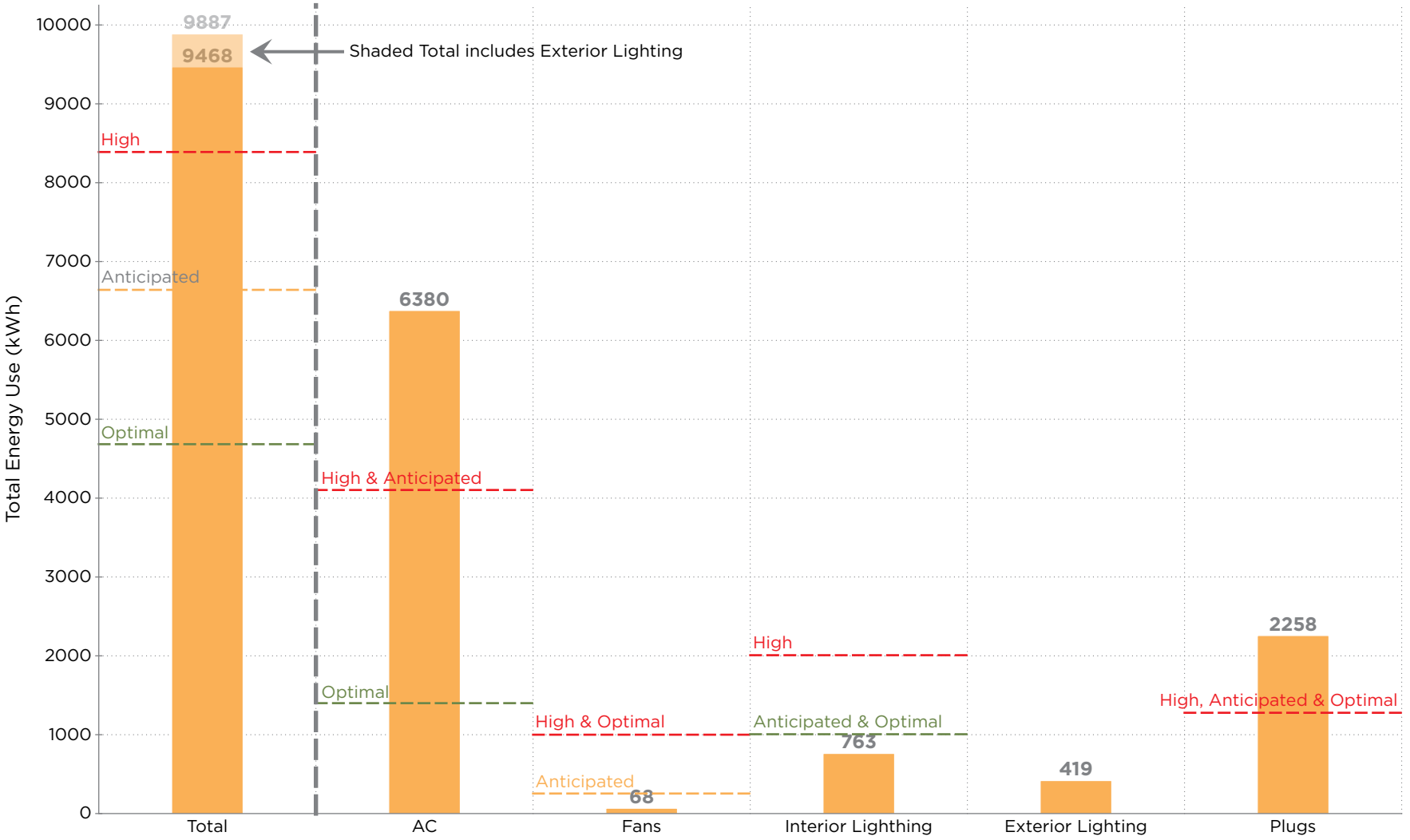
1: Exterior Lighting was the only energy consuming system that did not have a model prediction. We have included the energy consumed for reference and have included it in the Total compared to the model.

Annual Total Energy Use Actual vs. Modeled: Ilima

Description: Ilima energy models from the Phase II ONR Report are compared to measured values across energy end uses. Exterior lighting was included in the energy modelling but estimated as "0." Model scenarios are optimal (low), anticipated (medium) and high. More information on model scenarios can be found in the Methodology section.

Findings: Overall, Ilima consumed 18% more energy than the "High" modeling scenario. On the system level, both AC and Plugs overshot their "High" model predictions by 55% and 77%, respectively.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

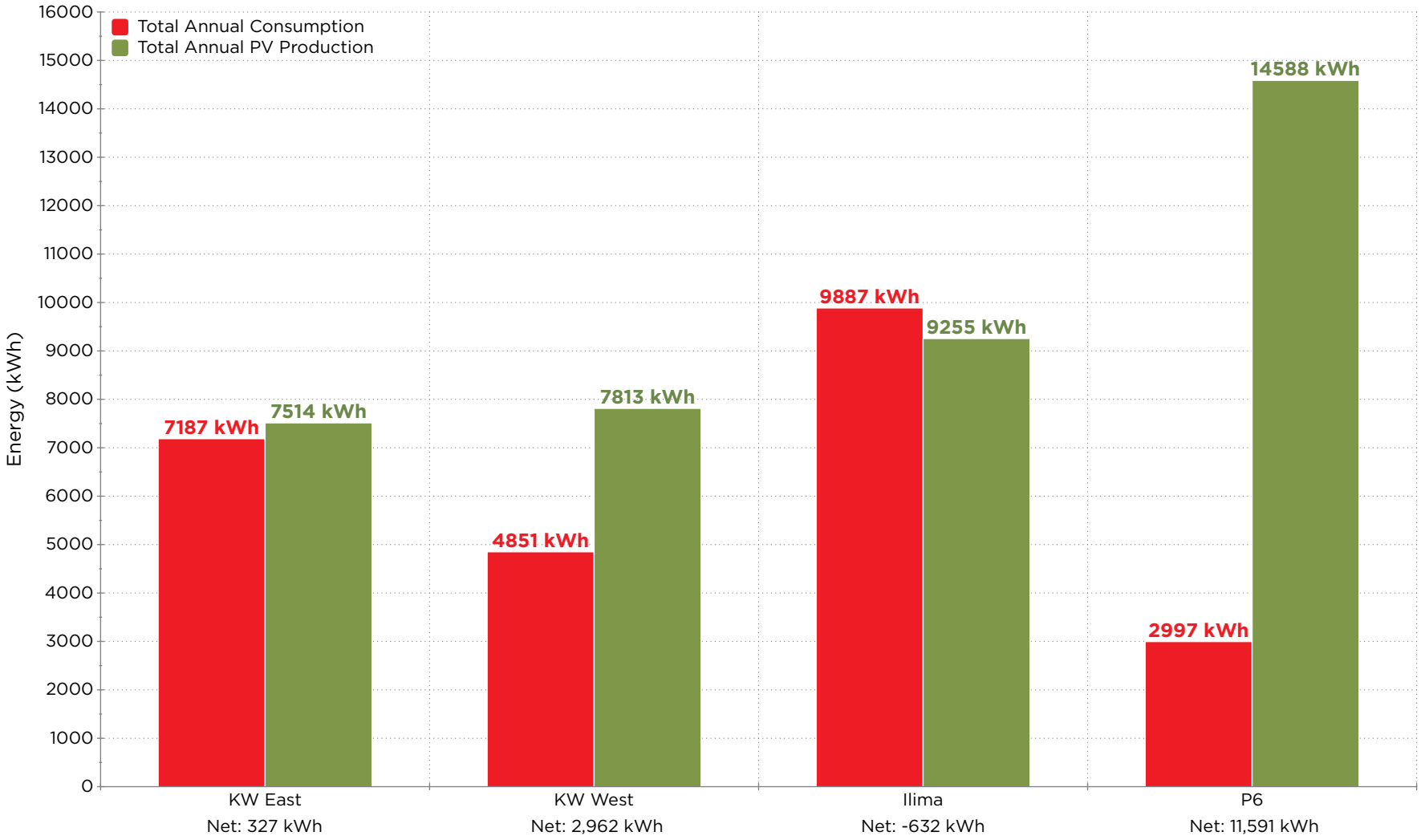


1: Exterior Lighting was the only energy consuming system that did not have a model prediction. We have included the energy consumed for reference and have included it in the Total compared to the model.

EQ1

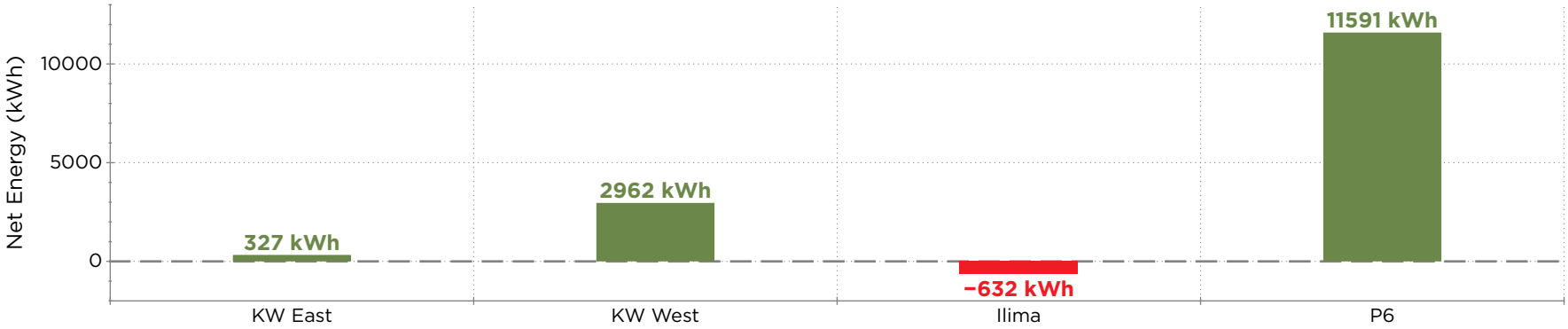
Kawaikini Frog Annual Net Zero Energy Summary

Description: These charts show the annual electricity consumption, PV electricity production and the net difference across four classrooms with PV systems.



Findings: While Ilima and Kawaikini East/West have the same PV system size, Ilima's system produced more electricity. Ilima was the only classroom to not achieve energy neutrality on an annual basis due to its high energy consumption. Ewa P6's PV generated the most electricity and consumed the least. However, Ewa P6's PV system is 2.3x bigger than the other 3 systems.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



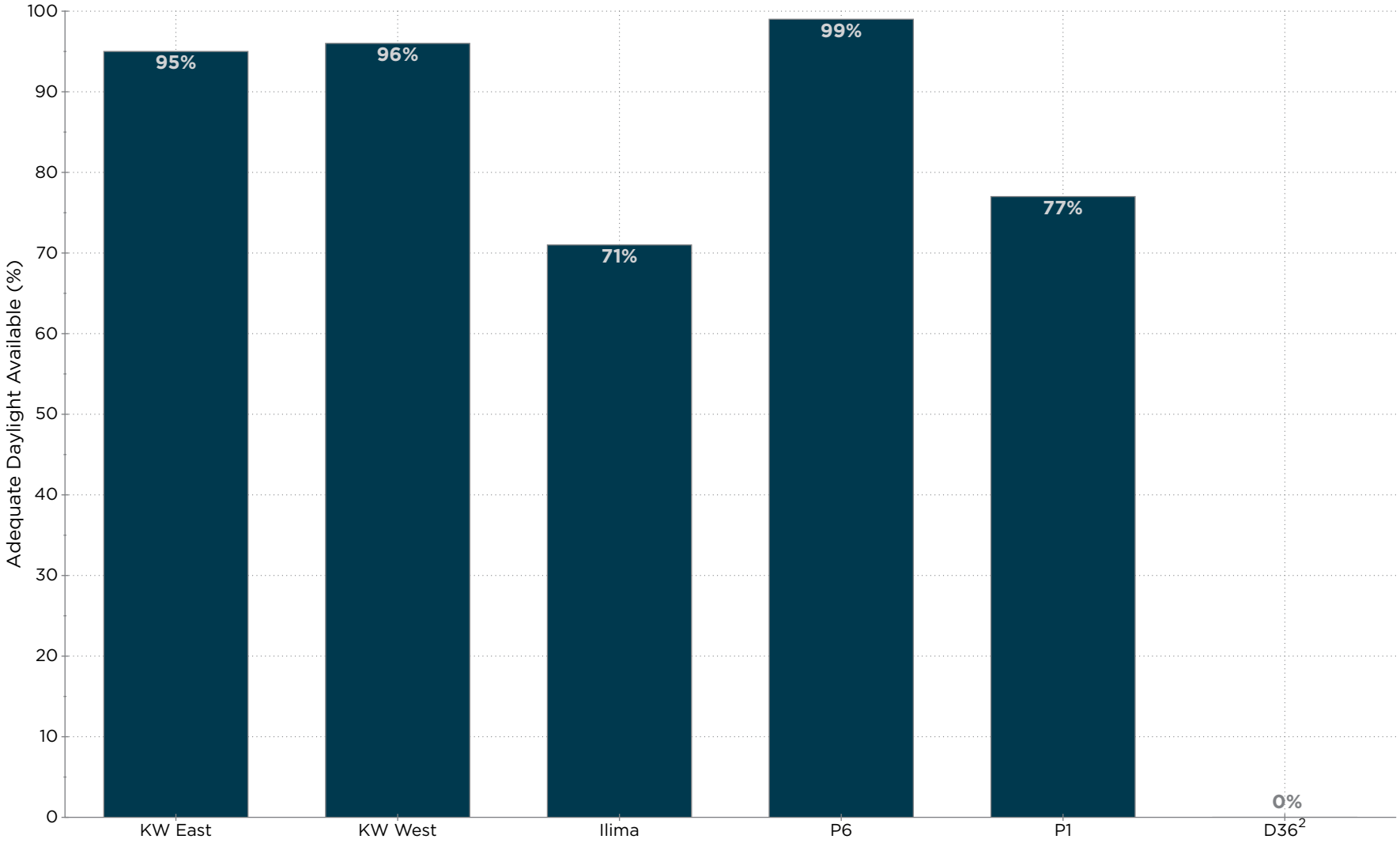
EQ2

Annual Observed Daylight Availability in School Hours on Non-School Days

Description: The percentage of time daylight was adequate to meet interior lighting quality criteria[1].

Findings: On average, the KW East, KW West, and P6 Test Platforms had 58% more time daylight met lighting criteria compared to Traditional classrooms of P1 and D36[2]. While Ilima is the same physical structure and orientation as KW East & West, occupants put newspaper on the front windows at Ilima for security reasons. Therefore, the percentage of time daylight met lighting quality criteria at Ilima was 25% less than KW West.

Study Period: 07/01/2014 - 06/30/2015
Days: Non-School Days
Hours: School Hours



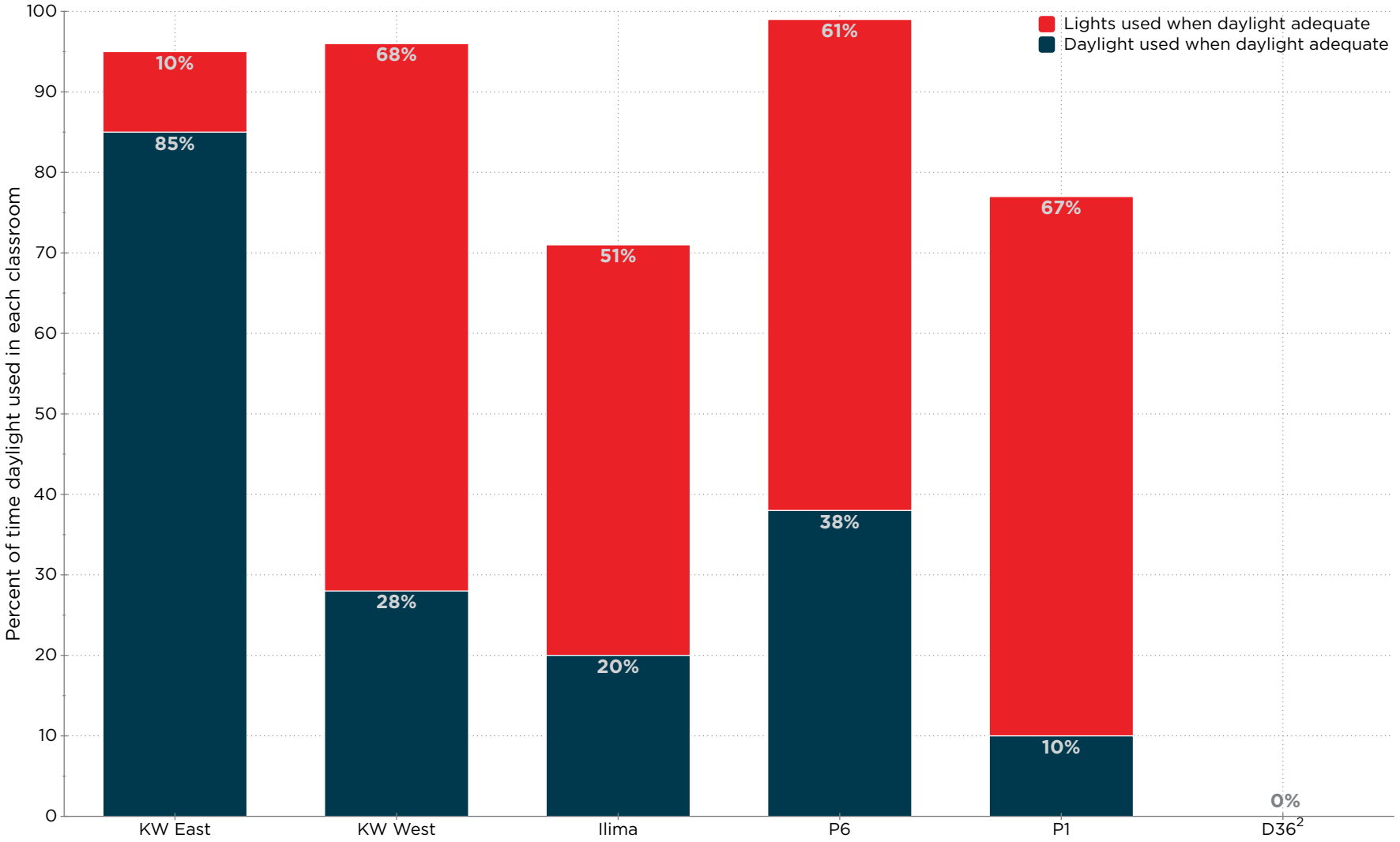
1: Lighting quality: the average wall illuminance > 5 ft-cd and the illuminance ratio (wall illuminance/ surface illuminance) <5
2: D36 did have windows but the shades were often closed as seen in Section 3.

Annual Daylight Use versus Daylight Availability

Description: The chart shows the percent of time the classroom used daylight or interior lights when natural daylight was adequate to meet lighting quality criteria[1].

Findings: Three out of four Test Platforms (i.e. KW East, KW West and P6) showed daylight capacity above 90% but only 1 used daylight above 50% uncovering a potential energy saving opportunity.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

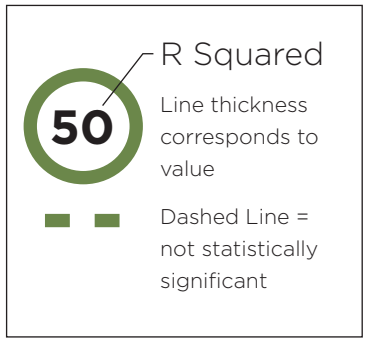


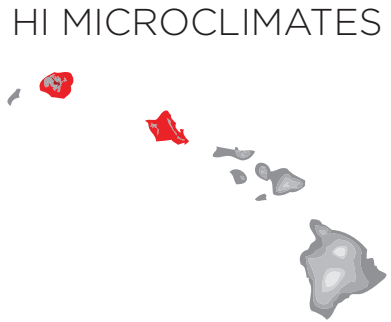
1: Lighting quality: the average wall illuminance > 5 ft-cd and the illuminance ratio (wall illuminance/ surface illuminance) <5
2: D36 did have windows but the shades were closed as seen in Section 3.

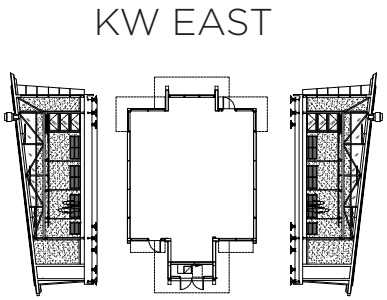
EQ3

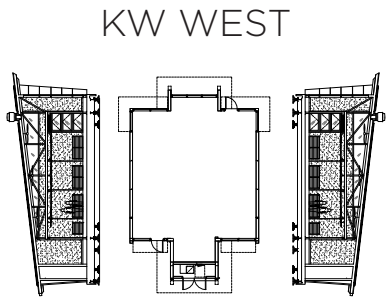
Weather/Microclimate Relationship to Daily Performance: Multiple Linear Regression Model

Description: The circles below represent the "R-Squared" values from a multiple linear regression model used to potentially explain selected performance metrics (dependent variables) from Weather data (independent variables). Weather variables included: Outdoor Air Temperature, Outdoor Relative Humidity, Wind Speed, and Solar Radiation. The "thicker" the line weight of the circle the more that weather could predict the performance of the building. Dashed lines represent results that were not statistically significant using an alpha = 0.05 (p-value <0.05).









Air Conditioning (kWh)

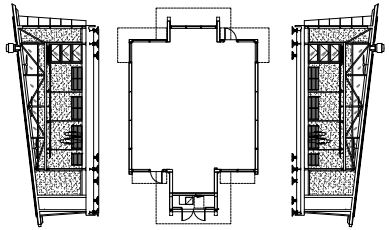
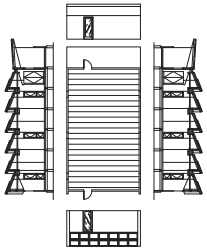
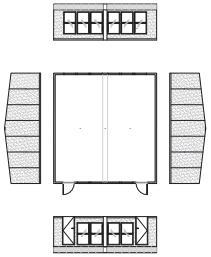
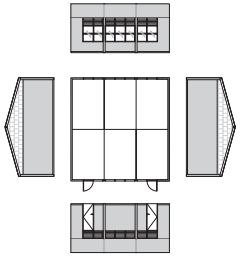
Lighting (kWh)

Thermal Comfort (PMV)

For HI Microclimates, differences in average daily weather between microclimates was modeled to fit differences in average daily performance

Findings: Differences in microclimates explained less than 5% of the variation in differences in performance between buildings in those microclimates and were not statistically significant. PMV models had the best “fits” of any model with weather able to explain >80% of the variation in PMV performance at three classrooms.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days (n=75)
Hours: All Hours

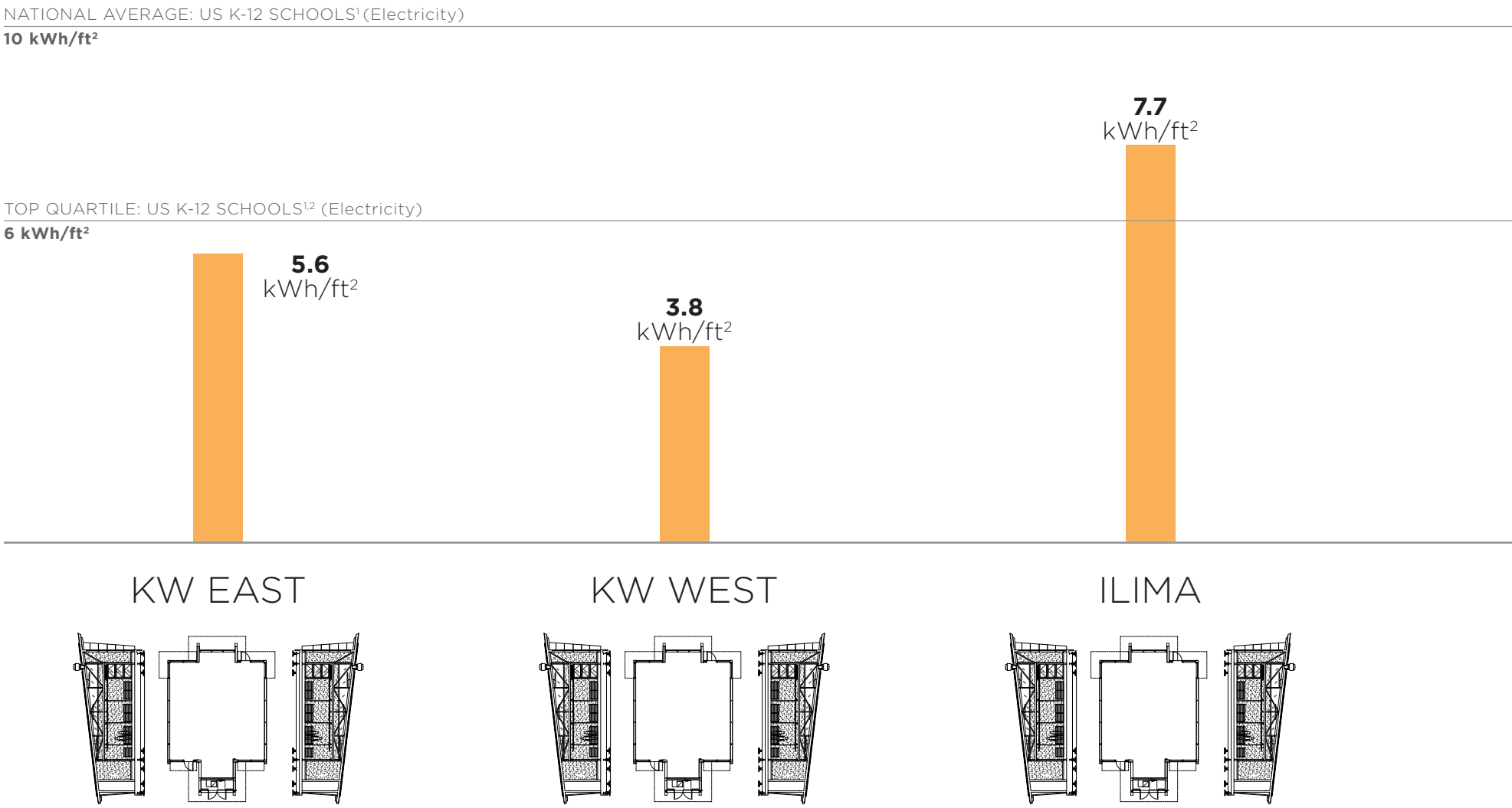
ILIMA	P6	P1	D36
			
8	n/a	n/a	n/a
2	15	14	14
27	91	14	53

For more information on the Multiple Linear Regression Model calculations, please refer to the Methodology section.

EQ4

Annual Energy Use Intensity Benchmarked Against National Reporting

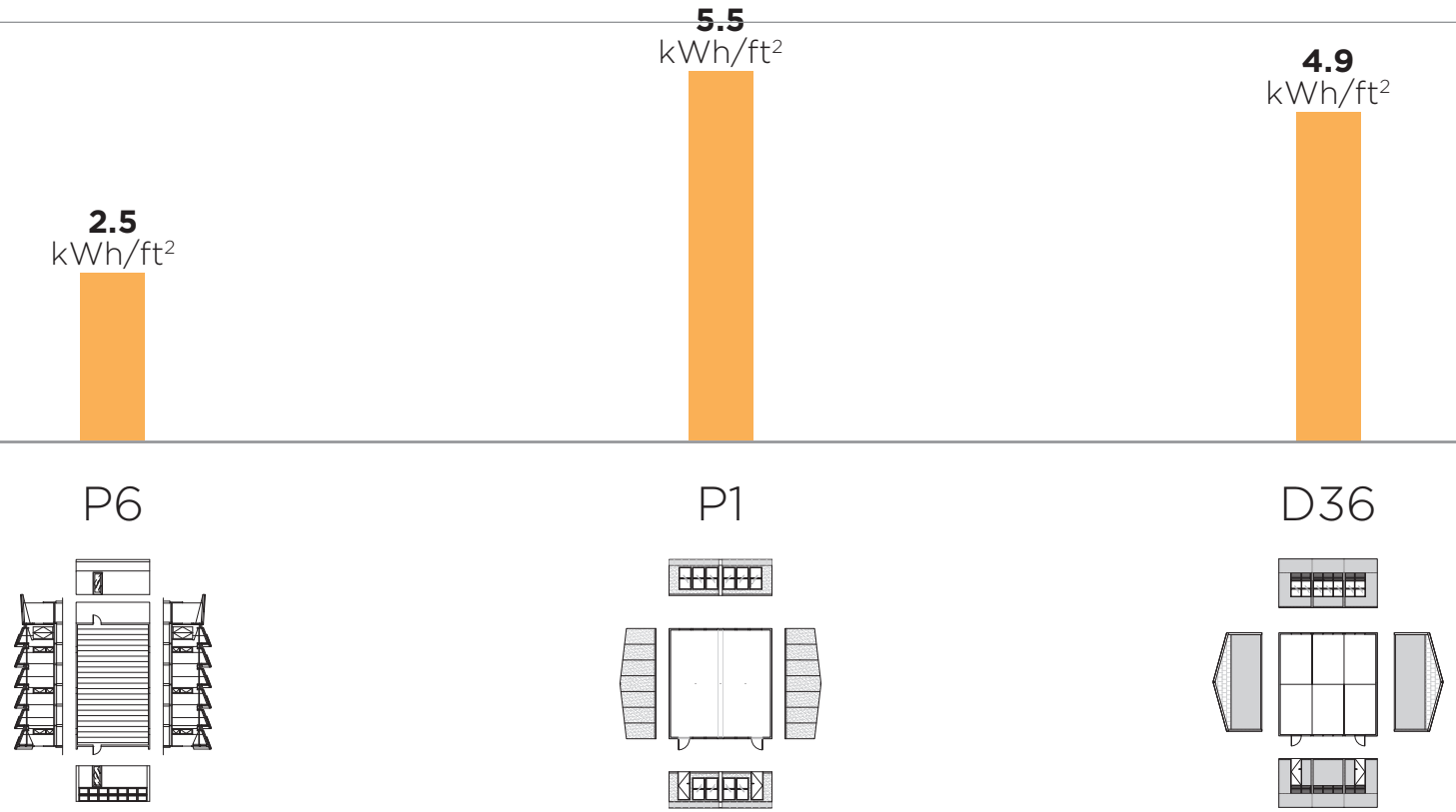
Description: Classrooms are compared by energy use intensity (i.e. the total annual energy (kWh) consumed divided by the classroom net square feet) to national school electricity benchmarks. Benchmarks are further described in the Methodology section.



1: Touchstone Energy Cooperatives: Schools Initiatives
2: US EPA Energy Star Building Manual: 10. Facility Type: K-12 Schools

Findings: Five out of six classrooms had lower EUIs than the top quartile of national schools; Kawaikini West and Ewa P6 had EUIs 37% and 58% lower, respectively.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



DESCRIPTION

Section 3 provides a summary of the contract and exploratory research questions including findings, interpretation and future work. In addition, energy saving recommendations are outlined for each classroom.

3

Discussion & Recommendations

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Discussion and Future Work - Contract Questions

Below summarizes the key study questions, corresponding findings and suggests additional research areas:

RESULTS

1. How do Test Platform performances compare to Traditional classrooms and to each other?

Finding

Test Platforms, on average, delivered 15% more comfort per energy consumed than Traditional classrooms.

Interpretation

It is not clear exactly why Test Platforms outperformed Traditional classrooms; and in fact, not all test platforms did outperform traditional classrooms. But with microclimate not a significant factor in the performance differences, the FROG Test platforms did demonstrate the potential for superior performance when considering comfort delivered per EUI.

2. Do Test Platforms perform as predicted by models?

Finding

Compared to the "Anticipated" model scenario, FROG Test Platforms' total energy consumption varied from +20% to -19% overall and by individual system from +77% to -72%.

Interpretation

Analyzing HVAC, Fan, and Lighting system operations compared to indoor and outdoor variables suggested that buildings were not operated per recommended operating guidelines. And since system usage didn't correspond with weather or consistent hourly schedules, it appears that the variability was likely due to user preference.

FUTURE STUDY

COMPARING COMFORT DELIVERED PER UNIT OF ENERGY

Approach

Comfort delivered per EUI helped connect the Energy and IEQ performance criteria, preventing buildings that used less energy with a minimum comfort level, and vice versa, from becoming the ideal. We recommend expanding the COMF/EUI metric to additional indoor environmental quality parameters in order to benchmark building performance more holistically.

Possible Research Questions

How does COMF/EUI change over time when different energy conservation programs are implemented?

What is the variation in COMF/EUI across building stock and how does that influence future investment decisions?

INPUTTING USER BEHAVIOR AND PREFERENCE

Approach

Accurate models depend on accurate assumptions for all drivers of system use. Building/system and weather characteristics are well studied, but occupant behaviors are generally unknown. Study occupants values and environmental preferences towards energy and comfort to more accurately model user demands.

Possible Research Questions

By knowing user values and preferences, can models better predict energy consumption?

Which energy conservation strategies are better aligned with which user preferences?

3. Do all classrooms perform within established guidelines (as per ASHRAE Standard 55 and 62.1)?

Finding

Test Platforms, on average, had 15% less time within the thermal comfort zone, had 41% more time with acceptable air quality and 2% more time with acceptable lighting conditions compared to Traditional Classrooms.

Interpretation

Test Platforms performed only slightly better on overall indoor environmental quality (IEQ) than traditional classrooms mostly due to superior performance in Lighting and Air Quality. While one of the FROG Test Platforms achieved the highest IEQ score overall, the other three Test Platforms underperformed compared to the Traditional classrooms. With building system operations controlled by users, perception of comfort may be different than calculated, leading to differences.

DEFINING COMFORT ACROSS CULTURAL NORMS

Approach

Understanding comfort differences across populations is crucial to setting design standards. We recommend gathering user satisfaction data from a range of occupants and operating environments to compare the levels of perceived comfort to calculated comfort based on ASHRAE or other guidelines. Results could be used to determine appropriate guideline adjustments.

Possible Research Questions

What are perceived comfort ranges in Hawaii classrooms and how does it compare to ASHRAE's thermal comfort model?

Can the same level of perceived comfort be achieved with other heat abatement solutions besides air conditioning?

Discussion and Future Work - Exploratory Questions

Below summarizes the key study questions, corresponding findings and suggests additional research areas:

RESULTS

1. How well did Test Platforms achieve "energy-neutrality"?

Finding

3 of 4 Test Platforms achieved energy neutrality or better on an annual basis.

Interpretation

The Kawaikini FROGs achieved Zero Net Energy (ZNE) by having a combined energy use approx. 15% below the "Anticipated" modeled consumption amount (excluding exterior lighting) and energy production above the Anticipated amount, as planned. Ilima FROG, however, produced more energy than its "High" estimate but consumed even more. P6 achieved ZNE by producing 3.9x the energy it consumed.

2. How do the classrooms compare in use of natural daylighting?

Finding

3 of 6 classrooms showed daylight capacity above 90% during school hours but only 1 platform achieved more than 50% utilization of that daylight potential.

Interpretation

Interior lights were often used when natural daylight was sufficient, which led to excess energy use, especially when buildings with dimming capabilities kept lights on at full power. This behavior could have resulted from, in part, occupant norms and/or lack of education on what sufficient daylight levels look like.

FUTURE STUDY

IMPROVING ADHERENCE TO HIGH-PERFORMANCE OPS

Approach

All classrooms have days that are close to achieving energy-neutrality but require a small amount (~1-5 kWh) of grid electricity. The need for grid electricity could be eliminated by either better adhering to the high-performance building operations manual for each building or otherwise implementing further energy efficiency or conservation initiatives.

Possible Research Questions

How can building operations better adhere to high-performance guidelines when occupants have access to controls?

Can net zero energy be achieved at a school level in Hawaii while maintaining a high level of occupant comfort?

TESTING PERCEIVED ADEQUATE LIGHTING

Approach

Survey occupants on perception of lighting levels and visual comfort when they are engaging in a range of activities to determine whether or not they can independently establish when lighting levels are sufficient, testing at what point occupants will adjust their lighting environment.

Possible Research Questions

How do people's perceptions of adequate light levels compare to calculated values?

How important are external views to feeling comfortable in a space?

3. How do the local weather and differences in microclimate impact classroom operations and performance?

Finding

Differences in microclimates did not reveal statistically significant relationships. Individual classrooms did exhibit moderate weather performance relationships.

Interpretation

Of the three performance criteria modeled by weather variables, only PMV exhibited a statistically significant relationship across FROG platforms in both Lihu'e and Ewa Beach. However, the % variation explained and the significance lowered when looking at these variables as potential reasons for differences in performance between platforms in Lihu'e and Ewa Beach. Given the lack of consistency in building system operations measured from system usage, it appears user preference influenced performance more than local weather did.

4. How do the classrooms compare against national averages for Energy Use Intensity (EUI)?

Finding

5 of 6 classrooms had lower EUIs than the top quartile of national schools; Kawaikini West and Ewa P6 had EUIs 37% and 58% lower, respectively

Interpretation

These 6 Hawaiian classrooms are already considered high-performing from a national EUI perspective; however, the national benchmarks don't account for differences in climate and other variables that may not make the benchmarks as useful as local comparisons, or comparisons to schools with similar operating requirements. Additionally, most national benchmarks are based on whole schools and not classrooms, so the exact benchmarking was approximated in this study and should be refined.

CONNECTING BUILDING SYSTEMS TO WEATHER

Approach

Install some classrooms with automated systems to adjust to varying outdoor and indoor conditions. In other classrooms, train occupants on how to optimally control the building.

Possible Research Questions

Compared to a building automation system, how well can educated occupants manage a building's operations?

Does an automated building lead to improved energy use performance while also satisfying occupants?

LOCALLY DEFINED BENCHMARKS

Approach

Comparing classroom energy use across a portfolio is useful for understanding performance context and potential. Analyze information on energy consumption, space use and program schedule for all Hawaii Department of Education's schools.

Possible Research Questions

What is the HIDOE's EUI benchmark by classroom type, school type, microclimate, and even academic performance?

How can the HIDOE benchmark be used for improved decision making within the Hawaii ecosystem?

Energy Saving Measures Specific to Issues in Classrooms

One to two key problems for each classroom are described followed by energy saving measures to address the problem.

System	Name	KW East	KW West
		1. The condensing unit was broken for 16 months before it was noticed and fixed. 2. 80% of AC use occurred below the optimal setpoint.	1. KW West had approximately double the amount of energy used for exterior lights than KW East. 2. 68% of the time interior artificial lights were used instead of daylight
All	Occupant Education	Educate the building occupants and maintenance staff on the operating procedures.	
	Building Automation System (BAS)		
	Energy Dashboard	An energy dashboard could alert maintenance staff to problems with equipment.	
HVAC	Cooling Setpoints		
	Demand Control Ventilation		
	Night Flushing		
Interior Lighting	Daylight Sensors		Daylight sensors could turn off interior lights when daylight is sufficient.
Exterior Lighting	Lighting Motion Sensors		Exterior lights could be triggered by motion sensors instead of always on at night.
Plug Loads	Energy Star Equipment		
	Smart Power Strips		

	Ilima	Ewa P6	Ewa P1	Ewa D36
	1. Air conditioning was used most of the time possibly due to manually operated windows and louvers. In addition, the space was over cooled.	1. P6 consumed 49% and 32% of the total classroom energy on plug loads and interior lights respectively.	1. Plug loads account for 54% of total classroom energy use. 2. 79% of school hours had CO_2 concentrations above the ASHRAE limit of 1100ppm.	1. The HVAC system is run from 6am to 6pm during weekdays regardless of occupancy. 2. Windows are covered preventing daylight into the space.
	The BAS could auto control the louvers and windows to open when advantageous. Also, the BAS could prevent the space from being over cooled.			The BAS could raise and lower blinds to control for glare or security concerns.
				Use specific cooling setpoints to turn on/off the HVAC system
			Demand control ventilation would bring in fresh outside air to replace high CO_2 air.	
	Night flushing removes inside heat with cool night air.			
		Daylight sensors could turn off interior lights when daylight is sufficient.		
		Ensure all equipment is Energy Star certified.	Ensure all equipment is Energy Star certified.	
		Smart power strips turn off equipment when not in use.	Smart power strips turn off equipment when not in use.	

Applicable Energy Saving Measures

Below are a broader list of energy saving recommendations worth considering for each classroom.

System	Name	Description
All	Occupant Education	Educate occupants and custodians on how to operate the buildings as intended
	Building Automation System	Install a building automation system so classrooms can respond to weather changes automatically
	Energy Dashboard	Install an energy dashboard to display how much energy is being used by various systems
	Custodial Operations	Implement daytime custodial services
	Wall/Roof Insulation	Retrofit the roof and walls with additional insulation
	Retro-commissioning	Conduct retro-commissioning to ensure all systems are working as intended
HVAC	Cooling Setpoints	Restrict the HVAC setpoint temperatures so that space cooling is only allowed above a certain temperature
	Demand Control Ventilation	Implement demand control ventilation for the HVAC system to bring outside air into a classroom based on occupancy
	Cool Roofs	Retrofit the roof to use a white membrane which reflects the solar radiation and decreases the heat flux through the roof
	Night Flushing	Open windows/louvers at night to allow cool air into the classroom
Interior Lighting	Daylight Sensors	Install daylight sensors which turn off lights when there is sufficient daylight
	Lighting Motion Sensors	Install motion sensors to turn on lights when motion is detected
	Lighting Controls	Install lighting controls to regulate lighting quality for specific tasks or situations
	Efficient Lighting	Upgrade to more efficient lighting
Exterior Lighting	Daylight Sensors	Install daylight sensors which turns off lights when there is sufficient daylight
	Lighting Motion Sensors	Install motion sensors to turn on/off lights when motion is detected
	Efficient Lighting	Upgrade to more efficient lighting
Ceiling Fans	Energy Star Equipment	Purchase Energy Star ceiling fans
Plug Loads	Energy Star Equipment	Require computers, stand-alone fans, printers, microwaves, and window AC units to be Energy Star certified
	Smart Power Strips	Use energy saving, smart power strips to cut off electricity to equipment when not in use

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TEST PLATFORM PERFORMANCE ANALYSIS P2

March 2016 | FINAL INTEGRATED REPORT | Researching the performance of 4 potentially Net-Zero Energy Test Platforms and 2 "traditional" Hawaiian classrooms

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HNEI SUBAWARD NO: MA130005

ONR Contract #N00014-12-1-0496

University of Hawaii's Asia-Pacific Research Initiative for Sustainable Energy Systems (APRISES)

Task 7 - Energy Efficiency

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Introduction

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In support of the University of Hawaii's Project "Asia Pacific Research Initiative for Sustainable Energy Systems" and under contract No.N00014-12-1-0496, MKThink instrumented six classrooms (4 high-performance "Test Platforms" and 2 "Traditional" classrooms) with energy use, indoor environmental quality, and system operation sensors to compare their respective performances to each other, to predictive models (where applicable), and to established guidelines for building performance. The study's stated goal is to increase the knowledge-base around key environmental and building (architectural) factors relevant to achieve energy neutral (net-zero) operations. This Part Two contract supports and expands on the Part One Project Frog Test Platform Study at Kawaikini NCPS in Līhu'e, Kaua'i (Contract No.N00014-11-1-0391). In total, this Final Integrated Report analyzes data collected from a one (1) year period 7/01/2014 - 6/30/2015, taken from a larger sample period from 7/16/2013- 7/16/2015, for all six classrooms located at three schools in two different climate zones. The classrooms are as follows:

NAME	aka	CLASSROOM TYPE	SCHOOL	LOCATION	NET ZERO ENERGY (NZE) DESIGN INTENT
Kawaikini West	KW West	Modular Portable FROG	Kawaikini New Century Public Charter	Līhu'e, Kaua'i	Yes
Kawaikini East	KW East	Modular Portable FROG	Kawaikini New Century Public Charter	Līhu'e, Kaua'i	Yes
Ilima FROG	Ilima	Modular Portable FROG	Ilima Intermediate	Ewa Beach, O'ahu	Yes
Ewa P6	P6	Modular ZNE Portable	Ewa Elementary	Ewa Beach, O'ahu	Yes
Ewa P1	P1	Standard Portable	Ewa Elementary	Ewa Beach, O'ahu	No
Ewa D36	D36	Standard Masonry	Ewa Elementary	Ewa Beach, O'ahu	No

The report is organized into the following content sections:

Dashboards: Summarizes answers the key questions of the report
Classroom Asset Information: Details the classroom physical characteristics
Environmental Summary: Details the local climate and weather characteristics
Group Behavior Summary: Details the occupant planned and actual behaviors within the classrooms
Performance Summary: Details the performance of the six classrooms across study criteria
Discussion & Recommendations: Discusses the results through insight, interpretation, and recommendations
Methodology & References: Details the calculations, references, and assumptions used in the report
Appendix: Includes additional charts and data related to the two year study

To conduct the study, MKThink established three (3) key questions to be answered with criteria and sub-criteria developed as the measurable components of each criterion. The three key questions are:

1. How do Test Platform performances compare to Traditional classrooms and each other?
   (Task 1- Planning: 1.1.4.1.1 - "compare...one platform to another")
2. Do Test Platforms perform as predicted by models?
   (Task 1- Planning: 1.1.4.1.2 - "compare...to model predictions in Phase II ONR")
3. Do all classrooms perform within established guidelines?
   (Task 1- Planning: 1.1.4.1.1 - "compare...to established guidelines for building performance")

The criteria and sub-criteria are as follows:

CRITERIA	SUB-CRITERIA	UNIT	DESCRIPTION
Energy Use	Total Loads	kWh	All electrical loads measured at the electrical panel
	Mechanical Cooling	kWh	Condensing Unit, Fan Coil Unit, and Exhaust Fan
	Ceiling Fans	kWh	Electrical energy use of ceiling fans
	Interior Lighting	kWh	Electrical energy use of primary classroom lighting
	Exterior Lighting	kWh	Outdoor lighting electrical energy use (where applicable)
	Plug Loads	kWh	Plug loads from in-classroom devices
Indoor Environmental Quality (IEQ)	Thermal Comfort	PMV	ASHRAE Adaptive Comfort Model
	Air Quality	ppm	CO_2 concentrations
	Lighting Quality	ft-cd	Luminosity and glare ratio at work surface
Building System Performance	Air Supply	°F	Rise in temperature between supply and distribution
	Natural Daylighting	ft-cd	Available daylight utilized without artificial lighting

Additionally, four more Exploratory Questions are asked and evaluated in the report. These questions are as follows:

1. How well did Test Platforms achieve "energy-neutrality"?
2. How do the classrooms compare in use of natural daylighting?
3. How do local weather and differences in microclimates impact building operations and performance?
4. How do the classrooms compare against national averages for Energy Use Intensity?

DESCRIPTION
This section summarizes the major findings of the 2-year study in a series of executive summary dashboards organized to support the study's primary and exploratory research questions. These dashboards compare energy consumption, indoor environmental quality, and system performance for a selected 1-year period.

WHY IMPORTANT
Provides quick access to the most interesting results from the report

2

Dashboards

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Key Findings

Contracted Questions (CQs)

To conduct the study, MKThink established three (3) key questions to be answered. Each question was dissected into measurable metrics with criteria and sub-criteria developed for comparison. The four (4) Test Platforms (TP) were KW East, KW West, Ilima and P6. The Traditional classrooms (TC) were P1 and D36. The questions and results are summarized below and in the following report pages:

(Task 1- Planning: 1.1.4.1.1 - "compare...one platform to another")

CQ1

1. How do Test Platform performances compare to Traditional classrooms and to each other?

On average, Test Platforms (TP) used 40% less energy per square foot, had 6% more time with comfortable interior conditions and delivered 15% more comfort per energy consumed than Traditional classrooms.

- EUI: **TP Avg 1.8 kWh/ft²** [KW East 1.2 EUI, KW West 1.5 EUI, Ilima 3.4 EUI, P6 0.9 EUI], **TC Avg 3 kWh/ft²** [P1 3.4 EUI, D36 2.6 EUI]
- IEQ (% time all 3 envir. criteria simult. met): **TP Avg 39%** [KW East 37%, KW West 75%, Ilima 24%, P6 18%], **TC Avg 33%** [P1 8%, D36 57%]
- COMF/EUI[1] (Comfort delivered (IEQ) per kWh/sf): **TP Avg 27** [KW East 31, KW West 50, Ilima 7, P6 20], **TC Avg 12** [P1 2, D36 22]

(Task 1- Planning: 1.1.4.1.2 - "compare...to model predictions in Phase II ONR")

CQ2

2. Do Test Platforms perform as predicted by models [based on anticipated operating modes]?

Compared to the "Anticipated" model scenario, FROG Test Platforms' total energy consumption varied from +20% to -19% overall, and by individual system from +77% to -72%. Additionally, 40% or less of Active Mode HVAC operations occurred during times recommended in the high-performance building operations guides.

- Total Energy Use: Compared to "anticipated": KW East 20% more, KW West 19% less, Ilima 18% more
- By System: Compared to "anticipated" predictions, systems varied by: KW East (Plugs) -72%, KW West (AC) -38%, Ilima (Plugs) 77%
- By Operating Mode: When "On", Active Mode (Cooling) was used above 82deg F (% time): KW East 40%, KW West 0%, Ilima 15%

(Task 1- Planning: 1.1.4.1.1 - "compare...to established guidelines for building performance")

CQ3

3. Do all classrooms perform within established guidelines (as per ASHRAE Standard 55 and 62.1)?

On average, Test Platforms (TP) had 15% less time within the thermal comfort zone, had 41% more time with acceptable air quality and 2% more time with acceptable lighting conditions compared to Traditional classrooms (TC).

- Thermal Comfort (% time in comfort zone): **TP Avg 41%** [KW East 39%, KW West 77%, Ilima 27%, P6 21%], **TC Avg 56%** [P1 44%, D36 68%]
- Air Quality (% time below 1100ppm): **TP Avg 100%** [KW East 100%, KW West 100%, Ilima 100%], **TC Avg 59%** [P6 100%, P1 21%, D36 96%]
- Lighting Quality (% time illum. met): **TP Avg 92%** [KW East 95%, KW West 97%, Ilima 84%, P6 92%], **TC Avg 90%** [P1 94%, D36 86%]

1: This performance metric was created during this study to link Indoor Environmental Quality (IEQ) to energy used

Exploratory Questions (EQs)

In addition to the contracted research questions, MKThink studied four (4) additional exploratory questions that were relevant to the intent of the research. The questions and results are summarized below and further detailed in the subsequent report pages:

EQ1

1. How well did Test Platforms achieve "energy-neutrality"?

3 of 4 Test Platforms achieved energy neutrality or better on an annual basis.

- Annual Energy (Net Generator (+), Net Consumer (-)): KW East +327 kWh, KW West +2,962 kWh, Ilima -632 kWh, P6 +11,591 kWh
- Daily (% days Net Generator / % days Net Consumer): KW East 59/41, KW West 74/26, Ilima 53/47, P6 99/1

EQ2

2. How do the classrooms compare in use of natural daylighting?

3 of 6 Classrooms showed daylighting capacity above 90% during school hours but only 1 classroom achieved >50% utilization of that daylighting potential.

- Empirical Daylighting Capacity (measured % time daylight can be used): KW East 95%, KW West 96%, Ilima 71%, P6 99%, P1 77%, D36 0%
- Actual Daylighting Achieved (measured % time daylight was used): KW East 85%, KW West 28%, Ilima 20%, P6 38%, P1 10%, D36 n/a

EQ3

3. How do local weather and differences in microclimates impact classroom operations and performance?

Differences in microclimates did not reveal statistically significant linear relationships (p-value < 0.05) with classroom performance; however, individual classrooms did exhibit moderate-strong (R^2 >= 0.60-0.80; p-value < 0.05) weather-performance relationships.

- Microclimate Impacts (Ewa Beach vs. Lihu'e): AC Energy R^2=0.02, Light Energy R^2=0.03, PMV R^2=0.06; p-value not sig.
- Weather vs. AC Energy Use: KW East R^2=0.50/yes, KW West R^2=0.69/yes, Ilima R^2=0.08/no
- Weather vs. PMV: KW East R^2=0.89/yes, KW West R^2=0.81/yes, Ilima R^2=0.27/yes,P6 R^2=0.91/yes, P1 R^2=0.14/yes, D36 R^2=0.53/yes
- Weather vs. Light Use: KW East R^2=0.21/yes, KW West R^2=0.06/no, Ilima R^2=0.02/no, P6 R^2=0.15/yes, P1 R^2=0.14/yes, D36 R^2=0.14/yes

(statistical significance=yes/no; weather/microclimate based on Air Temperature, Relative Humidity, Wind Speed, and Solar Radiation)

EQ4

4. How do the classrooms compare against national averages for Energy Use Intensity (EUI)?

5 of 6 Classrooms had lower EUIs (Energy Use Intensity) than the top quartile of national schools. Kawaikini West and Ewa P6 had EUIs 37% and 58% lower, respectively.

- Annual Average EUI (compared to US Top Quartile): KW East 7% less, KW West 37% less, Ilima 28% more, P6 58% less, P1 8% less, D36 18% less

CQ1, CQ3

Annual Energy and IEQ Classroom Comparison

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

ENERGY USE INTENSITY (EUI)[4]:
- energy end use and the classroom total per net square feet

INDOOR ENVIRONMENTAL QUALITY (IEQ)[5]:

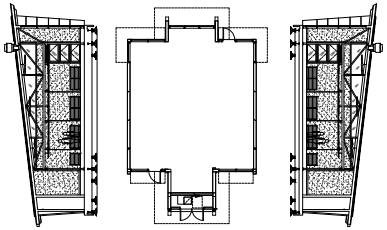
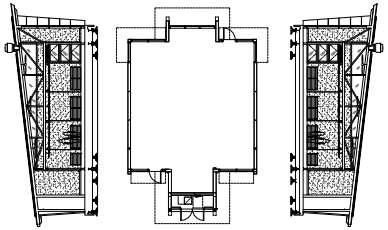
Thermal Comfort: % of time PMV score w/ in ASHRAE Comfort Zone

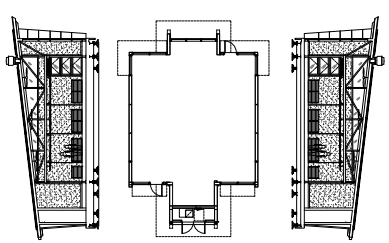
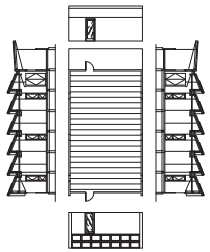
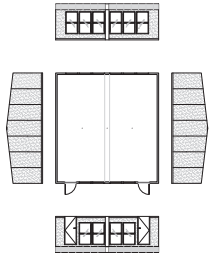
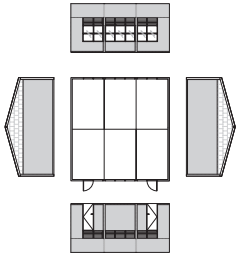
Air Quality: % of time CO_2 concentration below ASHRAE threshold (1100 ppm)

Lighting Quality: % of time wall illuminance >5 ft-c & illuminance ratio (wall illuminance/surface illuminance) <5

COMF/EUI[5]:
- working metric describing the amount of comfort delivered per unit of energy consumed

1: Classrooms had accompanying operating procedures that occupants were unaware of or did not use.
2: AC unit energy is included in Plugs
3: AC energy use is extrapolated for a year based on energy use from one week in November
4: Calculated using Net Square Feet (NSF)
5: Discussed further in the Methodology section

	KW EAST[1]	KW WEST[1]
		
EUI (kwh/ft²)	**1.2**	**1.5**
AC	0.9	0.9
FANS	0.2	0.1
PLUGS	0.04	0.2
INT. LIGHTING	0.1	0.3
IEQ (%)	**37%**	**75%**
THERMAL	39	77
AIR QUALITY	100	100
LIGHTING	95	97
COMF/ EUI	**31**	**50**

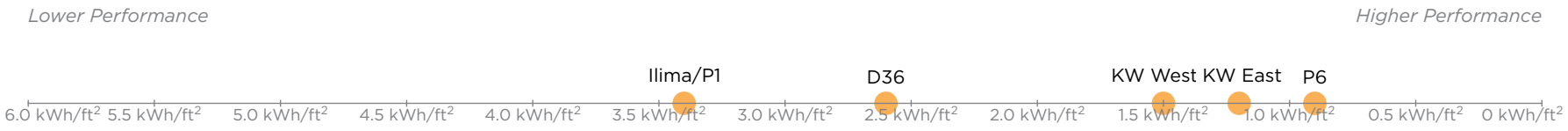
	ILIMA[1]	P6[1]	P1	D36
				
	3.4	**0.9**	**3.4**	**2.6**
	2.6	--	X[2]	2.4[3,5]
	0.04	0.1	0.7	0.0
	0.4	0.3	2.0	0.01
	0.4	0.5	0.7	0.2
	24%	**18**%	**8**%	**57**%
	27	21	44	68
	100	100	21	96
	84	92	94	86
	7	**20**	**2**	**22**

CQ1, CQ3

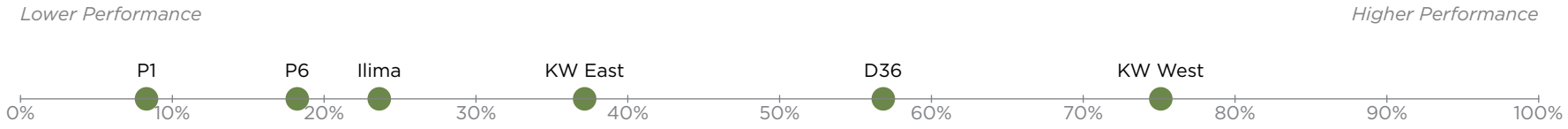
Annual COMF/EUI Classroom Comparison

Description: Classrooms are compared by annual energy use intensity, indoor environmental quality and amount of delivered comfort per unit of energy. Values of indoor environmental quality and energy use intensity are seen on page 12 and 13.

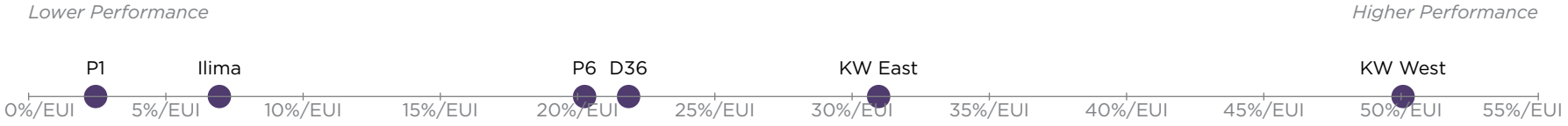
Energy Use Intensity[1] [total annual energy use consumed per square foot]



Indoor Environmental Quality [percentage of time thermal comfort, air quality and illuminance criteria are all met]



Comfort/Energy Use Intensity[2] [percentage of time all environmental criteria are met per kWh/sf²]

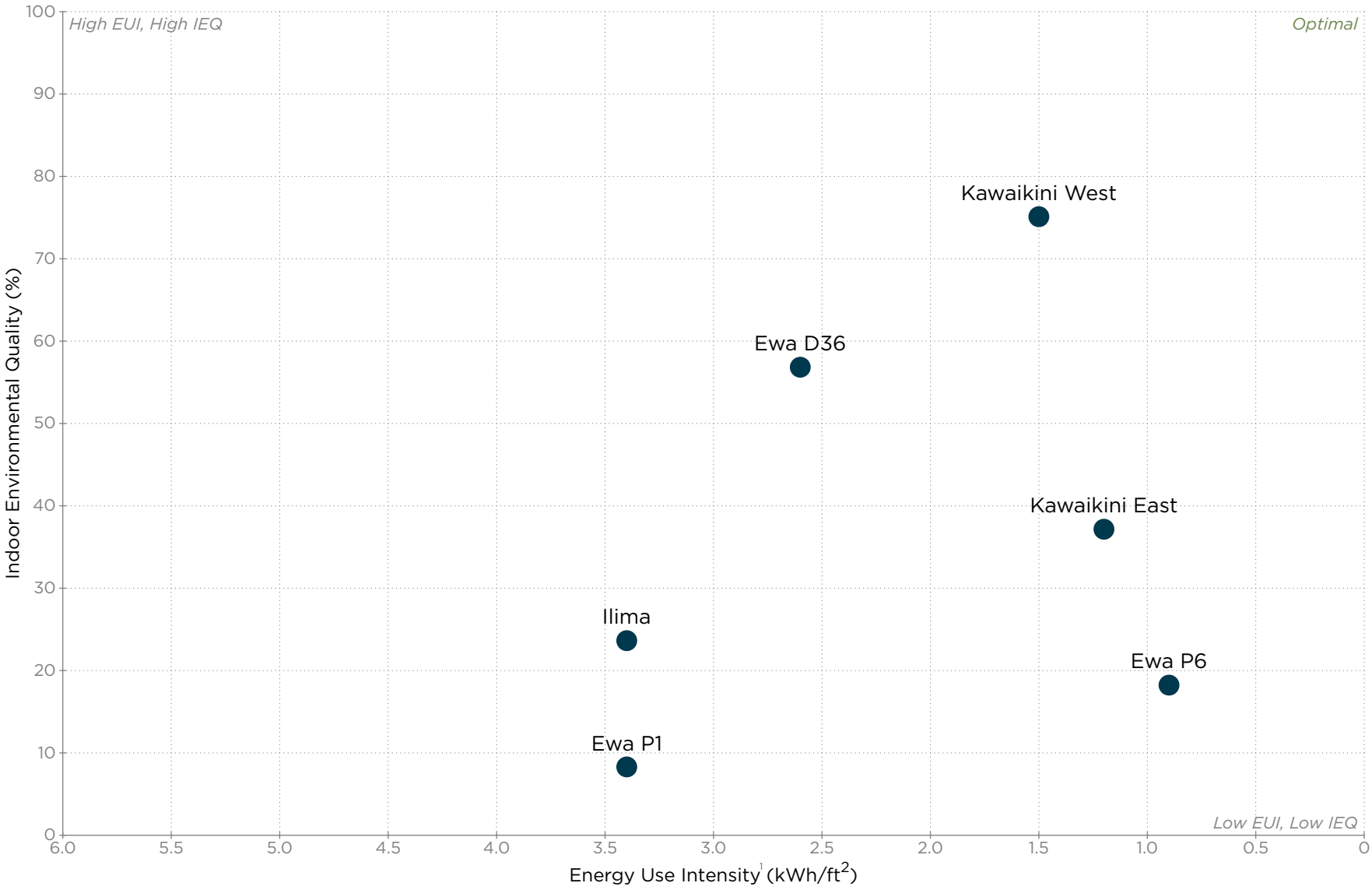


1: EUI axis ranges from 0 kwh/ft² to 6 kwh/ft² based on US Energy Consumption Data for Top Quartile US K-12 Schools electricity reported by Touchstone and US EPA Energy Star Building Manual 10

2: The Comfort/EUI axis will vary depending on the building. The Comfort/EUI upper bound of 55%/EUI was chosen to see variation in classroom performance.

Findings: On average, the Test Platforms used 40% less energy per square foot, provided 6% more time within IEQ thresholds and delivered 15% more comfort per unit of energy consumed than the Traditional classrooms.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

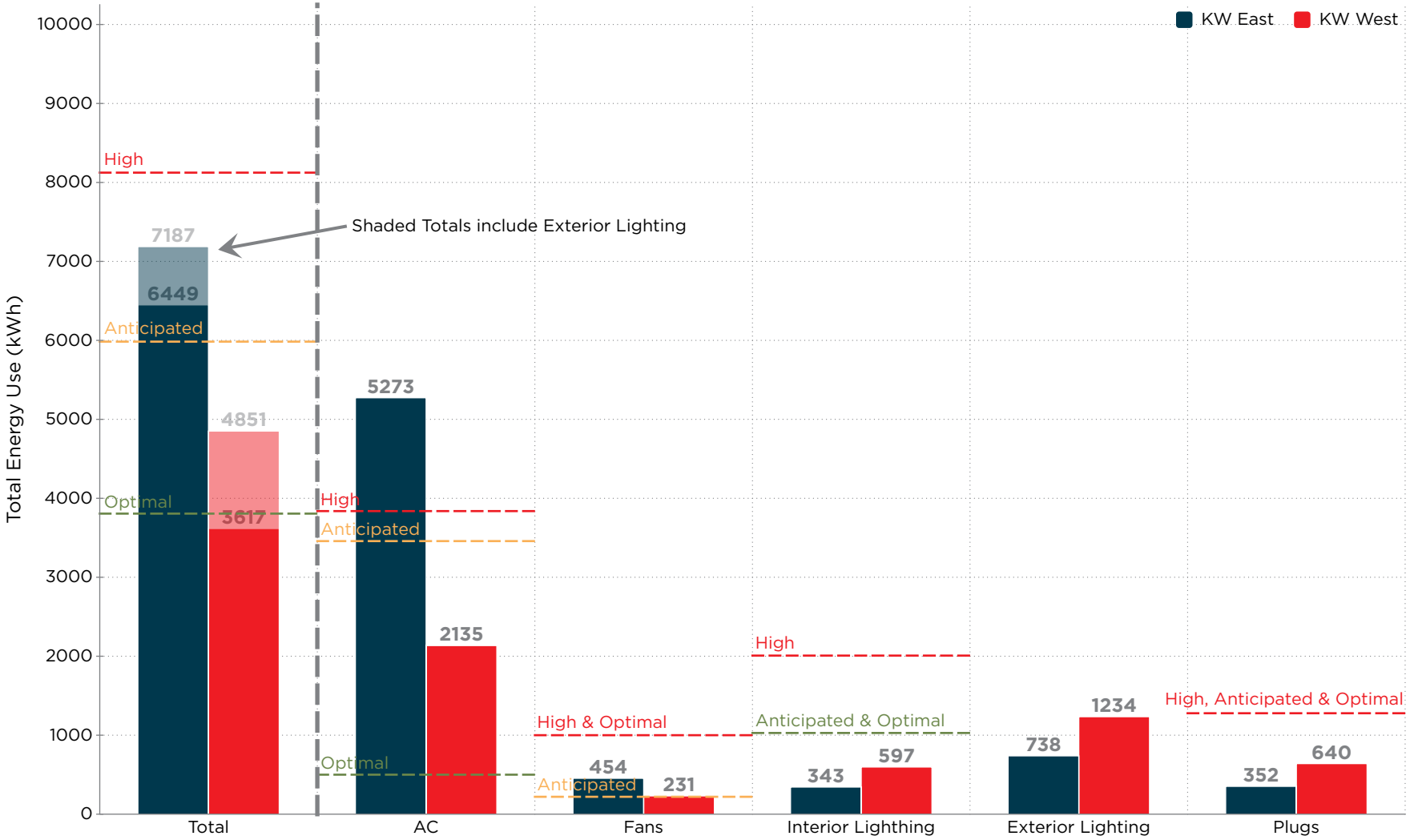


Annual Total Energy Use Actual vs. Modeled: Kawaikini East and West

Description: Kawaikini energy models from the Phase II ONR Report are compared to measured values across energy end uses. Exterior lighting was included in the energy modeling but estimated as "0." Model scenarios are optimal (low), anticipated (medium) and high. More information on model scenarios can be found in the Methodology section.

Findings: Overall, Kawaikini East consumed 20% more than "Anticipated" while Kawaikini West consumed 19% less than "Anticipated." Kawaikini East used 37% more AC energy than the "High" modeling scenario.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



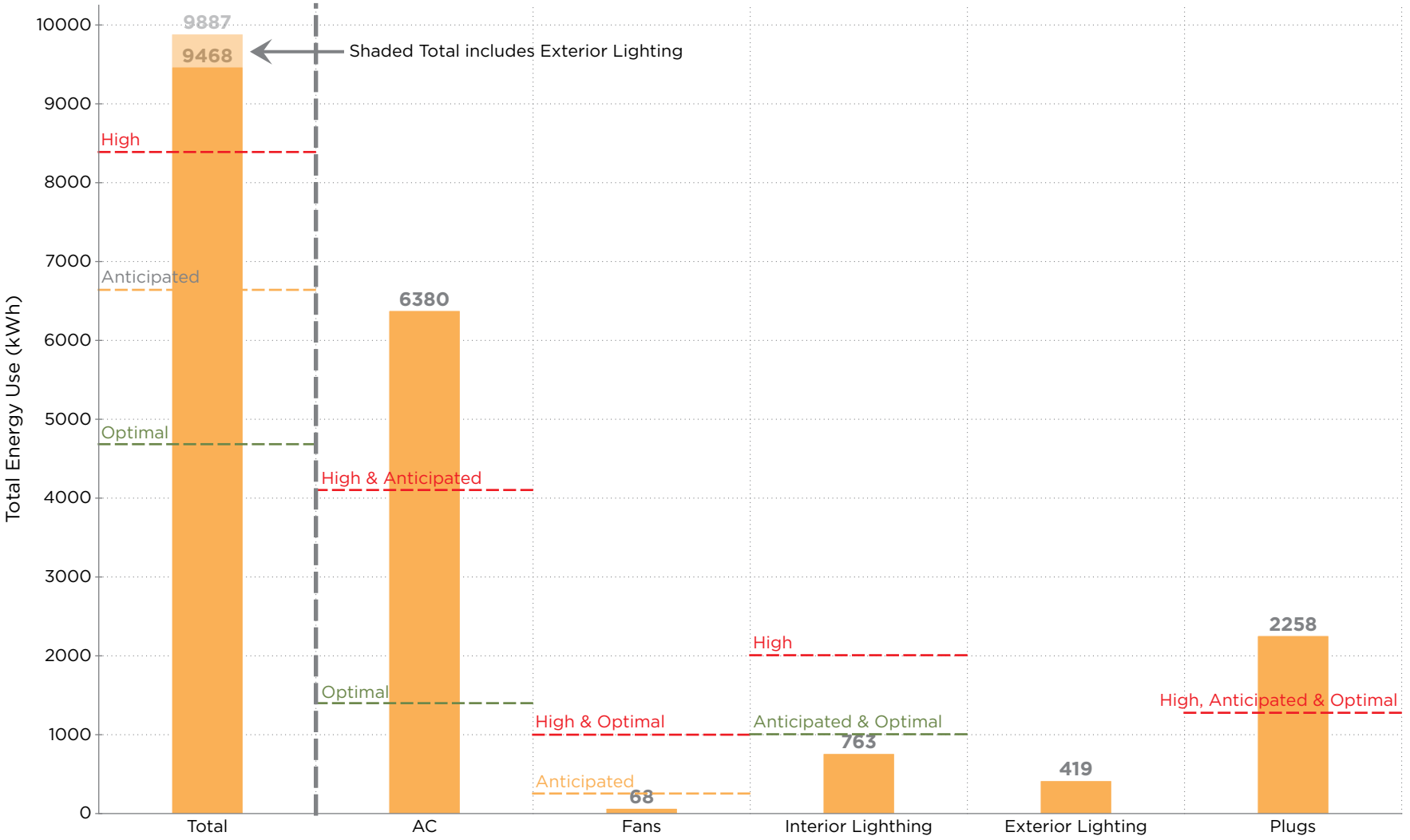
1: Exterior Lighting was the only energy consuming system that did not have a model prediction. We have included the energy consumed for reference and have included it in the Total compared to the model.

Annual Total Energy Use Actual vs. Modeled: Ilima

Description: Ilima energy models from the Phase II ONR Report are compared to measured values across energy end uses. Exterior lighting was included in the energy modelling but estimated as "0." Model scenarios are optimal (low), anticipated (medium) and high. More information on model scenarios can be found in the Methodology section.

Findings: Overall, Ilima consumed 18% more energy than the "High" modeling scenario. On the system level, both AC and Plugs overshot their "High" model predictions by 55% and 77%, respectively.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

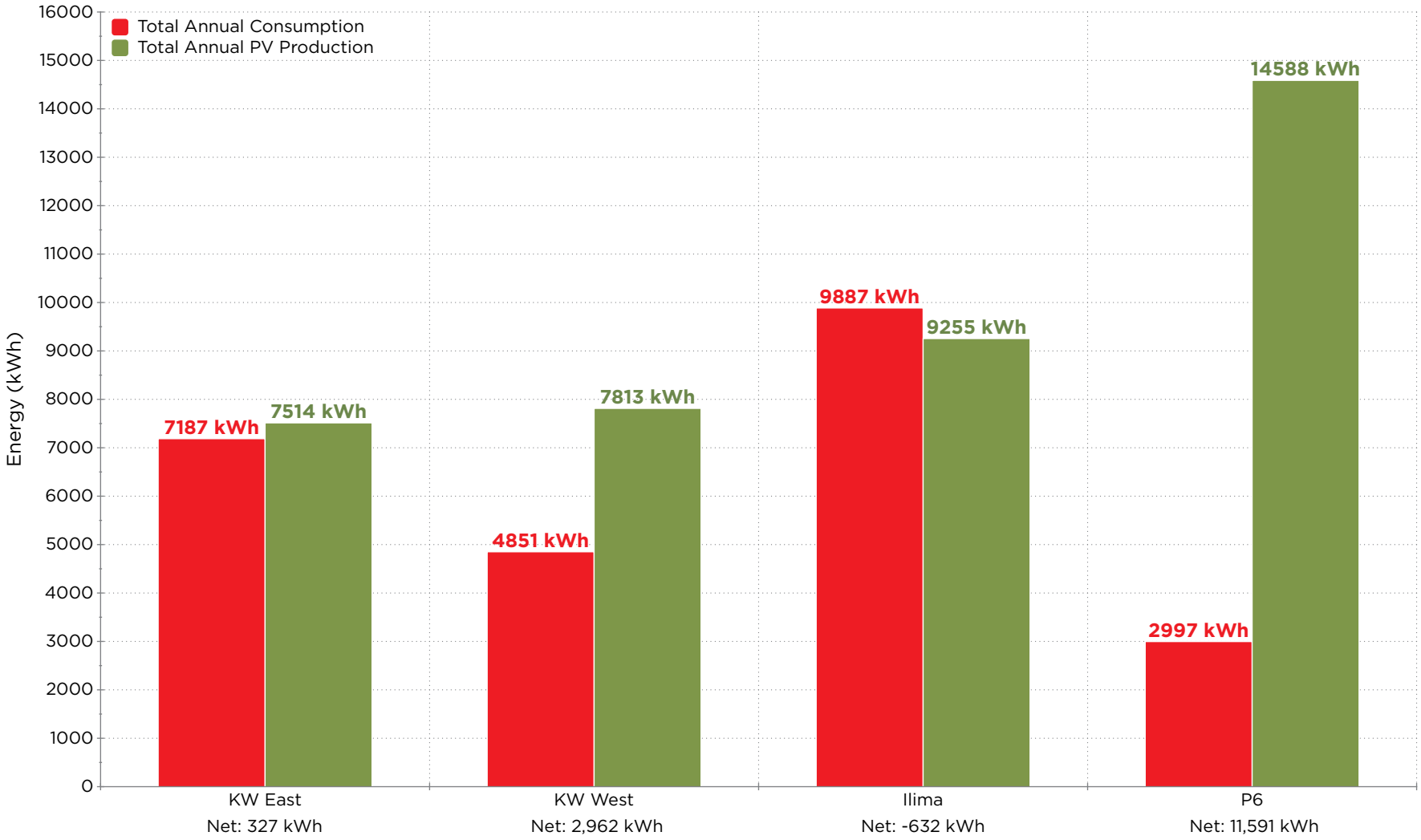


1: Exterior Lighting was the only energy consuming system that did not have a model prediction. We have included the energy consumed for reference and have included it in the Total compared to the model.

EQ1

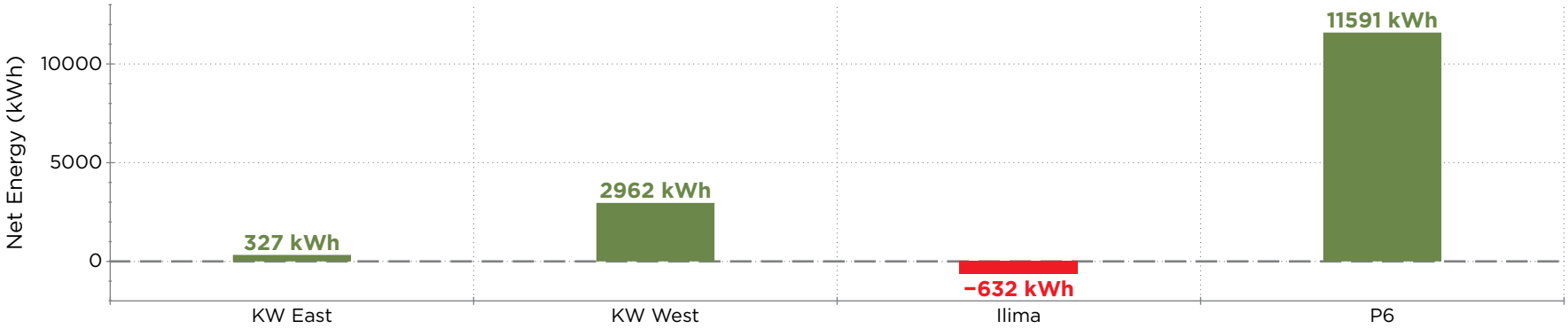
Kawaikini Frog Annual Net Zero Energy Summary

Description: These charts show the annual electricity consumption, PV electricity production and the net difference across four classrooms with PV systems.



Findings: While Ilima and Kawaikini East/West have the same PV system size, Ilima's system produced more electricity. Ilima was the only classroom to not achieve energy neutrality on an annual basis due to its high energy consumption. Ewa P6's PV generated the most electricity and consumed the least. However, Ewa P6's PV system is 2.3x bigger than the other 3 systems.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



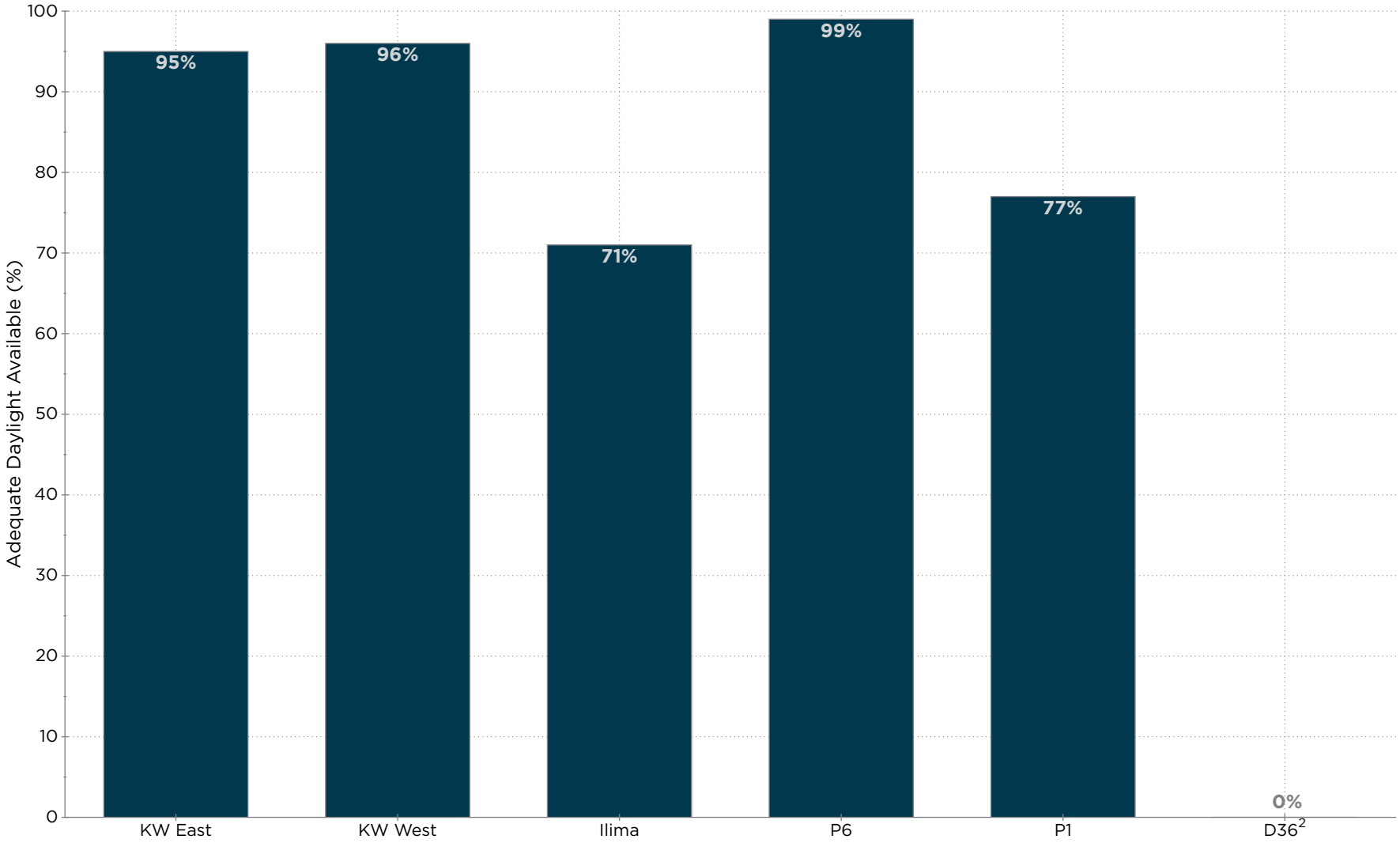
EQ2

Annual Observed Daylight Availability in School Hours on Non-School Days

Description: The percentage of time daylight was adequate to meet interior lighting quality criteria[1].

Findings: On average, the KW East, KW West, and P6 Test Platforms had 58% more time daylight met lighting criteria compared to Traditional classrooms of P1 and D36[2]. While Ilima is the same physical structure and orientation as KW East & West, occupants put newspaper on the front windows at Ilima for security reasons. Therefore, the percentage of time daylight met lighting quality criteria at Ilima was 25% less than KW West.

Study Period: 07/01/2014 - 06/30/2015
Days: Non-School Days
Hours: School Hours



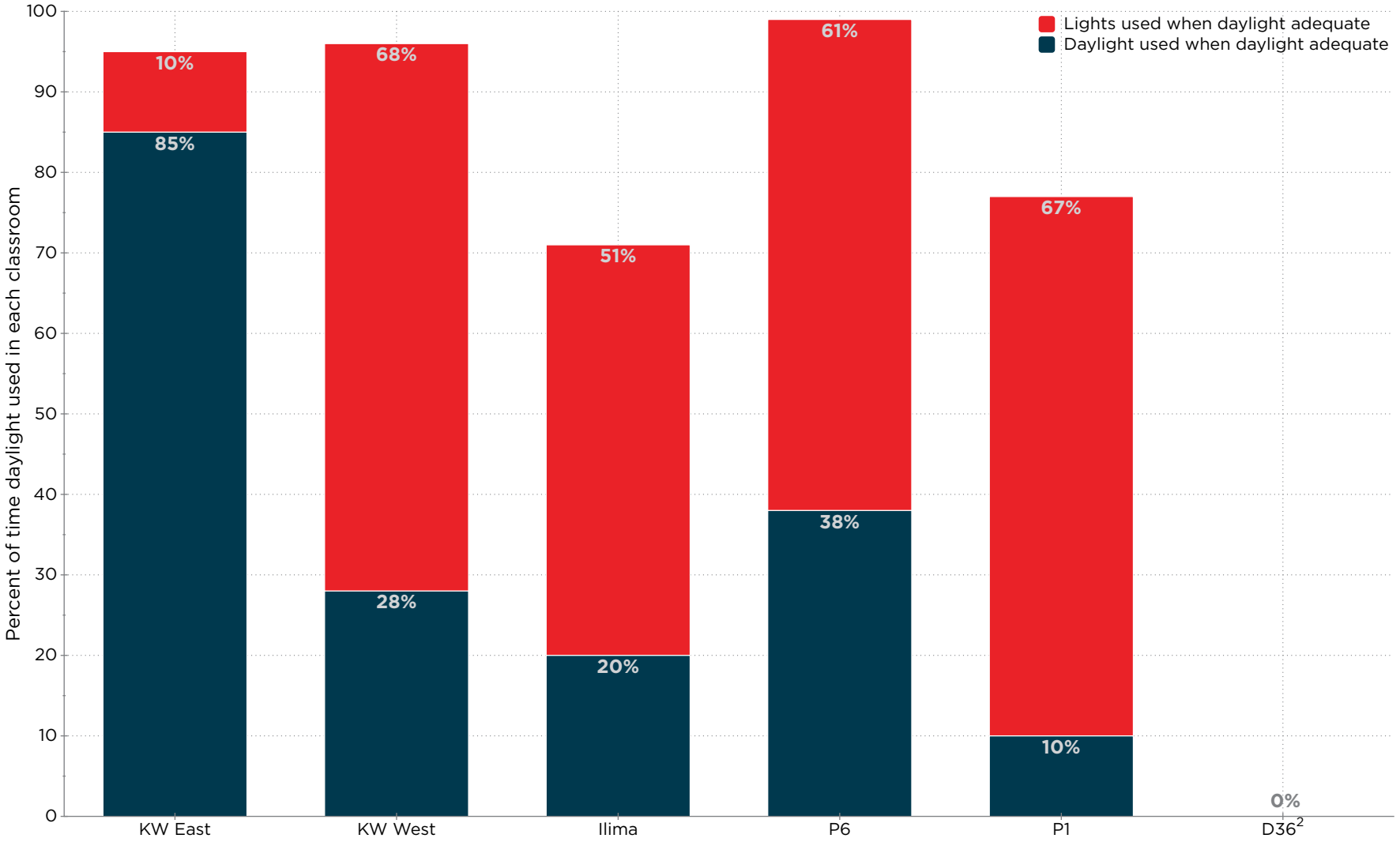
1: Lighting quality: the average wall illuminance > 5 ft-cd and the illuminance ratio (wall illuminance/ surface illuminance) <5
2: D36 did have windows but the shades were often closed as seen in Section 3.

Annual Daylight Use versus Daylight Availability

Description: The chart shows the percent of time the classroom used daylight or interior lights when natural daylight was adequate to meet lighting quality criteria[1].

Findings: Three out of four Test Platforms (i.e. KW East, KW West and P6) showed daylight capacity above 90% but only 1 used daylight above 50% uncovering a potential energy saving opportunity.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

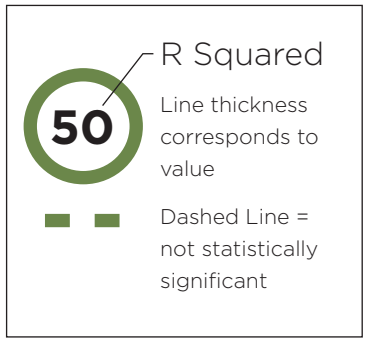


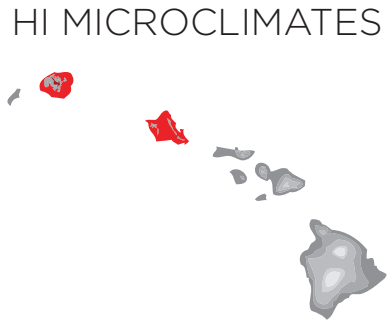
1: Lighting quality: the average wall illuminance > 5 ft-cd and the illuminance ratio (wall illuminance/ surface illuminance) <5
2: D36 did have windows but the shades were closed as seen in Section 3.

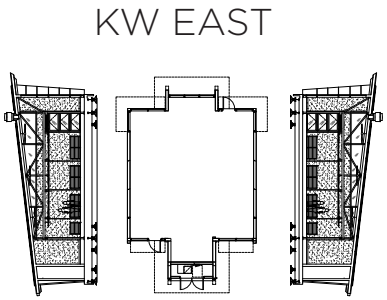
EQ3

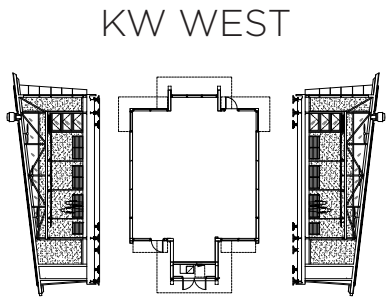
Weather/Microclimate Relationship to Daily Performance: Multiple Linear Regression Model

Description: The circles below represent the "R-Squared" values from a multiple linear regression model used to potentially explain selected performance metrics (dependent variables) from Weather data (independent variables). Weather variables included: Outdoor Air Temperature, Outdoor Relative Humidity, Wind Speed, and Solar Radiation. The "thicker" the line weight of the circle the more that weather could predict the performance of the building. Dashed lines represent results that were not statistically significant using an alpha = 0.05 (p-value <0.05).









Air Conditioning (kWh)

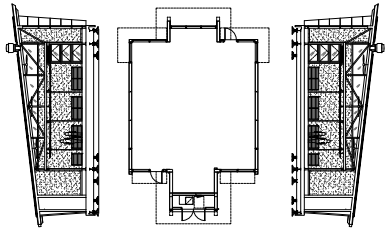
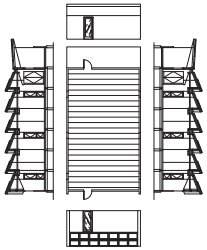
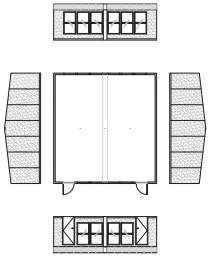
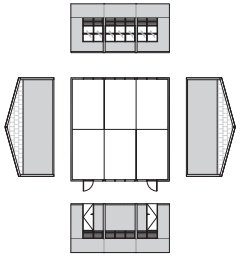
Lighting (kWh)

Thermal Comfort (PMV)

For HI Microclimates, differences in average daily weather between microclimates was modeled to fit differences in average daily performance

Findings: Differences in microclimates explained less than 5% of the variation in differences in performance between buildings in those microclimates and were not statistically significant. PMV models had the best “fits” of any model with weather able to explain >80% of the variation in PMV performance at three classrooms.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days (n=75)
Hours: All Hours

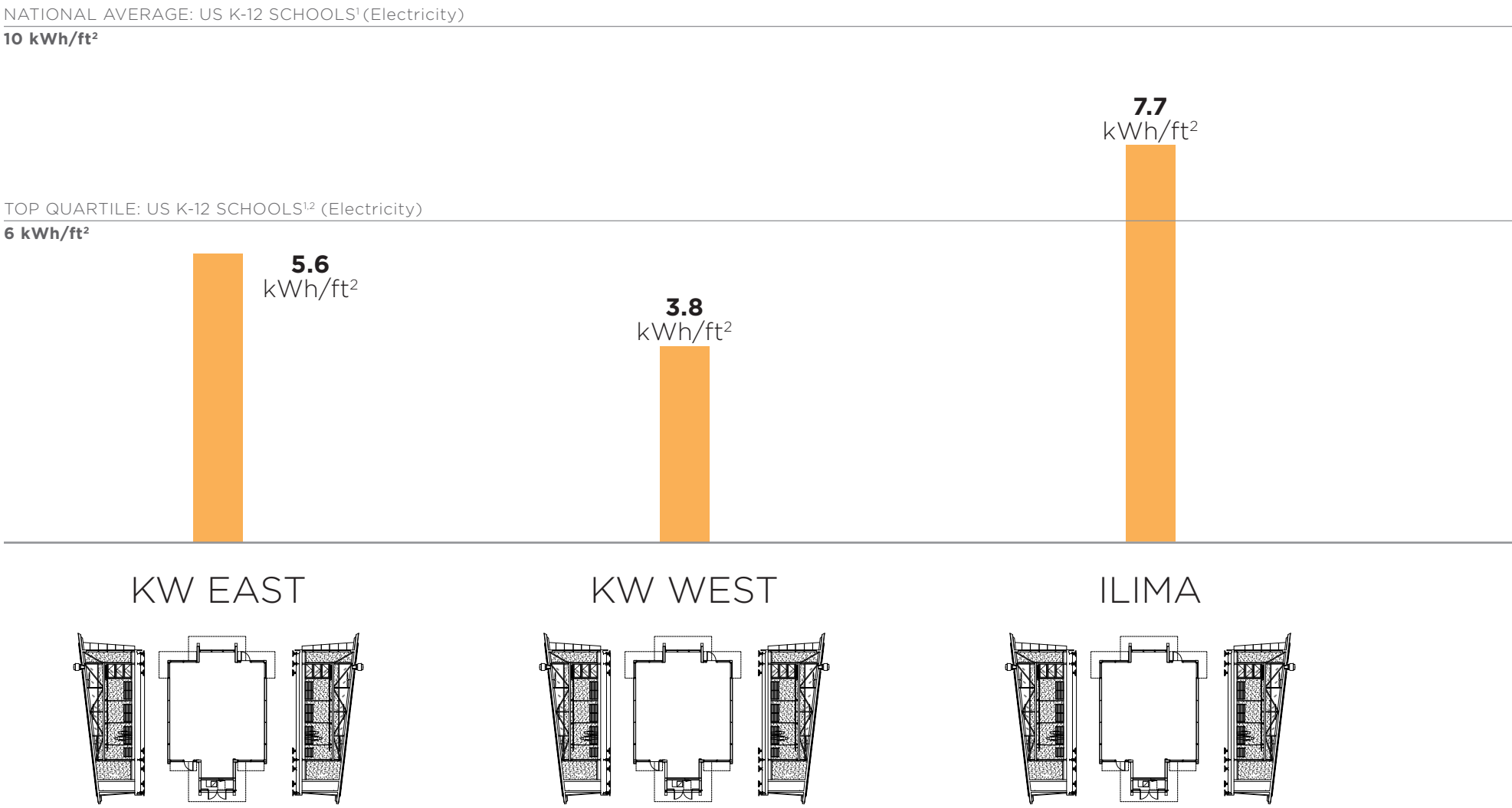
ILIMA	P6	P1	D36
			
8	n/a	n/a	n/a
2	15	14	14
27	91	14	53

For more information on the Multiple Linear Regression Model calculations, please refer to the Methodology section.

EQ4

Annual Energy Use Intensity Benchmarked Against National Reporting

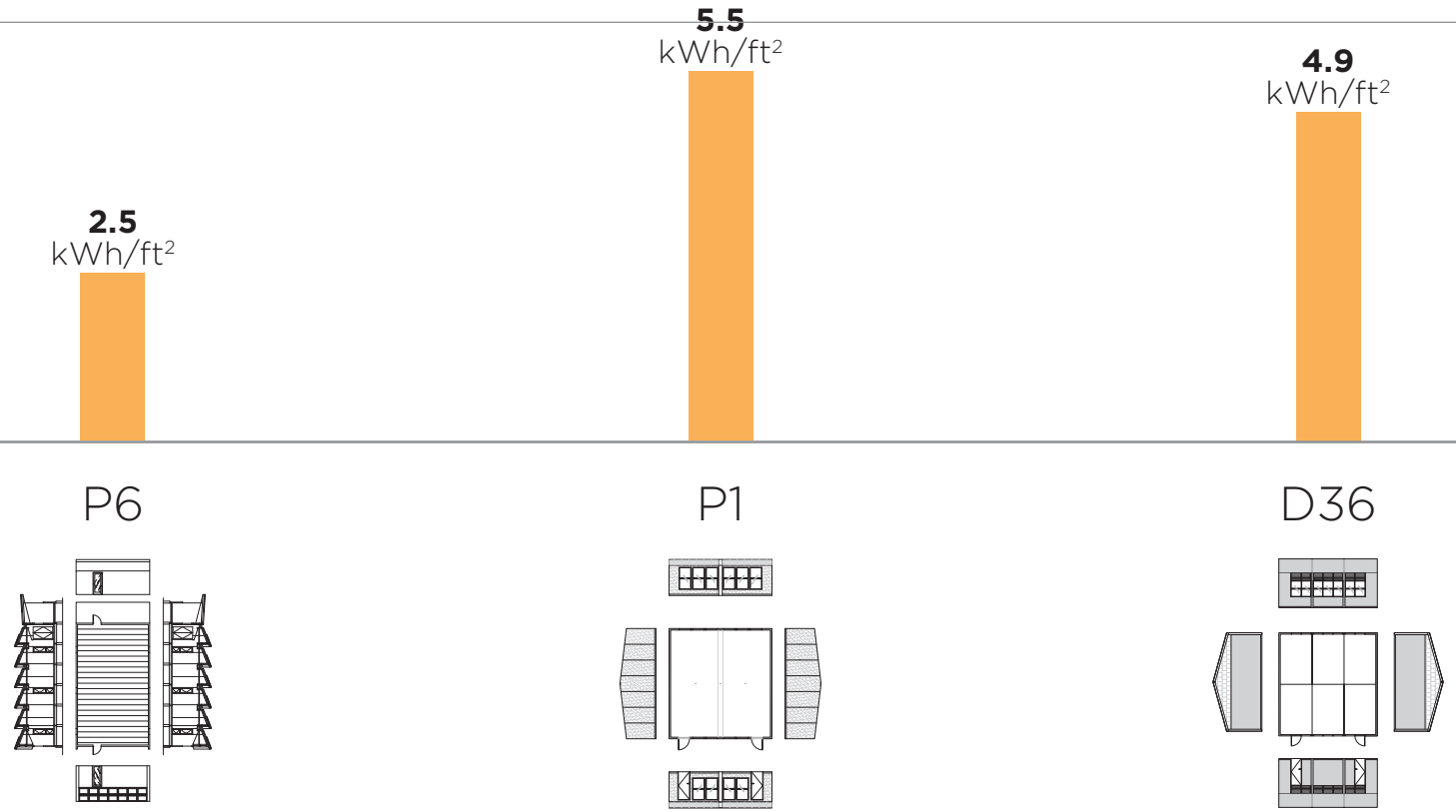
Description: Classrooms are compared by energy use intensity (i.e. the total annual energy (kWh) consumed divided by the classroom net square feet) to national school electricity benchmarks. Benchmarks are further described in the Methodology section.



1: Touchstone Energy Cooperatives: Schools Initiatives
2: US EPA Energy Star Building Manual: 10. Facility Type: K-12 Schools

Findings: Five out of six classrooms had lower EUIs than the top quartile of national schools; Kawaikini West and Ewa P6 had EUIs 37% and 58% lower, respectively.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



DESCRIPTION
This section provides details related to the classroom characteristics and system configurations within each of the study classrooms. Categories include: General Site Information, General Building Information, Building System Information, and Photovoltaic System Information (if applicable).

WHY IMPORTANT
To understand the differences among the technological characteristics of the classrooms that could have led to differences in performance.

3

Classroom Asset Information

Classroom Asset Summary	28
Kawaikini FROG East and West Test Platform Information	30
Ilima FROG Test Platform Information	32
Ewa P6 Test Platform Information	34
Ewa P1 Traditional Classroom Information	36
Ewa D36 Traditional Classroom Information	38

Classroom Asset Summary

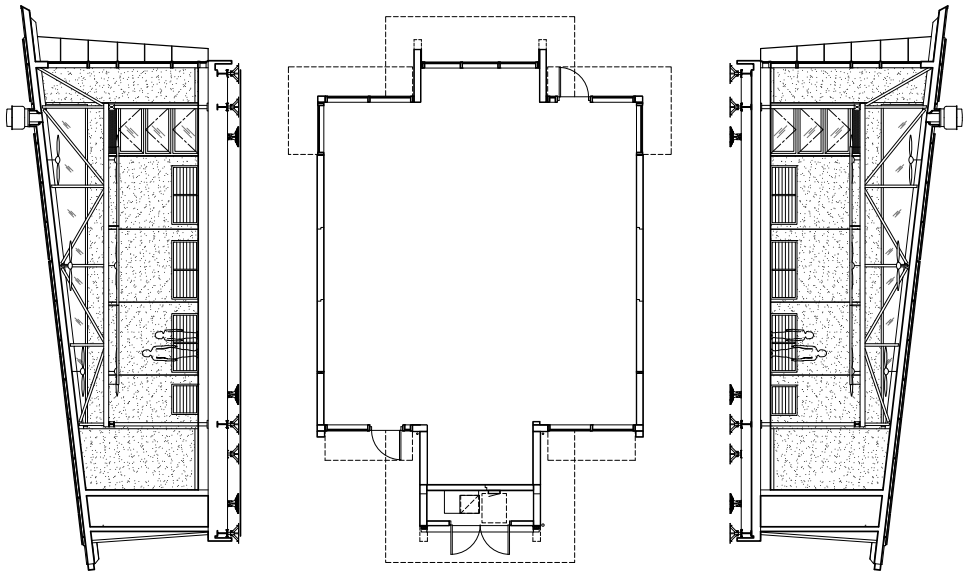
		Kawaikini East	Kawaikini West	Ilima
				
GENERAL	Location	Lihu'e, HI	Lihu'e, HI	Ewa Beach, HI
	School	Kawaikini New Country Public Charter School	Kawaikini New Country Public Charter School	Ilima Intermediate School
	Classroom Grade Level	7-12	7-12	7-8
	Classroom Type[1]	Modular Portable FROG	Modular Portable FROG	Modular Portable FROG
	Year Built	2013	2013	2010
	Classroom Size (NSF)	1,280 ft^2	1,280 ft^2	1,280 ft^2
BUILDING	Wall Assembly	Insulated Foam Panels (R-24)	Insulated Foam Panels (R-24)	Insulated Foam Panels (R-24)
	Roof Assembly	Insul + Single Ply (R-22/R-30)	Insul. + Single Ply (R-22/R-30)	Insul. + Single Ply (R-22/R-30)
	Primary Window Type	PPG Solarban 70 XL	PPG Solarban 70 XL	PPG Solarban 70 XL
SYSTEMS	AC Type	Mechanical Underfloor	Mechanical Underfloor	Mechanical Underfloor
	PV Type(s)	Thin film & Monocrystalline	Monocrystalline	Thin film & Monocrystalline
	PV System Size	5.24 kW	5.24 kW	5.24 kW
NOTES		Fan coil unit not working: 10/17/13 - 2/27/15. Classroom often had evening programs.		Air conditioning was used most of the time due to a bug and dust problem. Front windows were often covered for security concerns.

1: Five out of six classrooms are free standing buildings. D36 is in a building with 3 other classrooms which are not a part of this study.

		Ewa P6	Ewa P1	Ewa D36
				
GENERAL	Location	Ewa Beach, HI	Ewa Beach, HI	Ewa Beach, HI
	School	Ewa Elementary School	Ewa Elementary School	Ewa Elementary School
	Classroom Grade Level	K-6	K-6	K-6
	Classroom Type[1]	Modular ZNE Portable	Traditional Portable	Traditional Masonry
	Year Built	2010	1996	1960
	Classroom Size (NSF)	1,176 ft^2	840 ft^2	900 ft^2
BUILDING	Wall Assembly	Double wall metal cladding	Wood	Masonry
	Roof Assembly	Steel and rigid foam	Galvanized Steel	Wood
	Primary Window Type	Double Pane	Single Pane	Louvers with plexiglass
SYSTEMS	AC Type	None	Window AC Units	Window Units / Central
	PV Type(s)	mono & polycrystalline	N/A	N/A
	PV System Size	12.32 kW	N/A	N/A
NOTES		P6 was preinstalled with temperature, humidity and PV sensors. The installation of the lighting system prevented the operation of several windows.	P1 has insulated ceilings and walls. It also has vented windows with glass louvers and a wire mesh covering the windows on both sides of the structure.	Year 1 had a window AC unit. Year 2 had central AC. AC energy was extrapolated for 7/1/2014-6/30/2015 based on measured data from 11/12/15-11/20/15. The central AC runs from 6am to 6pm on weekdays.

Kawaikini FROG East and West Classroom Information

CLASSROOM TYPE	Modular Portable FROG
PERFORMANCE	High Performance ZNE
DESIGNER	Project FROG
SIZE	1,280 NSF
YEAR BUILT	2013
WALL TYPE	Insulated Foam Panels (R-24)
ROOF TYPE	Single Ply White Membrane & Insulation (R-22/R-30)
CLIMATE[1]	Warm, wet, moderate cloud cover
ORIENTATION	South-facing
USE TYPE	Elementary School Classroom



General Characteristics	
NSF	1,280 ft^2
Length	42 ft
Width	31 ft
Ceiling Height	11'4" - 17'2"
Doors	2
Window Type	PPG Solarban 70 XL
Glazing Area	750 ft^2
Louvers	Yes

Buildings Systems	
AC Type	Carrier Split System HVAC with underfloor air distribution
Fans	9 variable speed 60" Hampton Bay ceiling fans
Lighting	Cerra Indirect/Direct (80/20), fluorescent lights (T-8)
Plugs	Coffee maker, microwave, water cooler, printer

PV Systems (East)	
System 3: thin-film panels	
System Size	2.64 kW
Modules	Solar Frontier SF-165-S (16 modules)
Inverter	SMA SB2500HF-US
System 4: traditional monocrystalline silicon panels	
System Size	2.6 kW
Modules	Mitsubishi PV-MLE260HD (10 modules)
Inverter	SMA SB2500HF-US

1: Climate as defined in the Phase II Draft Report, pg 3

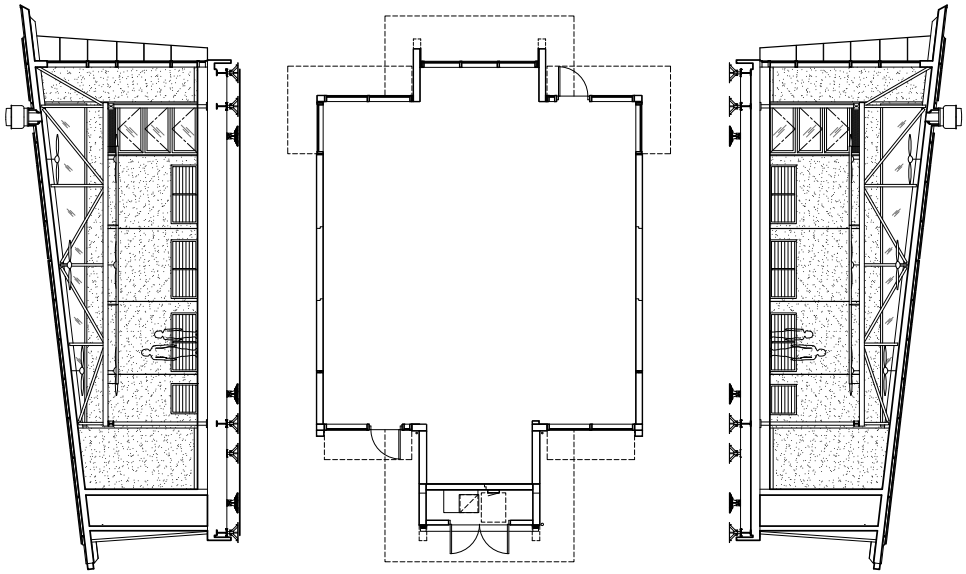
Platform Locations on site

PV Systems (West)	
System 1: hetero-junction panels (monocrystalline & amorphous silicon)	
System Size	2.64 kW
Modules	Panasonic / Sanyo VBHN220AA01 (12 modules)
Inverter	SMA SB2500HF-US
System 2: traditional monocrystalline silicon panels & micro-inverters	
System Size	2.6 kW
Modules	Mitsubishi PV-MLE260HD (10 modules)
Inverter	Emphase M215

Top-Bot, Picture of Kawaikini FROGs front facades; Kawaikini FROGs surroundings; classroom interior

Ilima FROG Classroom Information

CLASSROOM TYPE	Modular Portable FROG
PERFORMANCE	High Performance ZNE
DESIGNER	Project FROG
SIZE	1,280 NSF
YEAR BUILT	2010
ENCLOSURE TYPE	Insulated Foam Panels (R-24)
ROOF TYPE	Single Ply White Membrane & Insulation (R-22/R-30)
CLIMATE[1]	Warm, dry, low cloud cover
ORIENTATION	South-facing
USE TYPE	Middle School Classroom



General Characteristics	
NSF	1,280 ft^2
Length	42 ft
Width	31 ft
Ceiling Height	11'4" - 17'2"
Doors	2
Window Type	PPG Solarban 70 XL (0.26 U-Value, 0.27 SHGC)
Glazing Area	750 ft^2
Louvers	Yes

Buildings Systems	
AC Type	Carrier Split System HVAC with underfloor air distribution
Set Point	65°F
Fans	9 variable speed 60" Hampton Bay ceiling fans
Lighting	Cerra Indirect/Direct (80/20), fluorescent lights (T-8)
Plugs	2 computers, printer

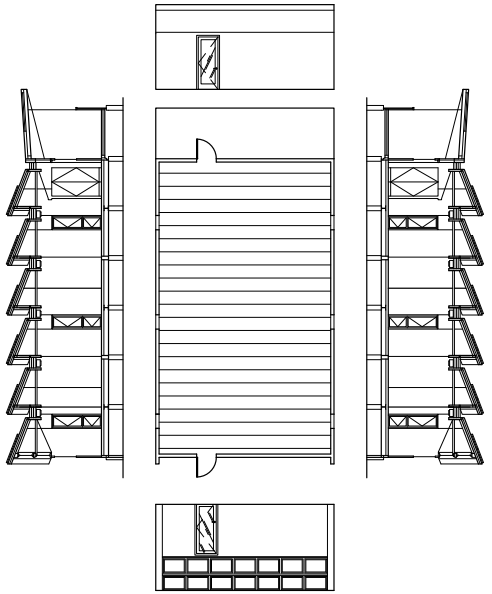
PV Systems	
System 1: thin-film panels	
System Size	2.64 kW
Modules	Solar Frontier SF-165-S (16 modules)
Inverter	SMA SB2500HF-US
System 2: traditional monocrystalline silicon	
System Size	2.6 kW
Modules	Mitsubishi PV-MLE260HD (10 modules)
Inverter	SMA SB2500HF-US

1: Climate as defined in the Phase II Draft Report, pg 3

Top-Bot, L-R: Picture of Ilima FROG front facade; Ilima FROG surrounded by two buildings and tree; interior photos of space

Ewa P6 Classroom Information

CLASSROOM TYPE	Modular ZNE Portable
PERFORMANCE	High Performance ZNE
DESIGNER	Anderson Anderson Architecture
SIZE	1,176 NSF
YEAR BUILT	2010
WALL TYPE	Double wall metal cladding
ROOF TYPE	Steel and rigid foam
CLIMATE[1]	Warm, dry, low cloud cover
ORIENTATION	South-facing
USE TYPE	Elementary School Classroom



General Characteristics	
NSF	1,176 ft^2
Length	42 ft
Width	28 ft
Ceiling Height	8'6"
Doors	2
Window Type	Double Pane
Louvers	No

Buildings Systems	
AC Type	None
Fans	8 ceiling fans
Lighting	10 light fixtures (24 bulbs)
Plugs	2 stand alone fans, projector, portable TV

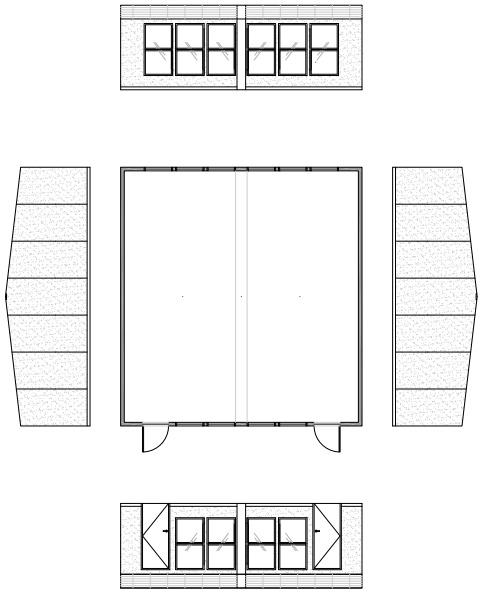
PV Systems	
System 1: polycrystalline panels	
System Size	9.72 kW
Modules	Kyocera KC135 GX-LPU (72 modules)
Inverter	Sunny Boy 5000-US
System 2: traditional monocrystalline silicon panels	
System Size	2.6 kW
Modules	Mitsubishi PV-MLE260HD (10 modules)
Inverter	SMA SB2500HF-US

1: Climate as defined in the Phase II Draft Report, pg 3

Top-Bot: Picture of Ewa P6 from north; interior photos of space

Ewa P1 Classroom Information

CLASSROOM TYPE	Traditional Portable
PERFORMANCE	Traditional Performance
DESIGNER	-
SIZE	840 NSF
YEAR BUILT	1996
ENCLOSURE TYPE	Wood
ROOF TYPE	Galvanized Steel
CLIMATE[1]	Warm, dry, low cloud cover
ORIENTATION	South-facing
USE TYPE	Elementary School Classroom



General Characteristics	
NSF	840 ft^2
Length	30 ft
Width	28 ft
Ceiling Height	9 ft
Doors	2
Window Type	Single Pane
Louvers	Yes

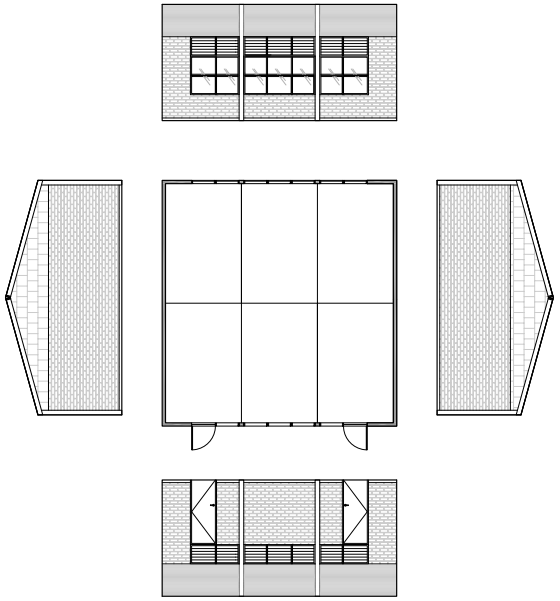
Buildings Systems	
AC Type	2 window units
AC Manufacturer	Frigidaire
A/C cooling capacity	10,000 Btu/hr
Fans	3 gossamer ceiling fans
Lighting	16 fixtures (48 light bulbs - T-8)
Plugs	projector, 1 computer, 2 window AC units

1: Climate as defined in the Phase II Draft Report, pg 3

Top-Bot: Picture of Ewa P1 from south; interior photos of space

Ewa D36[1] Classroom Information

CLASSROOM TYPE	Traditional Masonry
PERFORMANCE	Traditional Performance
DESIGNER	-
SIZE	900 NSF
YEAR BUILT	1960
ENCLOSURE TYPE	Masonry
ROOF TYPE	White Membrane
CLIMATE[2]	Warm, dry, low cloud cover
ORIENTATION	South-facing
USE TYPE	Elementary School Classroom



General Characteristics	
NSF	900 ft^2
Length	30 ft
Width	30 ft
Ceiling Height	10’7”
Doors	2
Window Type	louvers with plexiglass
Louvers	Yes

Buildings Systems	
AC Type	Year 1: 2 window units
	Year 2: Central AC
Set Point	79°F
Fans	Year 1: 2 rows of 2 ceiling gossamer fans
	Year 2: 1 row of ceiling fans
Lighting	18 fixtures (36 bulbs - T8)
Plugs	2 computers, microwave, mini refrigerator, portable TV

1: D36 is located at the end of a 4 row classroom structure with only two classroom walls exposed to exterior conditions. The other two walls are shared by another classroom and a bathroom.
2: Climate as defined in the Phase II Draft Report, pg 3

Top-Bot: Picture of Ewa D36 from south; interior photos of space

DESCRIPTION
This section provides details related to the weather and climate characteristics for the study sites, Ewa Beach on Oahu and Lihu'e on Kauai.

WHY IMPORTANT
To understand the differences in weather conditions at the two sites that could have led to differences in performance.

4

Environmental Summary

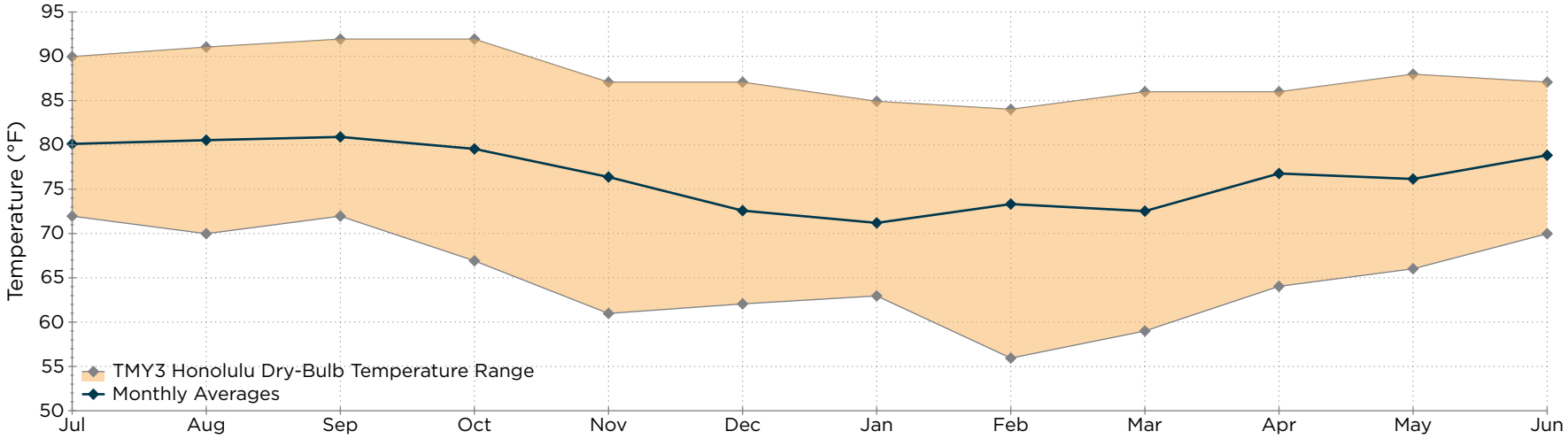
Monthly TMY3 Climate Comparisons	42
Monthly Environmental Comparisons	44
Annual Weather Types	46

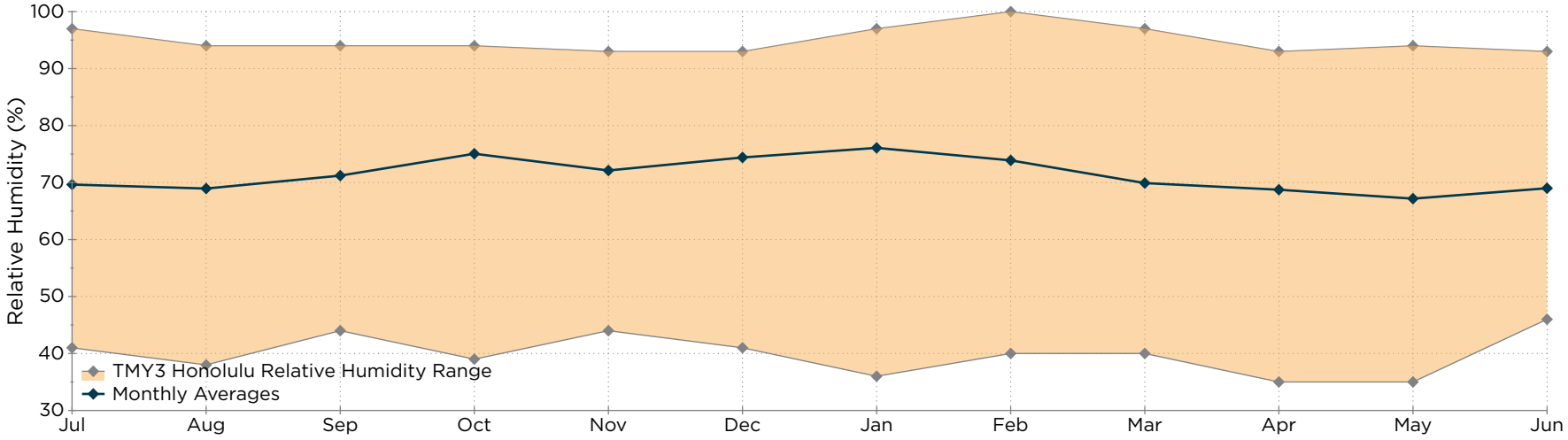
Monthly Honolulu TMY3 Climate Comparison

Description: The graph shows measured average monthly outdoor temperature and relative humidity for Ilima, P6, P1, and D36 located in Honolulu compared with the monthly maximum and minimum values for a typical meteorological year[1].

Findings: The temperature and relative humidity in Honolulu for the 1 year study period (7/1/14- 6/30/15) was consistent with a typical meteorological year[1].

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours





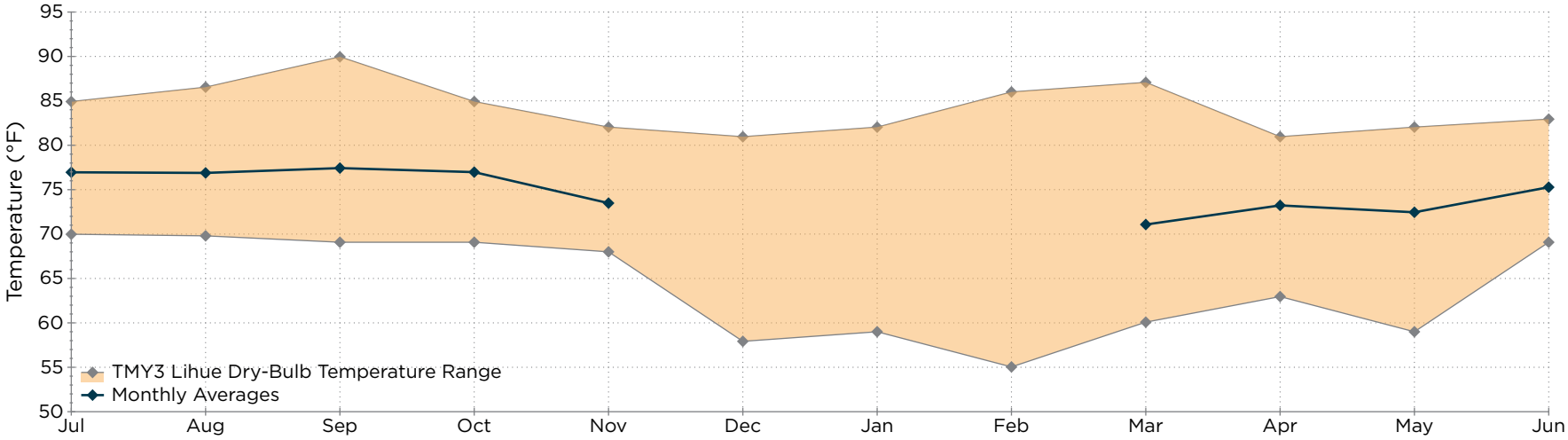
1: A typical meteorological year is an hourly weather dataset for a specific location created by the National Renewable Energy Laboratory from data collected across 30 years (1991 - 2005).

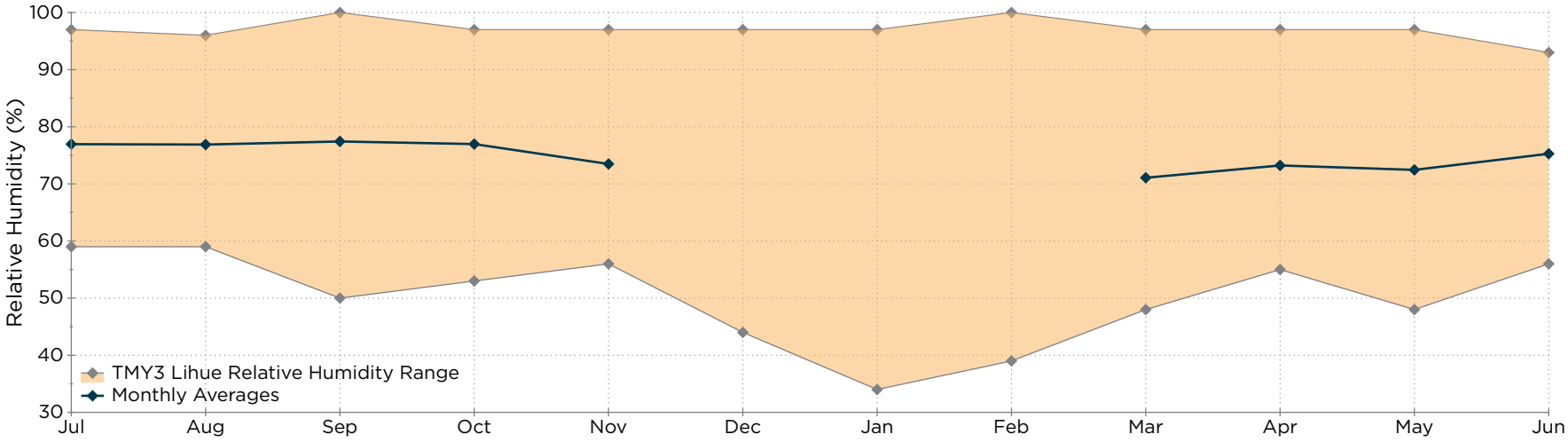
Monthly Lihu'e TMY3 Climate Comparison

Description: The graph shows measured average monthly outdoor temperature and relative humidity for KW East and West located in Lihu'e compared with the monthly maximum and minimum values for a typical meteorological year[1].

Findings: The temperature and relative humidity in Lihu'e for the 1 year study period (7/1/14- 6/30/15) was consistent with a typical meteorological year[1].

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours





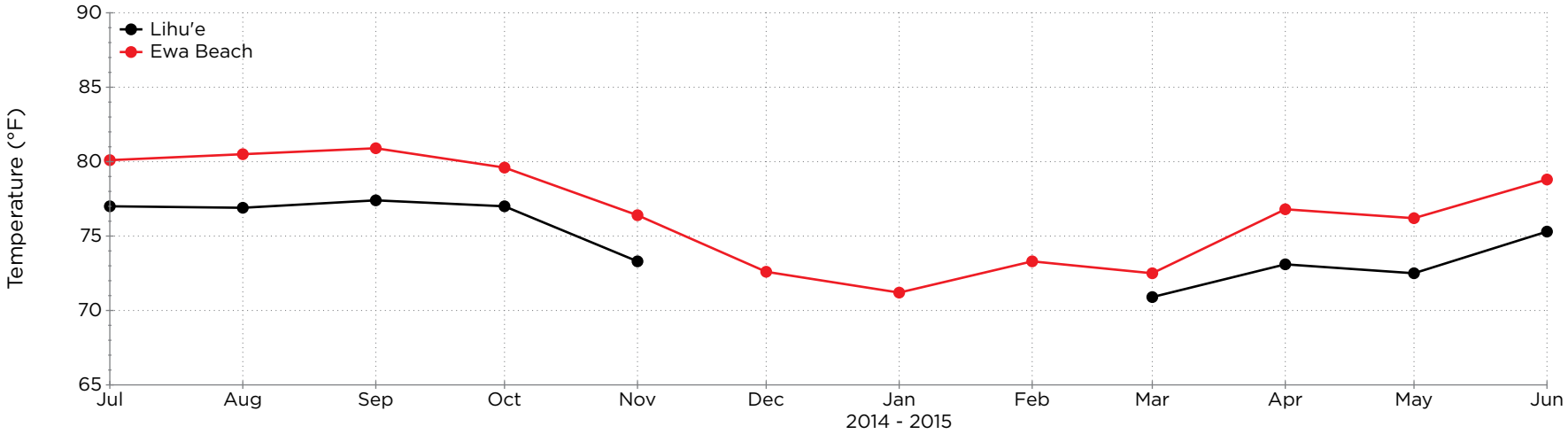
1: A typical meteorological year is an hourly weather dataset for a specific location created by the National Renewable Energy Laboratory from data collected across 30 years (1991 - 2005).

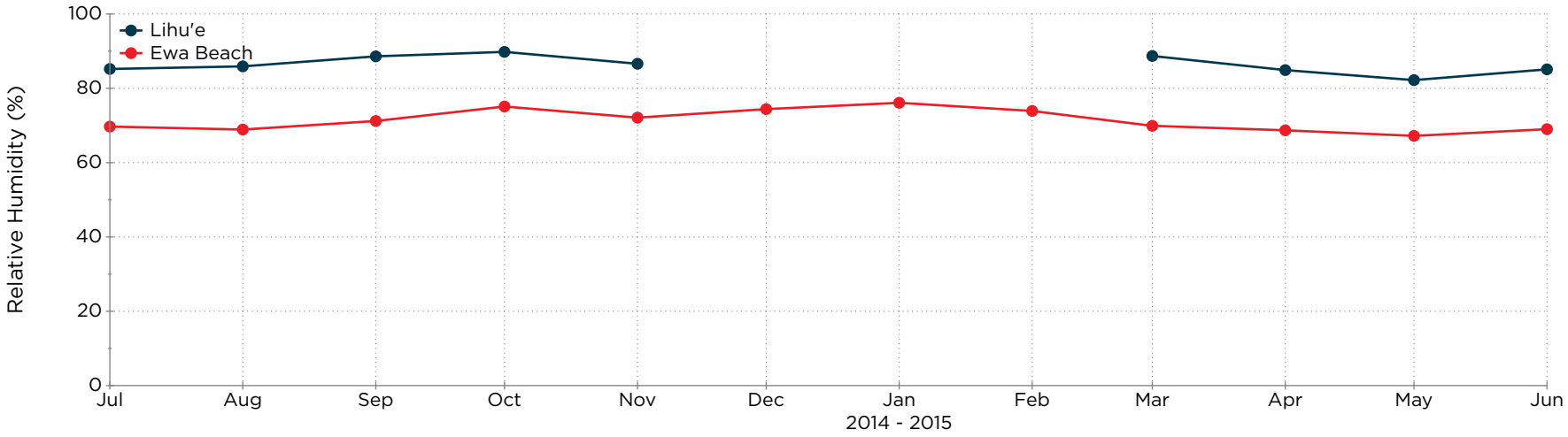
Monthly Temperature and Relative Humidity Site Comparison: Lihu'e & Ewa Beach

Description: Average monthly temperature and relative humidity comparison for Ewa Beach (i.e. Ilima, P6, P1, D36 classrooms) and Lihu'e (i.e. KW East and KW West) weather stations. No weather information was collected for Lihu'e from 11/25/14 to 3/19/15 due to hardware issues.

Findings: On average, Lihu'e was 3°F cooler than Ewa Beach but had 7% higher relative humidity throughout the year.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



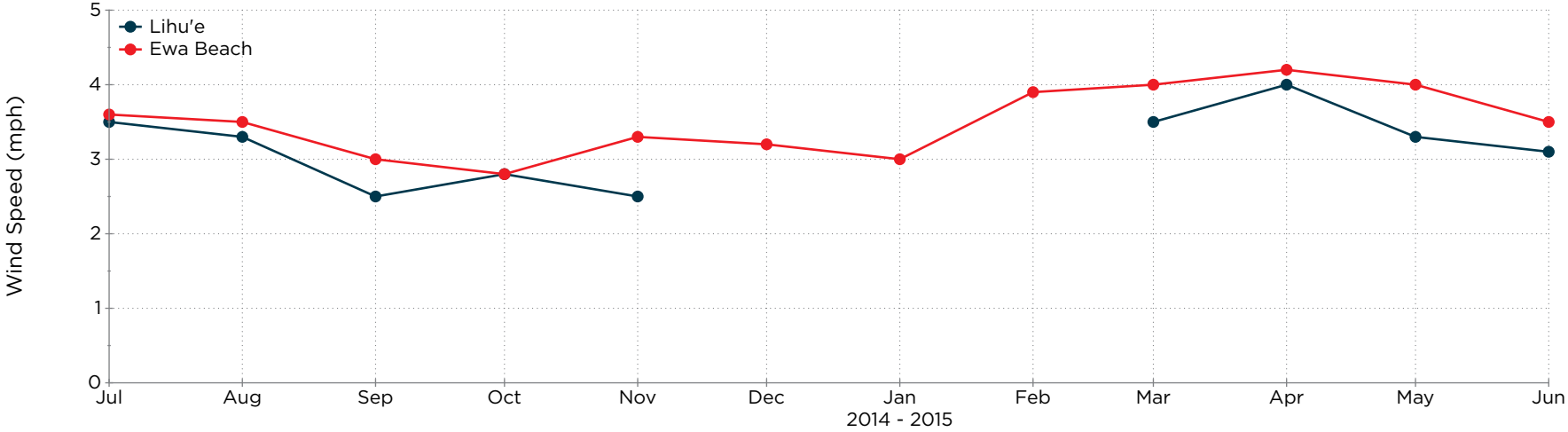


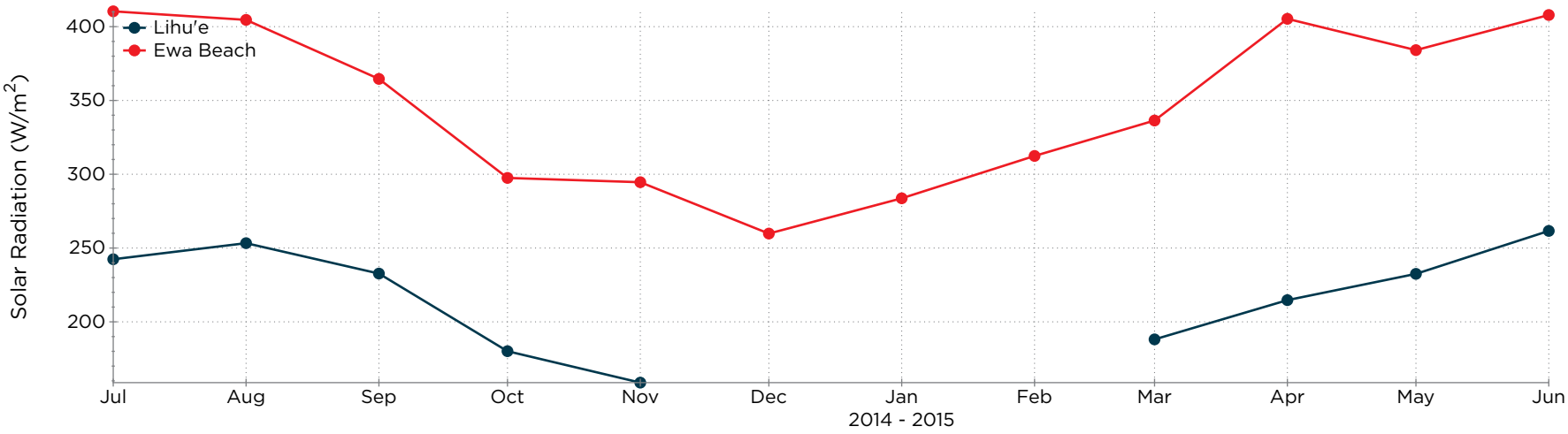
Monthly Wind Speed and Solar Radiation Comparison: Lihu'e & Ewa Beach

Description: Average monthly wind speed and solar radiation comparison for Ewa (i.e. Ilima, P6, P1, D36 classrooms) and Lihu'e (KW East and West classrooms) weather stations. No weather information was collected for Lihu'e from 11/25/14 to 3/19/15 due to hardware issues.

Findings: Ewa Beach and Lihu'e have similar monthly wind speeds but Ewa Beach has 150 W/m^2 more solar radiation on average than Lihu'e across all months.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



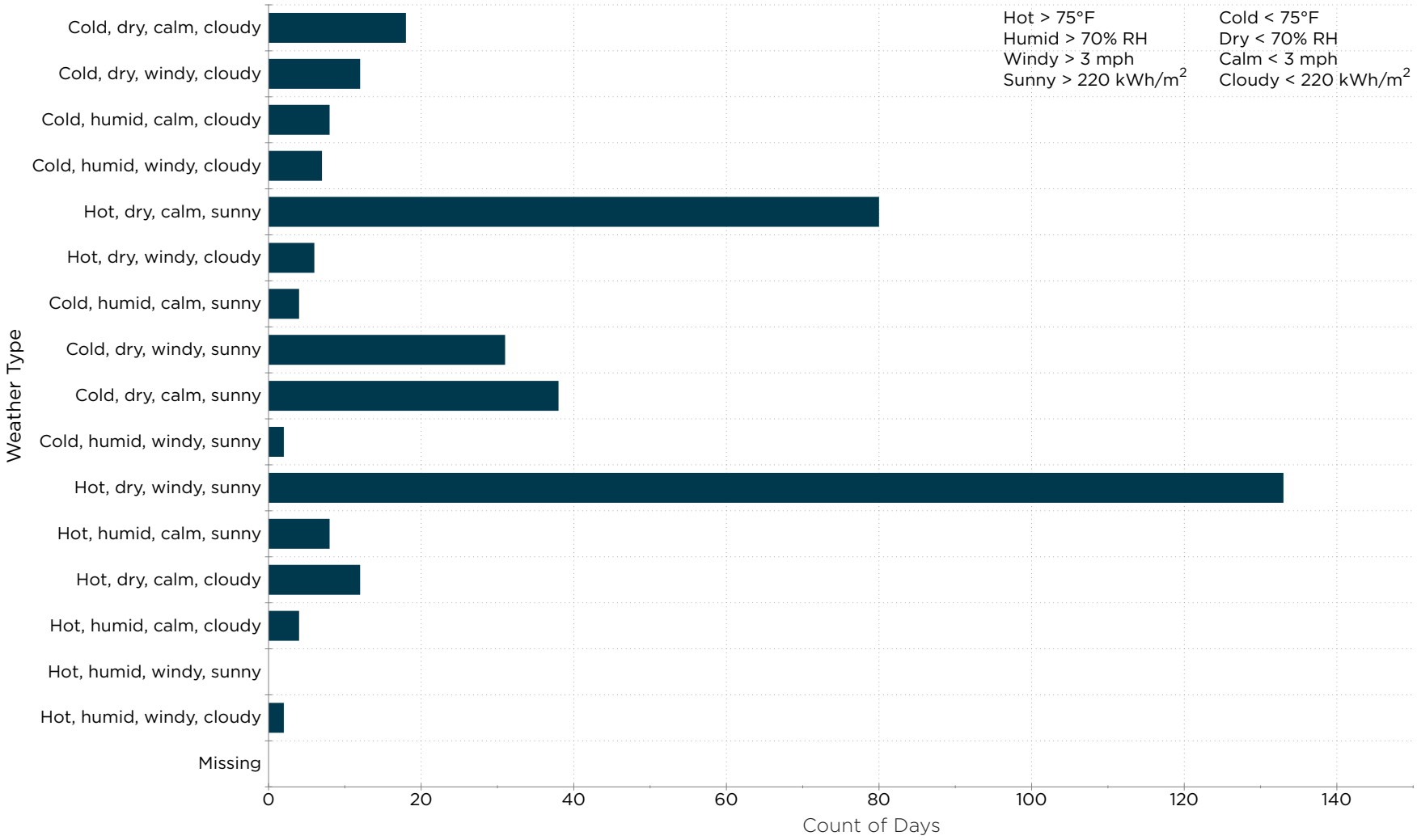


Daily Weather Types: Ewa Beach

Description: Weather types are categorizations of weather (temperature, relative humidity, wind speed, solar radiation) based on weather averages for each day. They give a simple look at weather variable combinations above/below a single mean benchmark for all variables, consistent across sites. Ewa Beach's weather is used for the Ilima, P6, P1 and D36 classrooms.

Findings: Ewa Beach had 2 weather types that accounted for 58% of all days. Common among these two weather types are hot, dry and sunny conditions.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

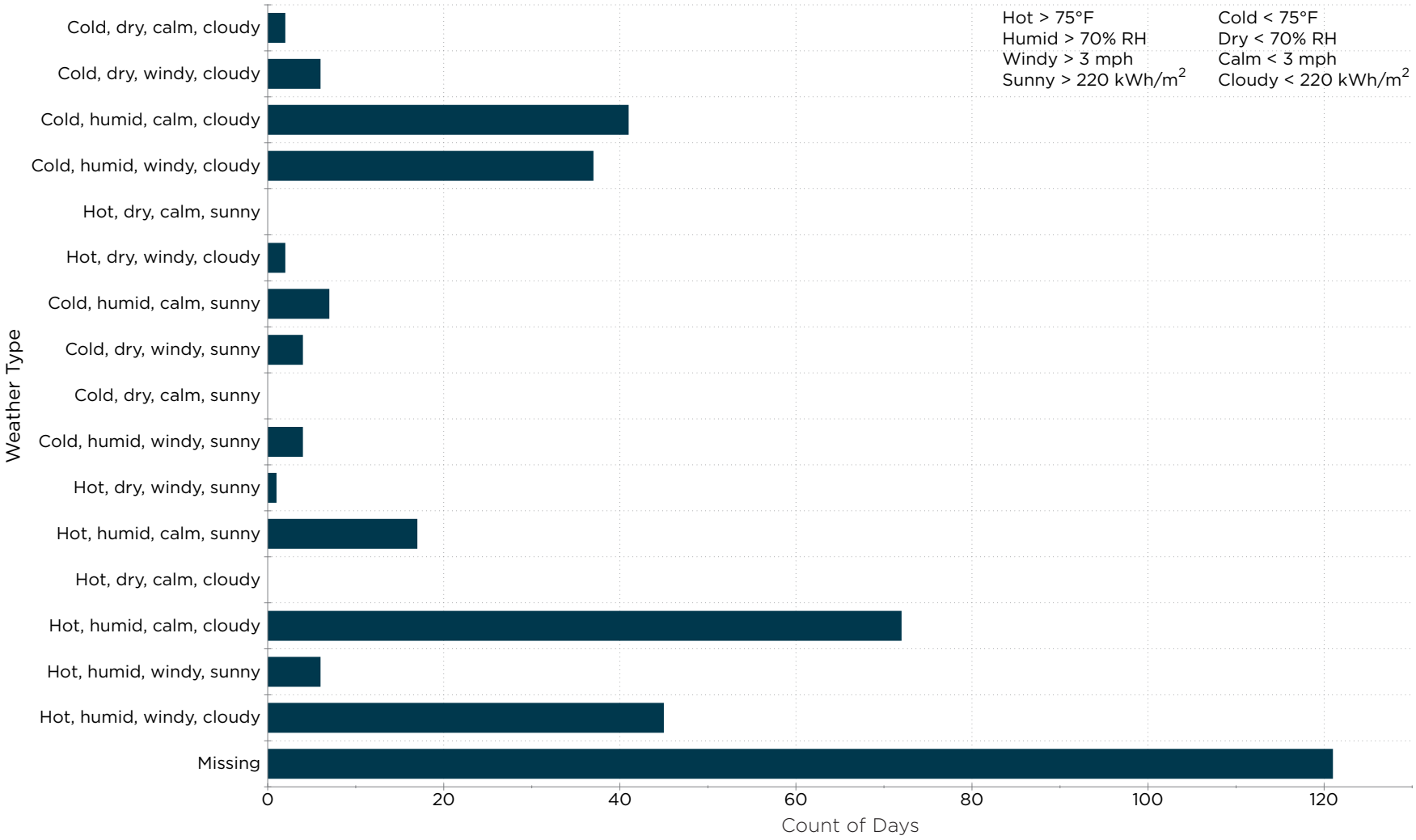


Daily Weather Types: Lihu'e

Description: Weather types are categorizations of weather (temperature, relative humidity, wind speed, solar radiation) based on weather averages for each day. They give a simple look at weather variable combinations above/below a single mean benchmark for all variables, consistent across sites. Lihu'e's weather is for the KW East and KW West classrooms. The "missing" weather resulted from a sensor hardware issue from 11/25/14- 3/19/15.

Findings: Lihu'e had 4 weather types that accounted for 80% of all days. High humidity and cloudiness were the common factors among all four weather types.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



DESCRIPTION
This section provides details related to the operational and behavioral parameters as planned and as observed during the study.

WHY IMPORTANT
To understand the user group behavior that may have influenced the performance of the classrooms

5

Group Behavior Summary

Operational School Days and Hours	50
Hourly Interior Lighting Averages	51
Hourly Total Energy Use by Percent	52
Hourly Cumulative Average Total Energy Use by Percent	53

Planned Operational School Days and Hours

Description: Number of school and non-school days by month based on the Hawaii Department of Education official 2014-15 calendar. School hours for the three schools are shown.

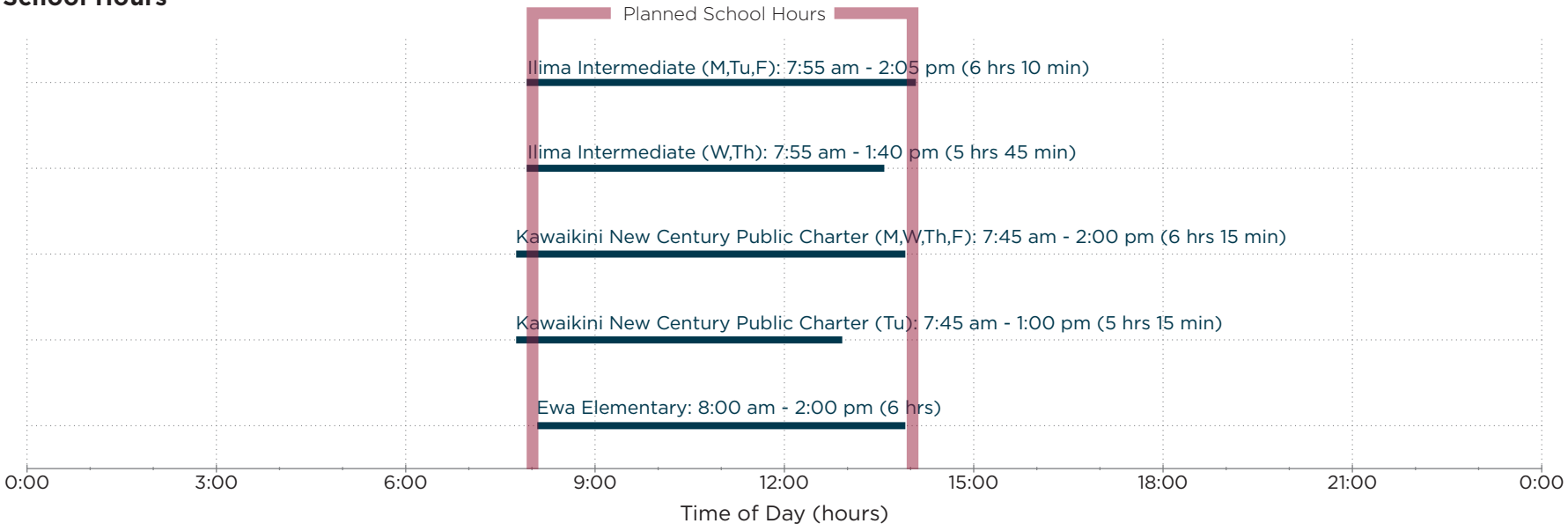
Findings: School days were primarily between August to May. Although the ONR Phase 2 report shows that the energy models were based on a "worst-case scenario" for classroom occupancy of 8am - 6pm, the three school schedules show that 8am - 2pm was more accurate for planned school hours.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

School Days

	2014						2015						
DAY TYPE	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**TOT**
School Days	0	20	21	18	17	15	14	19	16	21	20	4	185
Non-School Days[1]	31	11	9	13	13	16	17	11	15	9	11	26	180
TOTAL	31	31	30	31	30	31	31	28	31	30	31	30	365

School Hours[2]



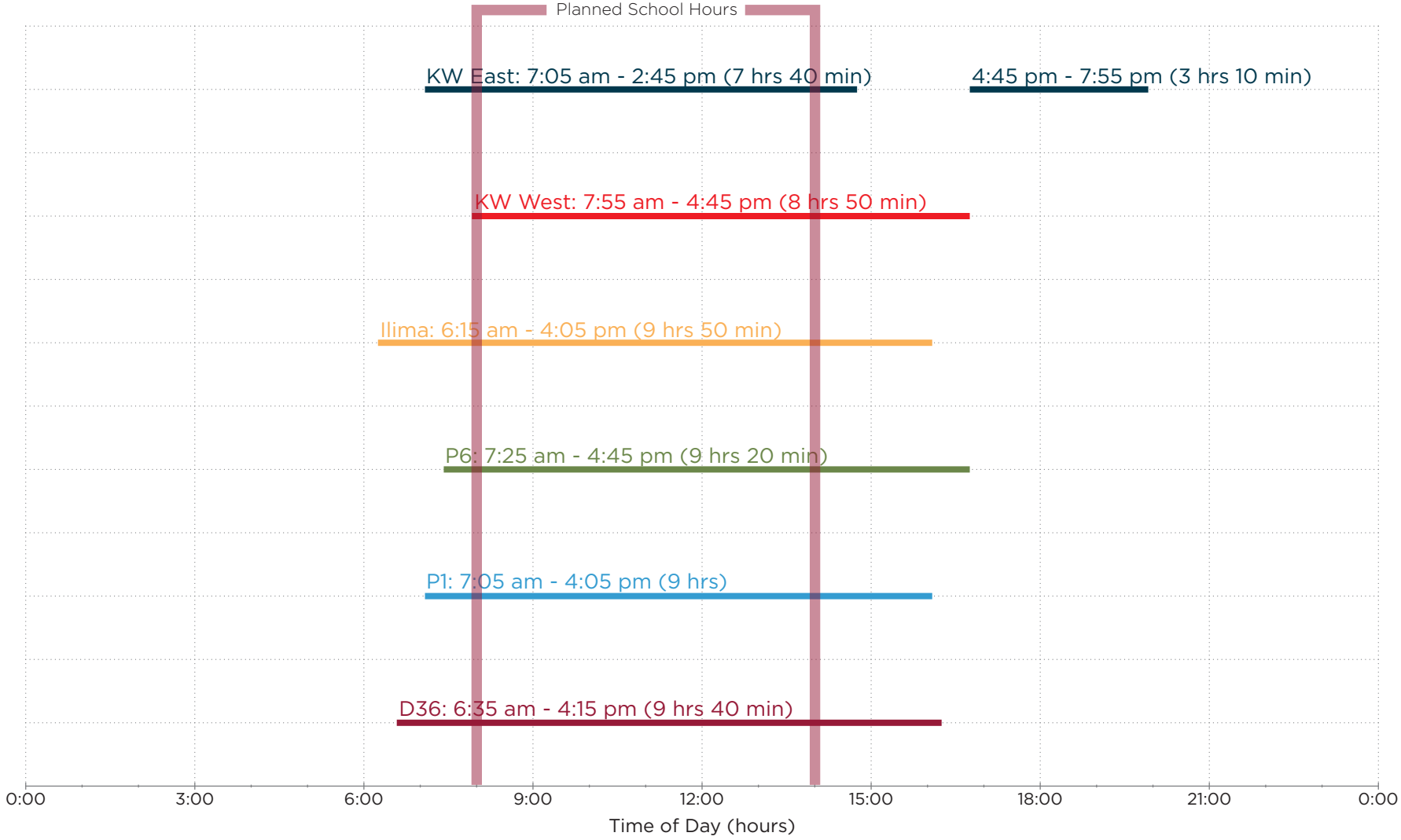
1: Non-School Days include holidays and weekends
2: References for school hour schedules are found on the References page

Actual School Hours inferred from Hourly Interior Lighting Averages

Description: The average time periods for when interior lights were on[1] during school days for each classroom. Interior lighting is used as a proxy to indicate when each classroom was occupied.

Findings: On average, KW East was occupied for the longest period of time (10 hours, 50 minutes). It was the only classroom that was also occupied during the night. KW West was occupied for the shortest amount of time (8 hours 50 minutes).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



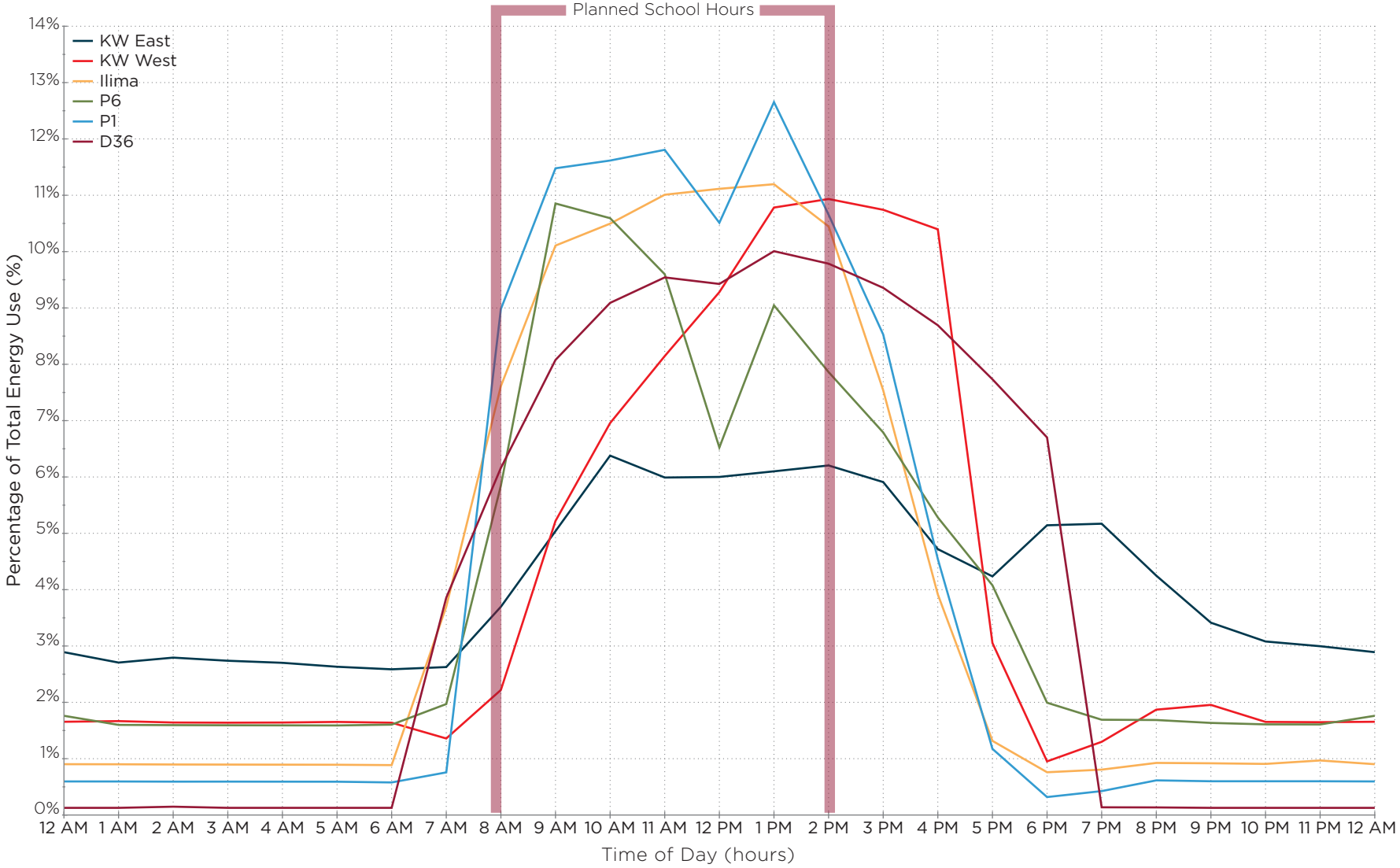
1: Lights are "on" when the measured power consumption is greater than 0.02kW.

Group Consumption Behavior inferred from Hourly Total Energy Use by Percent

Description: Average hourly school day energy use profile for each classroom by percent.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: On average, energy use peaked between 12pm - 2pm at KW West, Ilima, P1 and D36. At KW East and P6, energy use peaked between 8am - 10am.

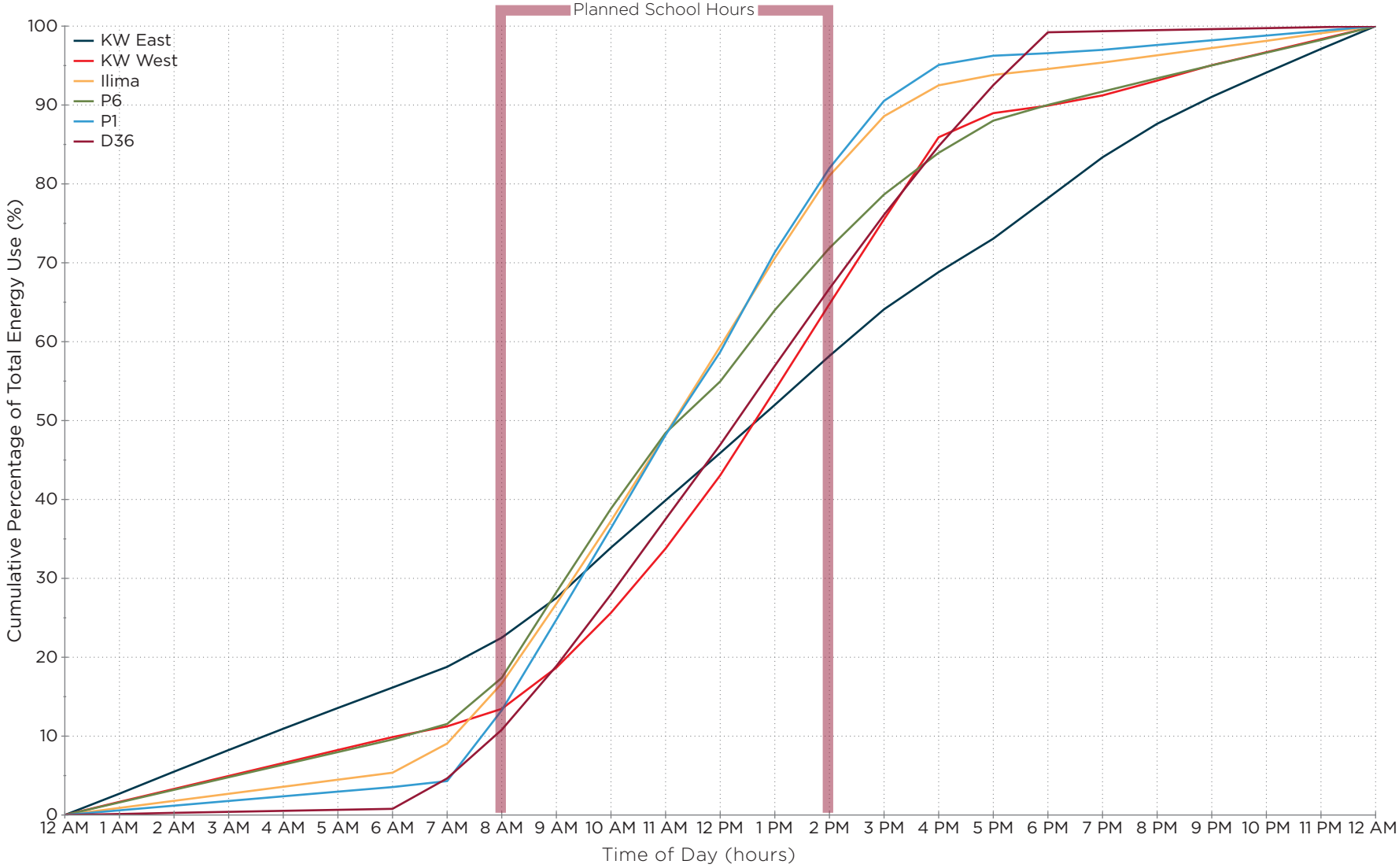


Group Behavior inferred from Hourly Cumulative Total Energy Use by Percent

Description: Average hourly school day cumulative energy use profile for each classroom

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: At every classroom other than KW East, over 80% of the total daily energy use occurred before 4pm. At KW East, less than 70% of the total daily energy use occurred before 4pm.



DESCRIPTION
This section analyzes classroom performance across the study criteria, looking at performance annually, monthly, and daily where appropriate. Performance is also analyzed with respect to asset characteristics, weather characteristics, and group behavior characteristics to uncover what factors influenced performance.

WHY IMPORTANT
To answer the study questions:
CQ1: How do Test Platform performances compare to Traditional classrooms and to each other?
CQ2: Do Test Platforms perform as predicted by models?
CQ3: Do all classrooms perform within established guidelines?
EQ1: How well did Test Platforms achieve "energy-neutrality"?
EQ2: How do the classrooms compare in use of natural daylighting?
EQ3: How do local weather and differences in microclimates impact classroom operations and performance?

6

Performance

6.1	Energy Consumption	57
6.2	Indoor Environmental Quality (IEQ)	82
6.3	Modeling	86
6.4	Guidelines (Standards)	88
6.5	Net Zero Energy (NZE)	90
6.6	Daylighting	100
6.7	Operations	102
6.8	Weather Impacts	112

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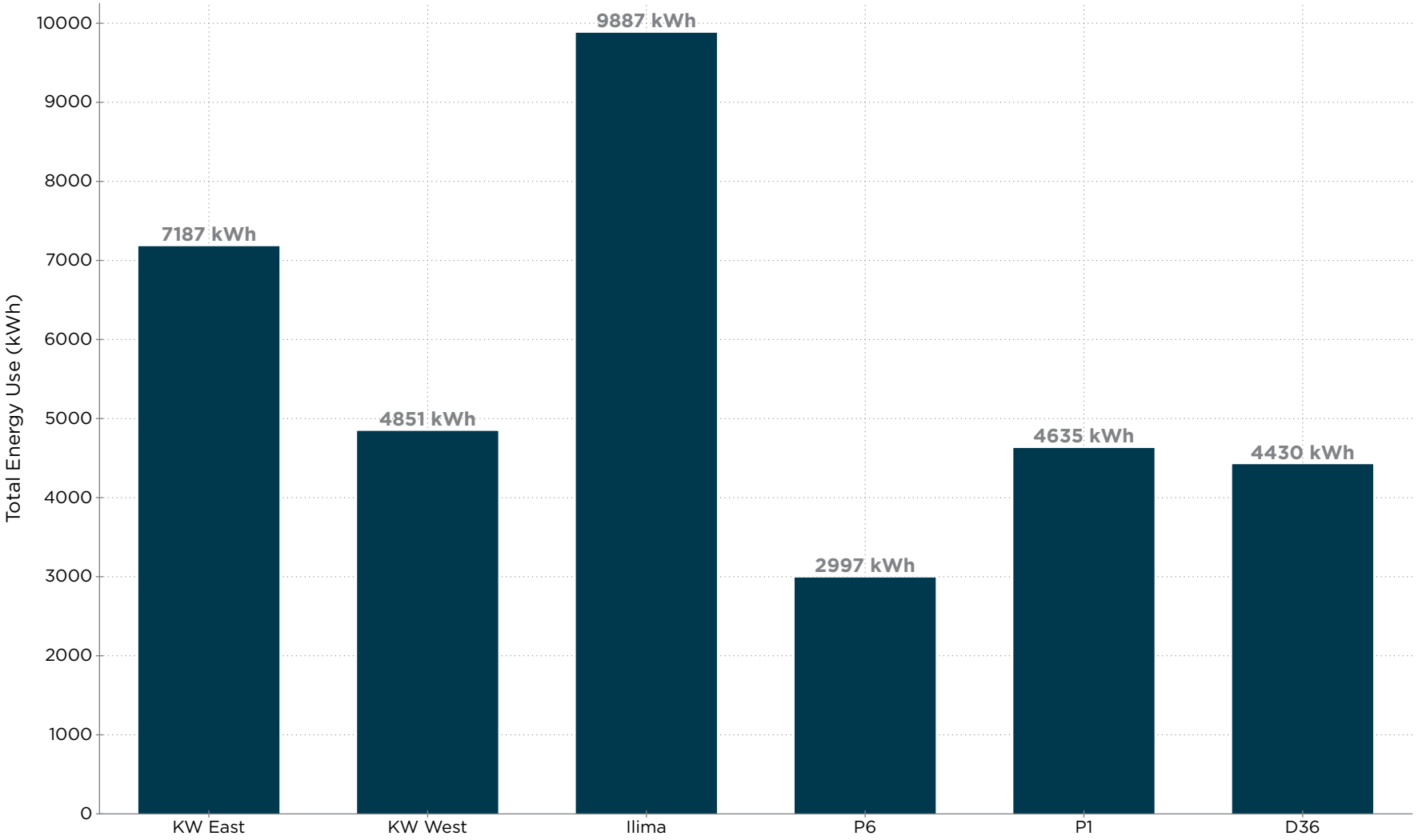
Annual Total Energy Use

Description: Chart depicts total energy use for each classroom compared to each other for the study period

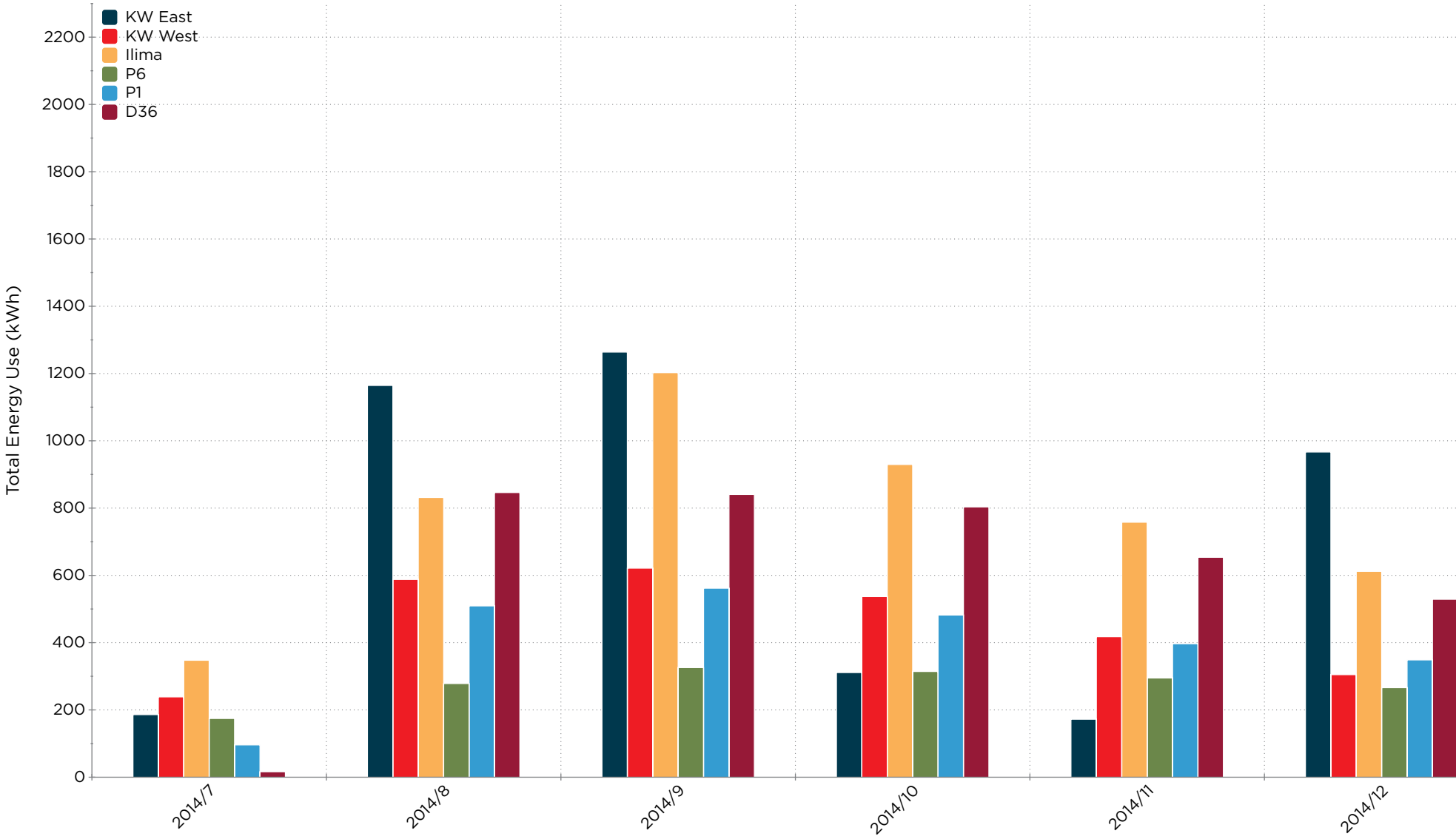
Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: Ilima used more than double the amount of energy used at every other classroom except for KW East.
Ilima used 38% more energy than KW East.



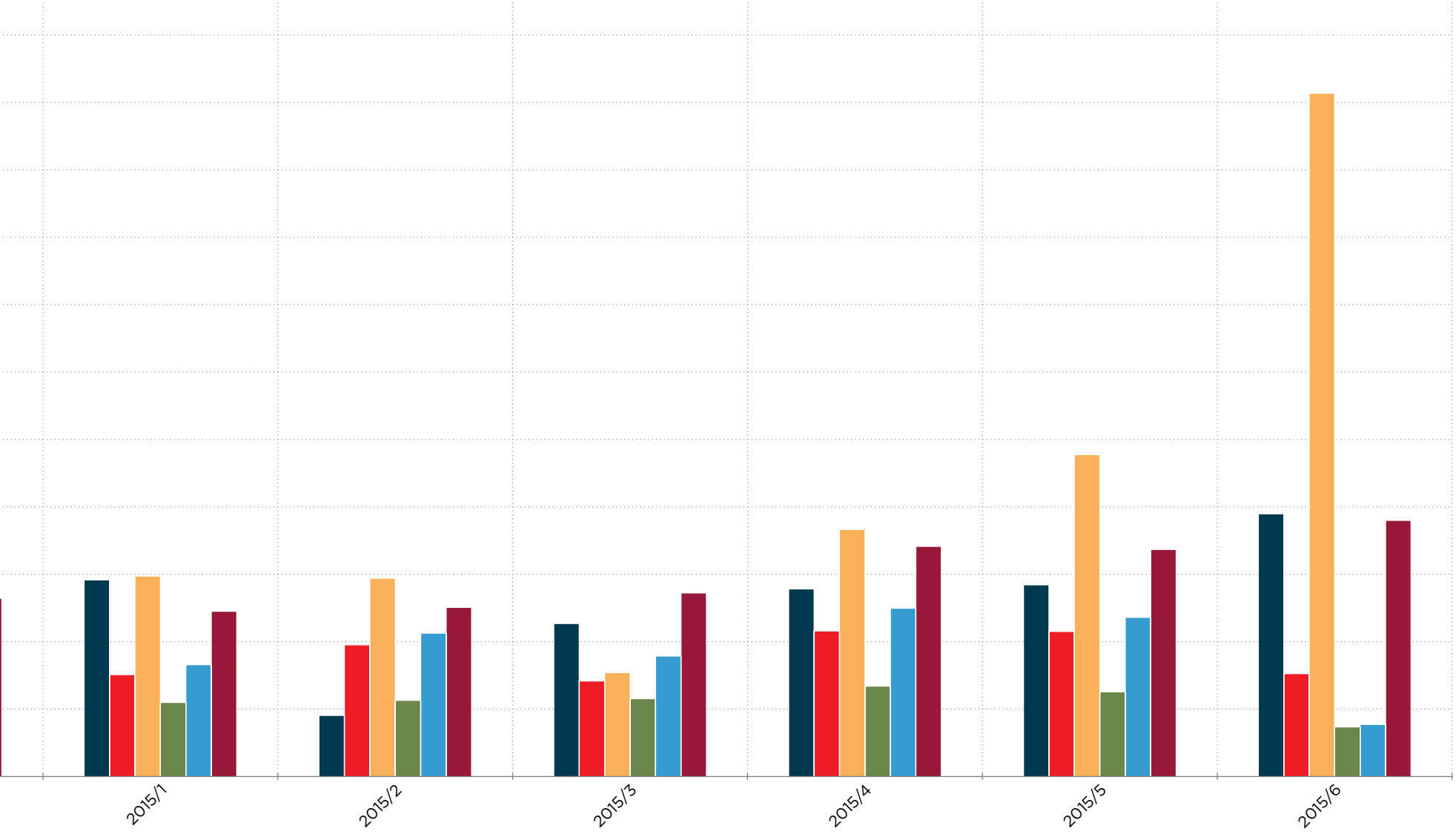
Monthly Average Total Energy Use

Description: Total energy use for each classroom, grouped by month



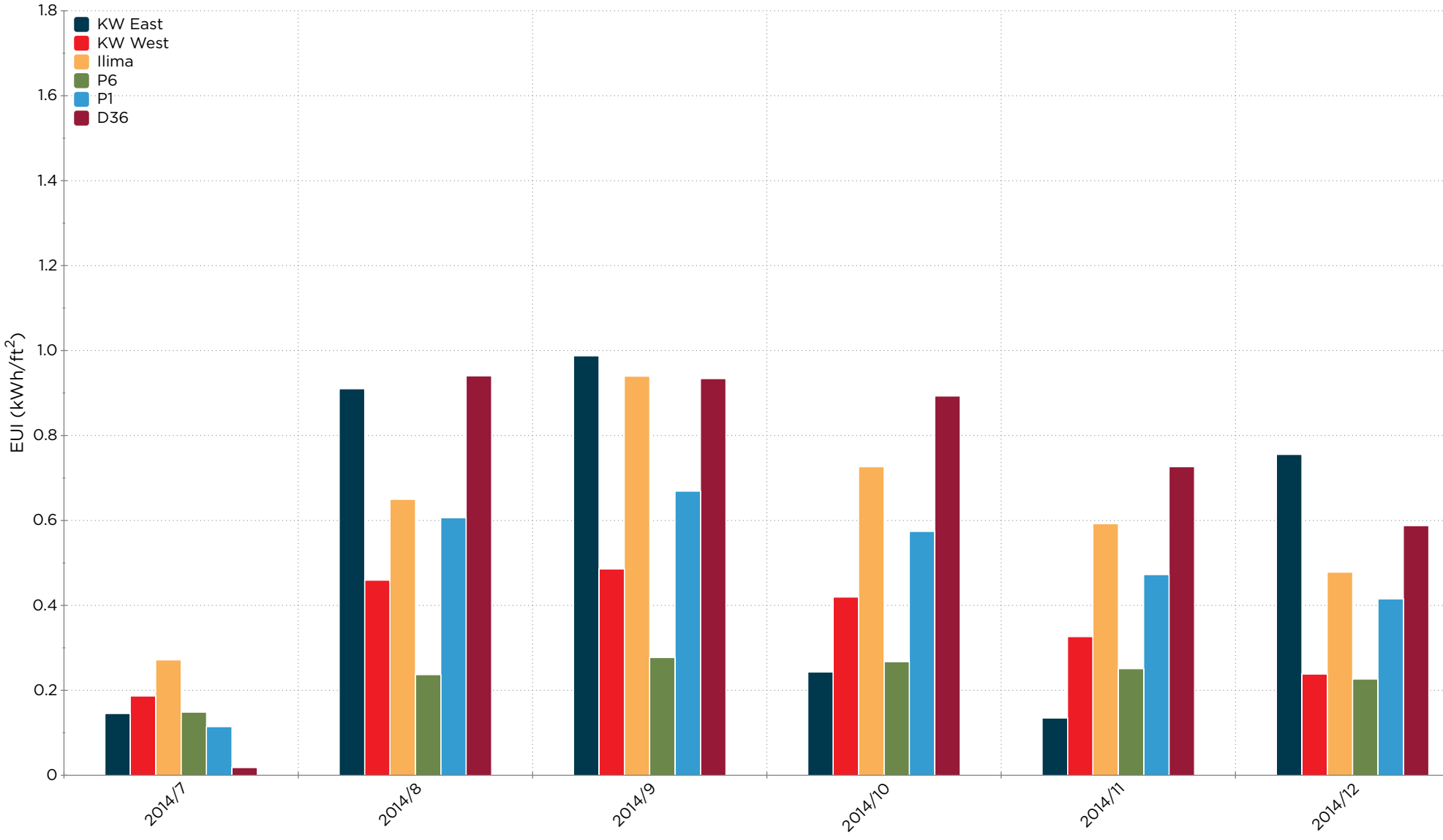
Findings: In total for all classrooms, September had the largest energy consumption which was over 300% higher than the least energy consuming month of July. The large spike in June 2015 at Ilima was due to the AC left continuously on for 19 days (6/6/15-6/25/15) which corresponded to 80% of the energy consumed in June.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



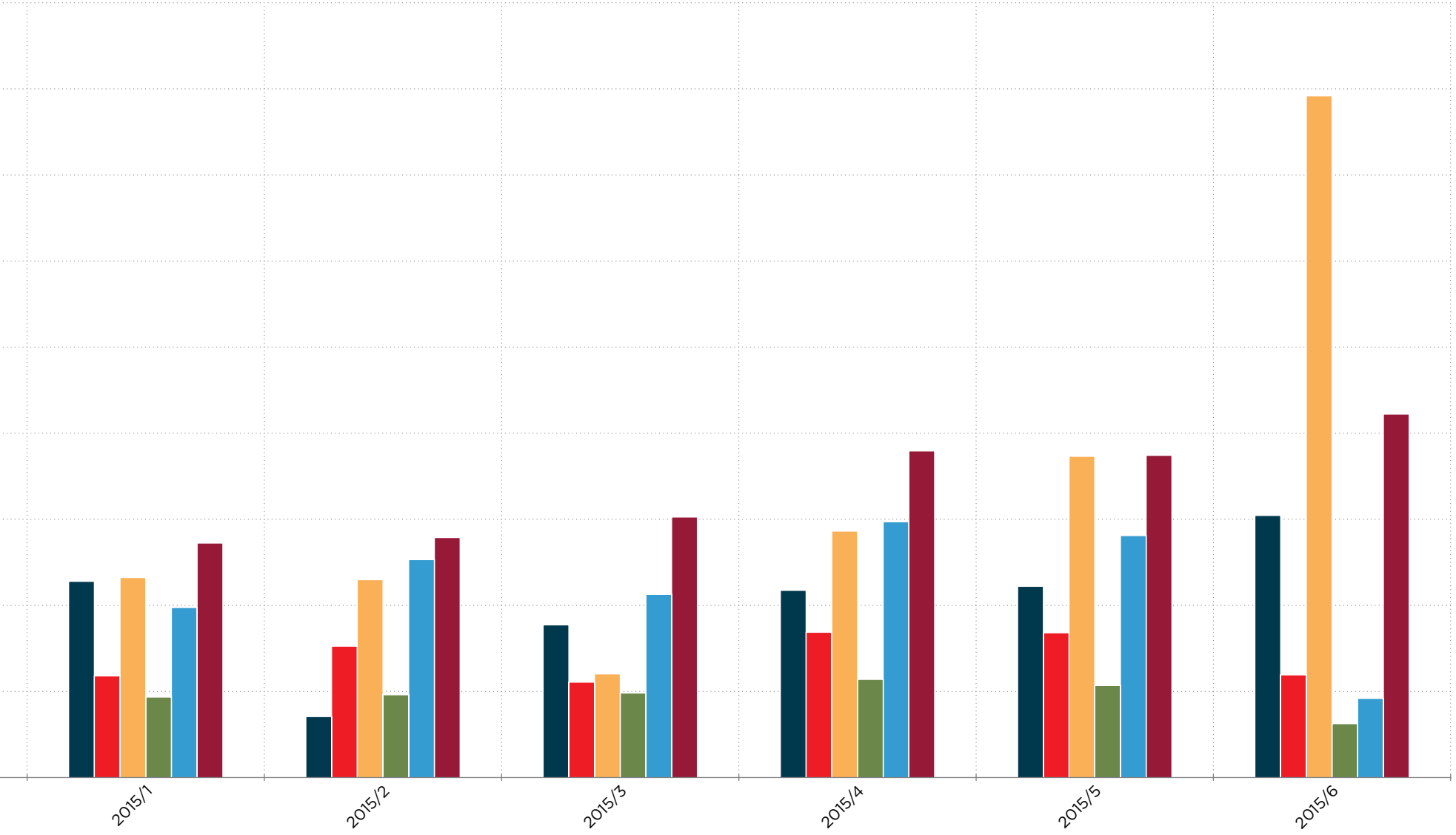
Monthly Energy Use Intensity

Description: Energy use intensity (EUI) for each classroom grouped by month



Findings: Across all months, P6 had the narrowest EUI range (0.13 - 0.28 kWh/ft²) and the smallest average EUI (0.21 kWh/ft²). Ilima has the largest monthly EUI range (0.24-1.58 kWh/sf²) but D36 had the largest monthly EUI average (0.92kWh/sf). The large spike in June 2015 at Ilima was due to the AC left continuously on for 19 days (6/6/15-6/25/15).

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

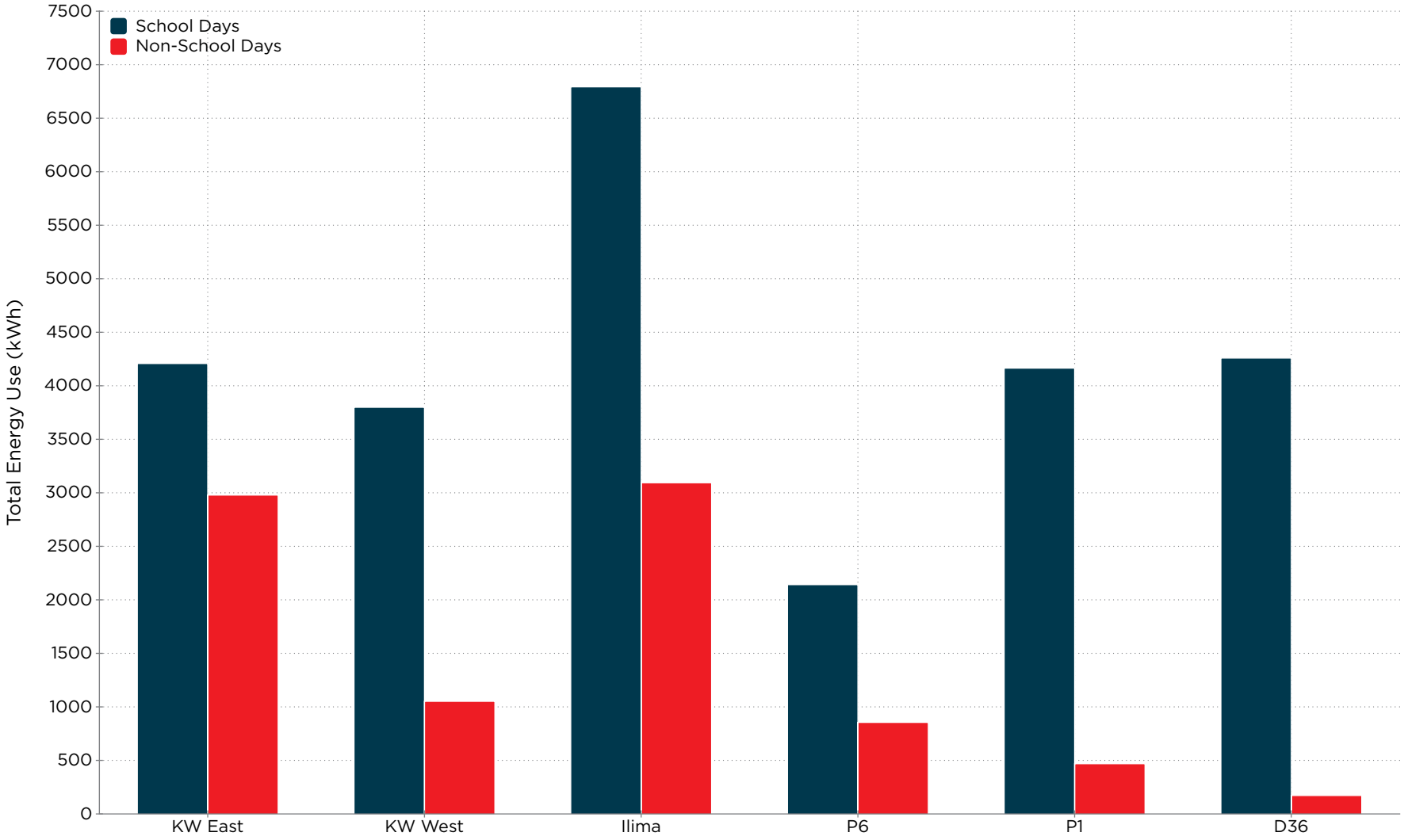


Annual Total Energy Use by School Day and Non-School Day

Description: Total annual energy use for each classroom separated by school days and non-school days

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: On average, school days were responsible for the majority of the energy use (75%).

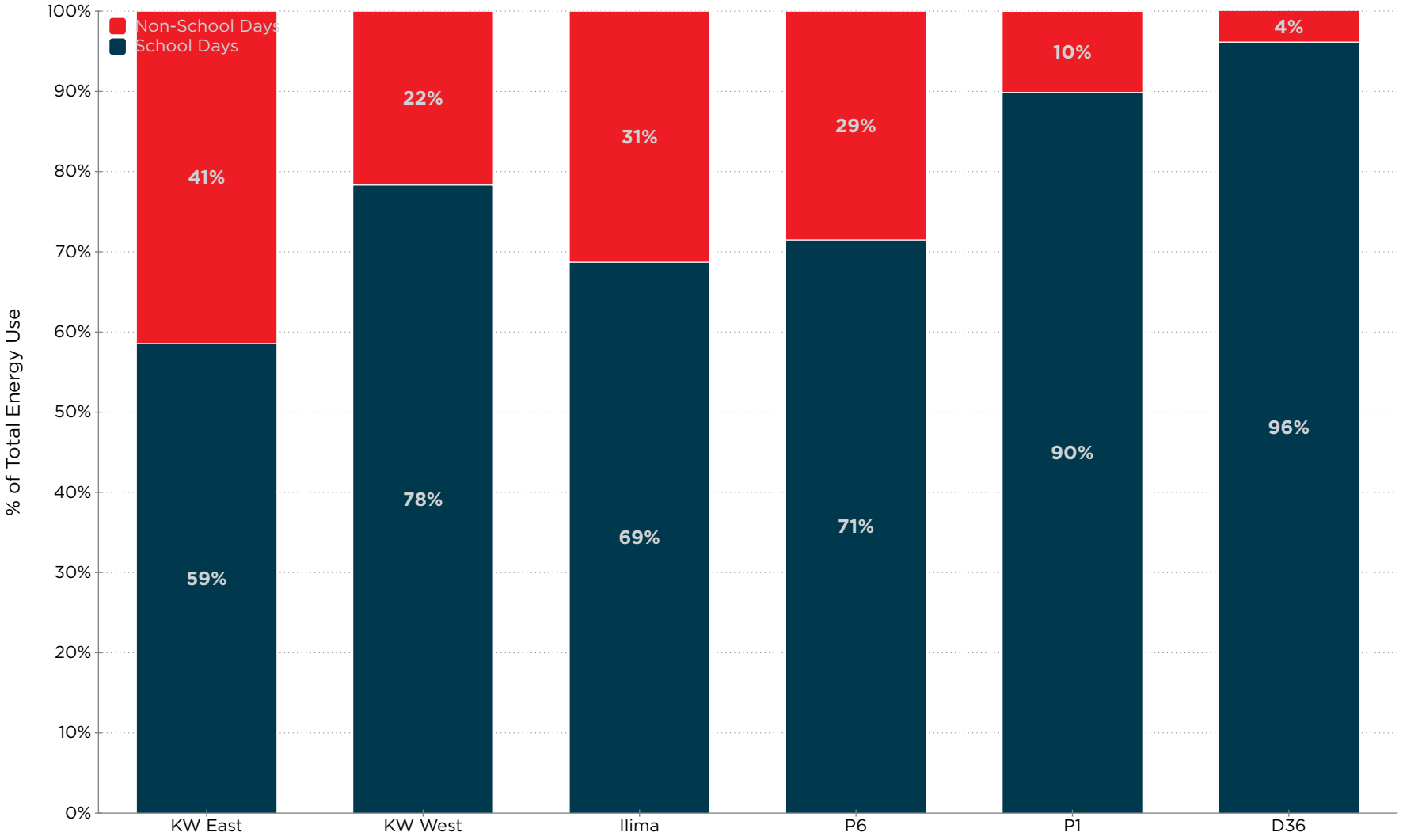


Annual Total Energy Use by Percent

Description: The percentage of total energy use which occurred during school days versus non-school days

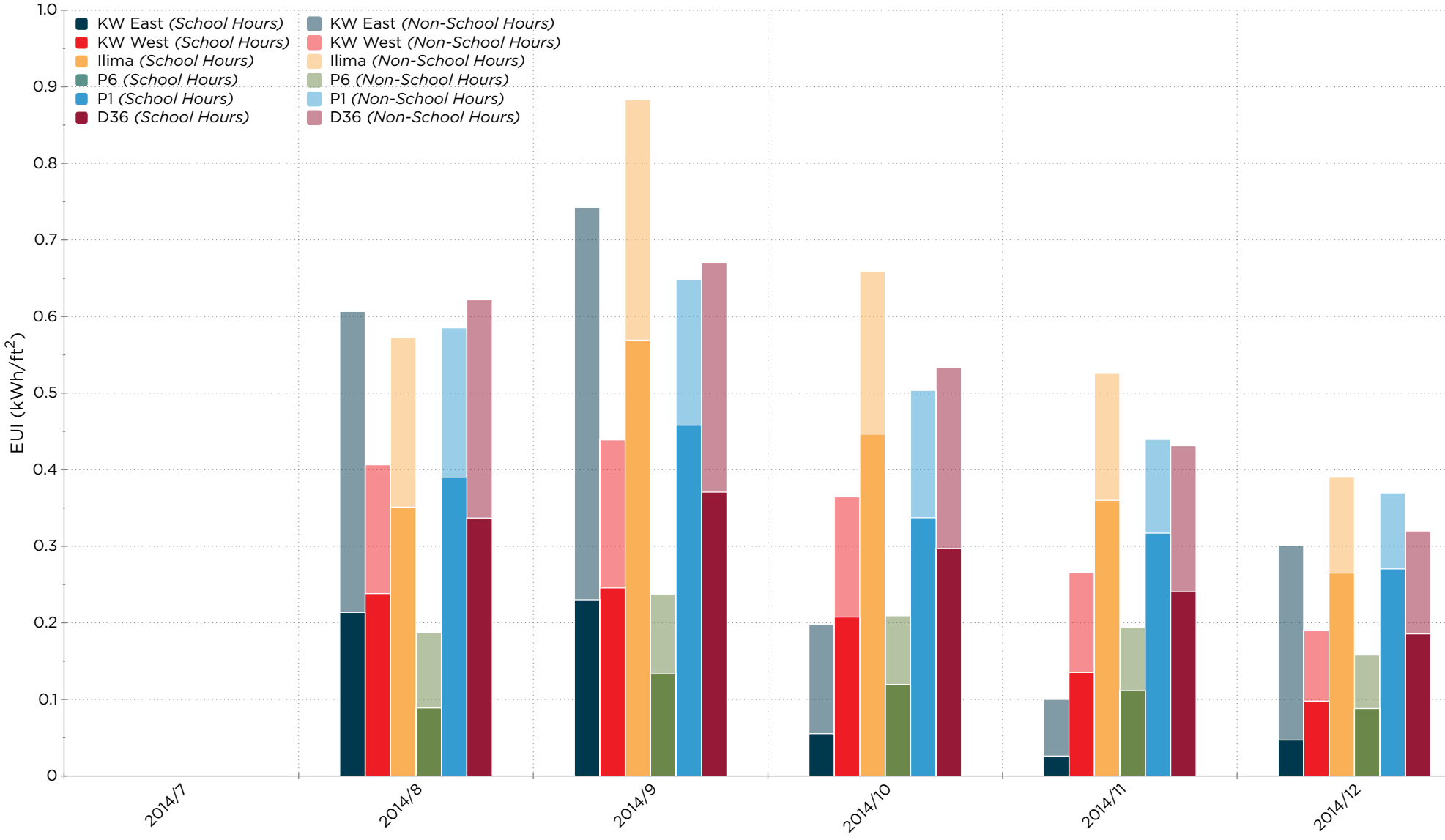
Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: More energy was consumed during school days compared to non-school days. D36 consumed 96% of energy during school days compared to only 59% for KW East.



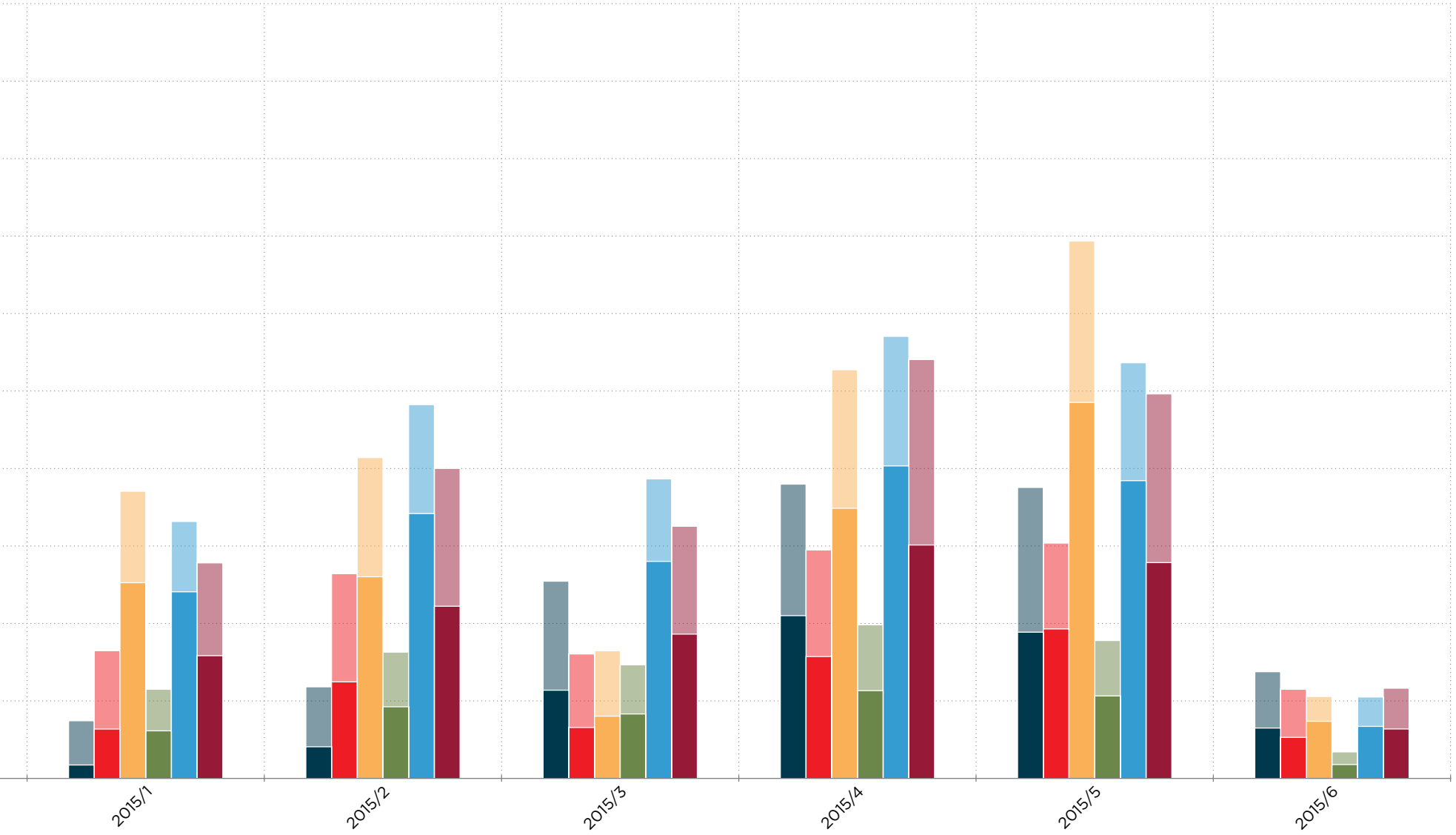
Monthly Energy Use Intensity for School Days

Description: Energy use intensity (EUI) on school days separated by school hours and non-school hours for each month and each classroom. No school days occurred in July. The number of school days in each month can be found in Section 5.



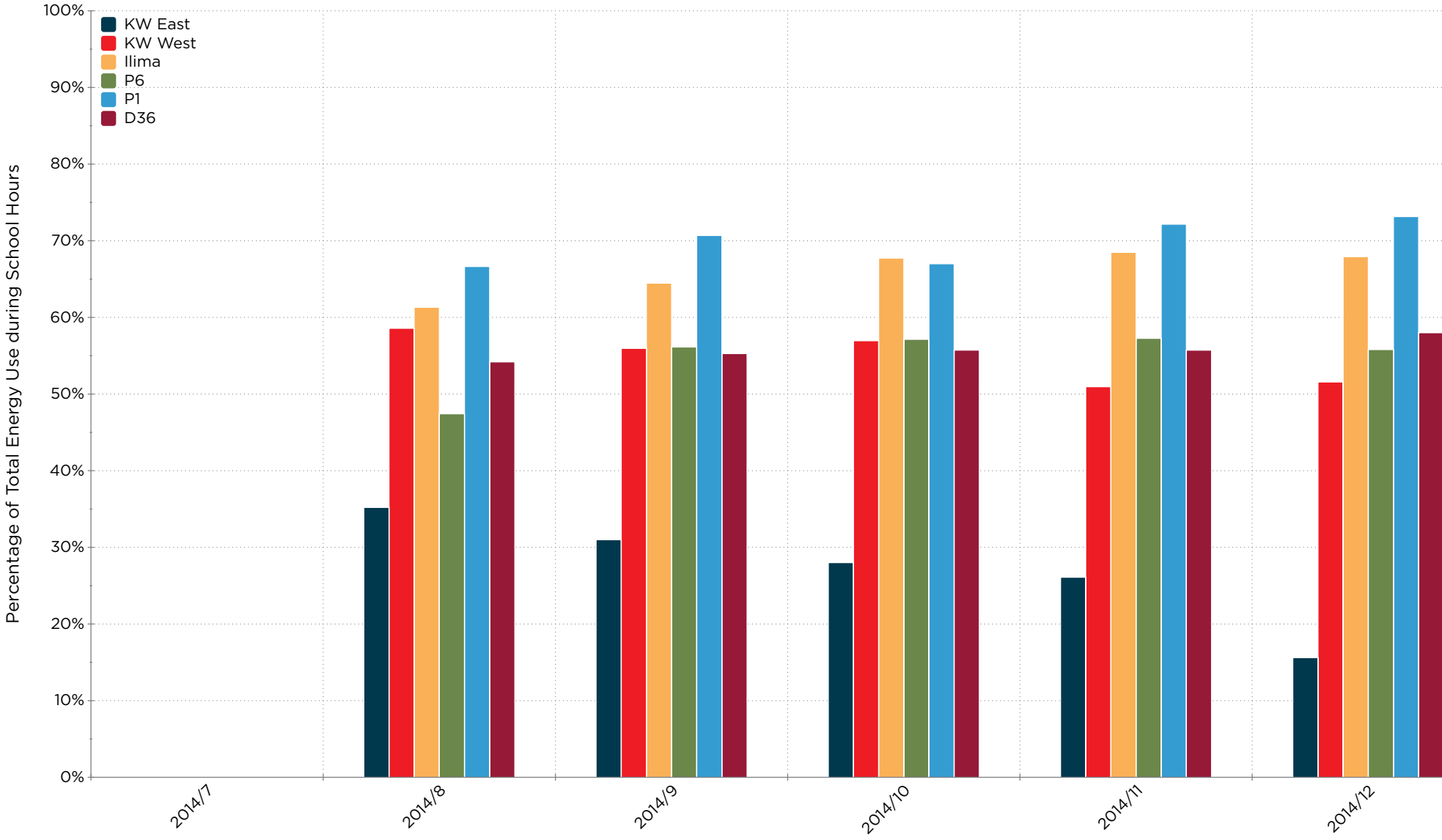
Findings: Ilima had the largest variability across the year in average monthly school day energy use intensity (0.11 to 0.88 kWh/ft²). P6 was the most consistent in monthly energy use intensity with the smallest variability (0.03 to 0.24 kWh/ft²).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



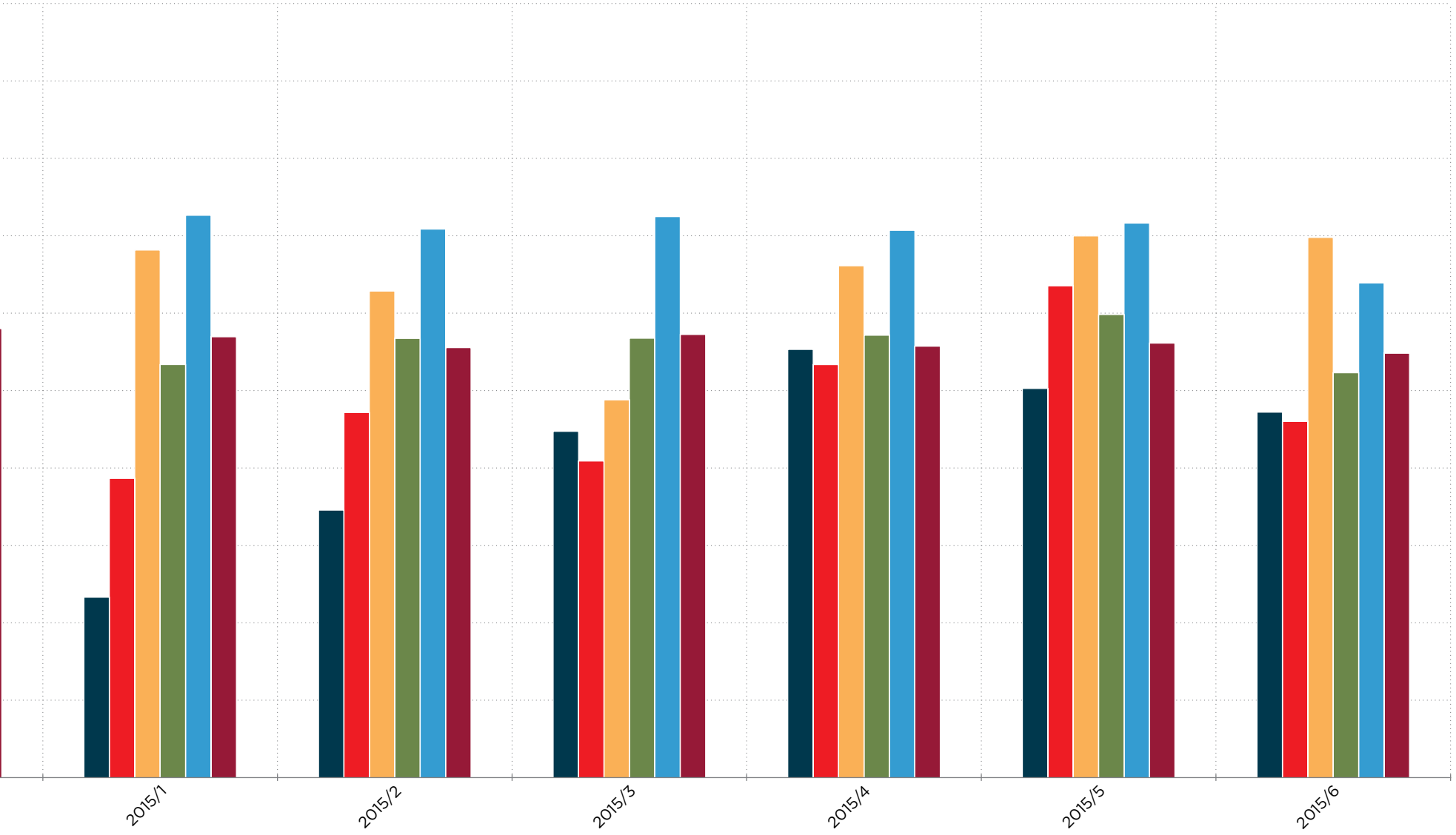
Monthly Total Energy Use during School Hours by Percent

Description: The percentage of total energy use on school days which occurred during school hours for each month and each classroom. No school days occurred in July. The number of school days in each month can be found in Section 5.



Findings: Monthly energy use during school hours was relatively consistent across most buildings. Comparing the Kawaikini FROG Test Platforms, KW East had, on average, 33% less energy used during 8am-2pm compared to KW West.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

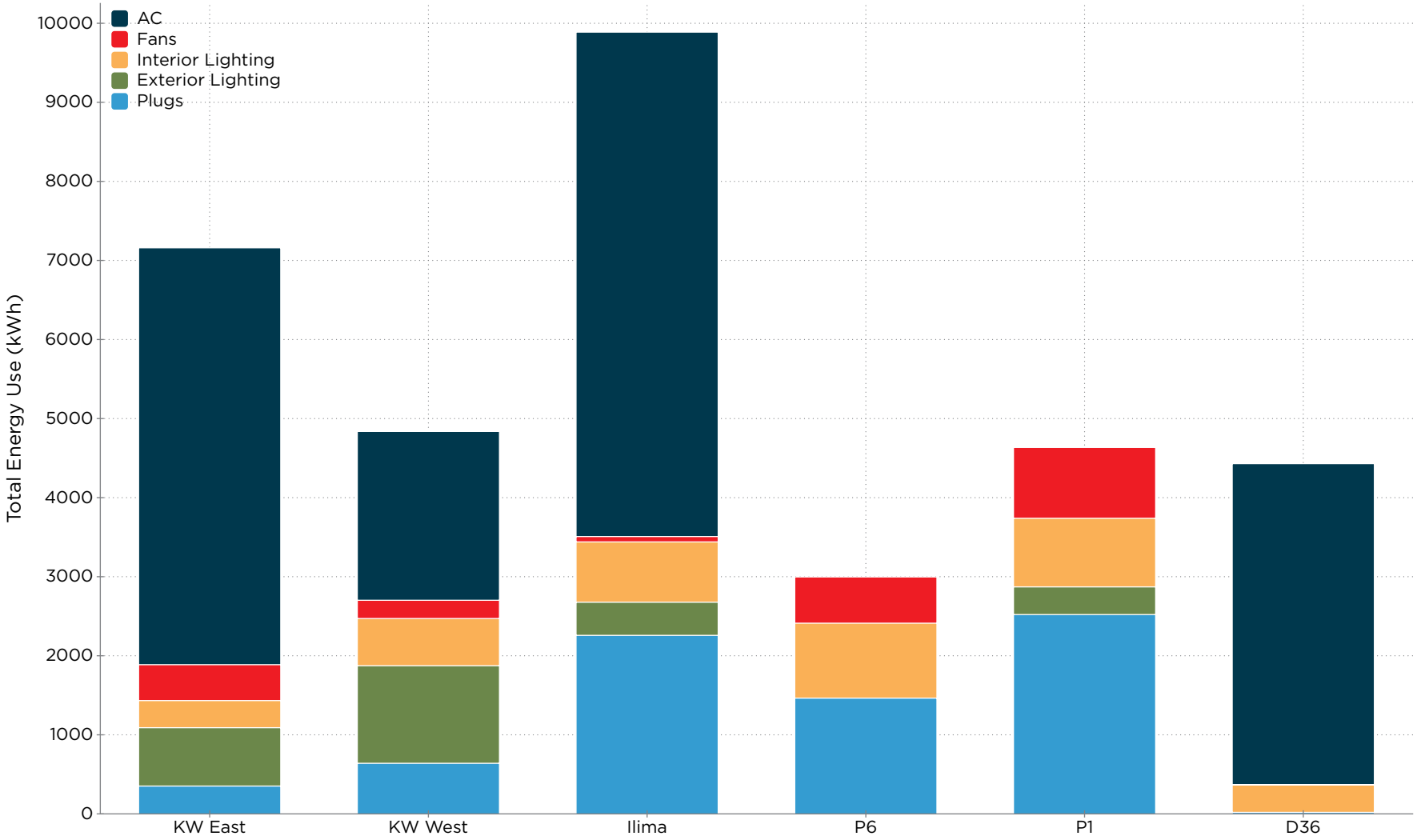


Annual Total Energy by End Use

Description: Total energy use separated by end use for each classroom. The categories of end uses were AC, fans (ceiling fans only), interior lighting, exterior lighting and plugs.

Findings: Ilima's AC energy use was higher than any other classroom's total energy consumption except for KW East.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

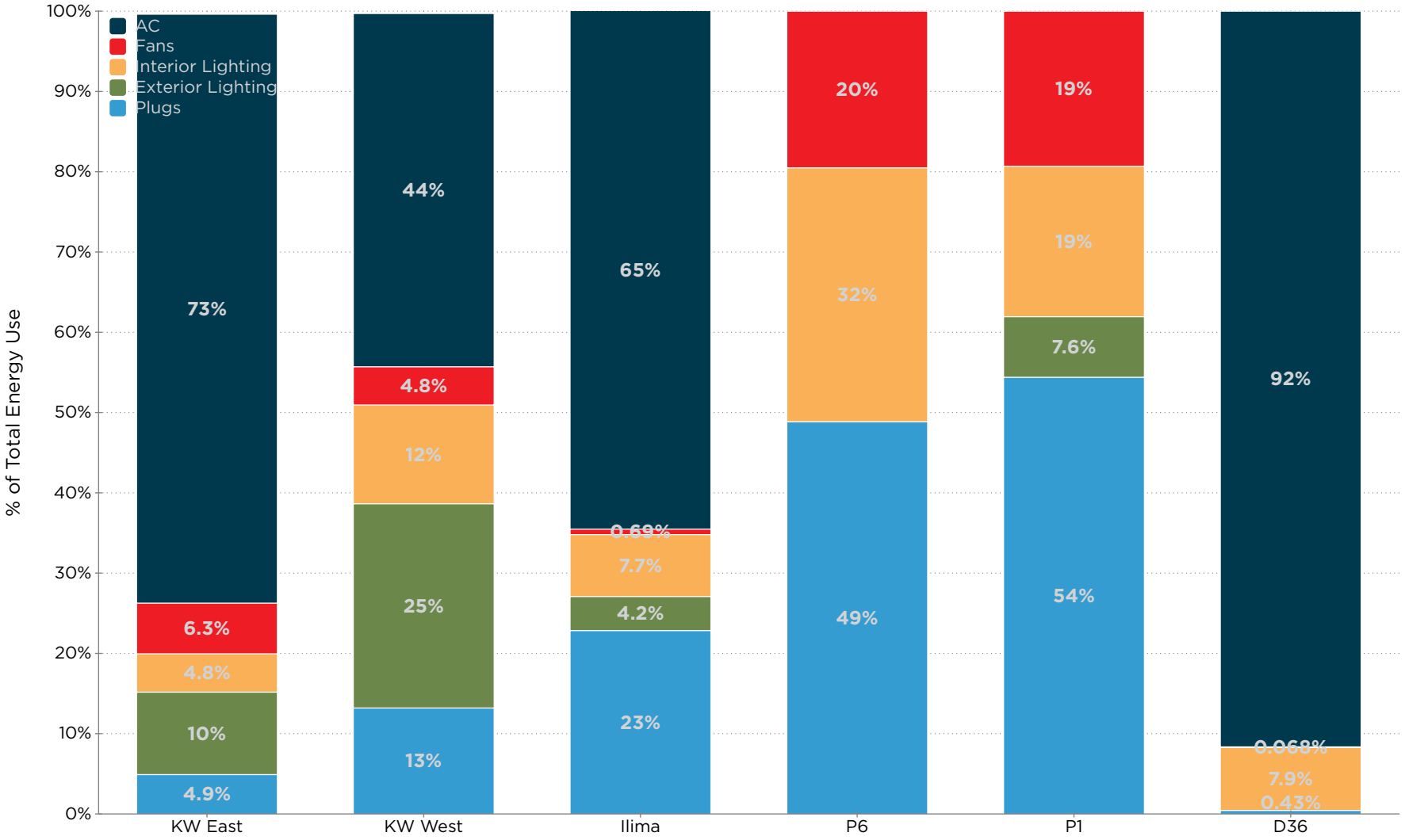


Annual Total Energy by End Use by Percent

Description: Total energy use separated by end use as a percentage for each classroom. The categories of end uses were AC, fans (ceiling fans only), interior lighting, exterior lighting and plugs.

Findings: On average, the three end uses that consumed the most energy were AC (69%), plugs (24%), and interior lighting (14%). P1's large plug load included two window AC units.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

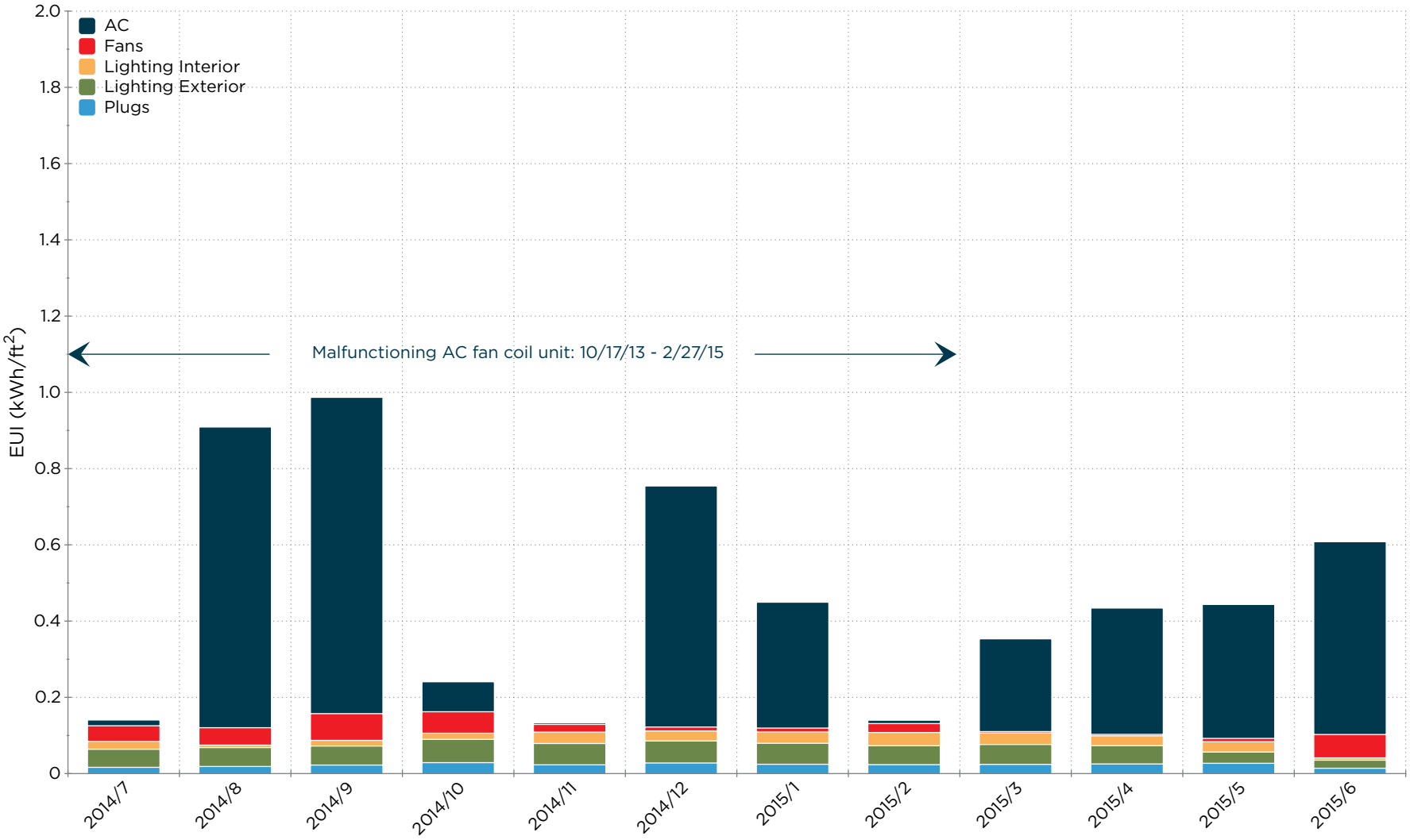


Monthly Energy Use Intensity by End Use: Kawaikini East

Description: Energy use intensity divided by end use for each month for KW East. The fan coil unit in the split system AC was malfunctioning between 10/17/13 - 2/27/15, which skewed the AC energy use intensities during that period.

Findings: From March through June 2015, AC was 60% to 80% of the monthly EUI.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

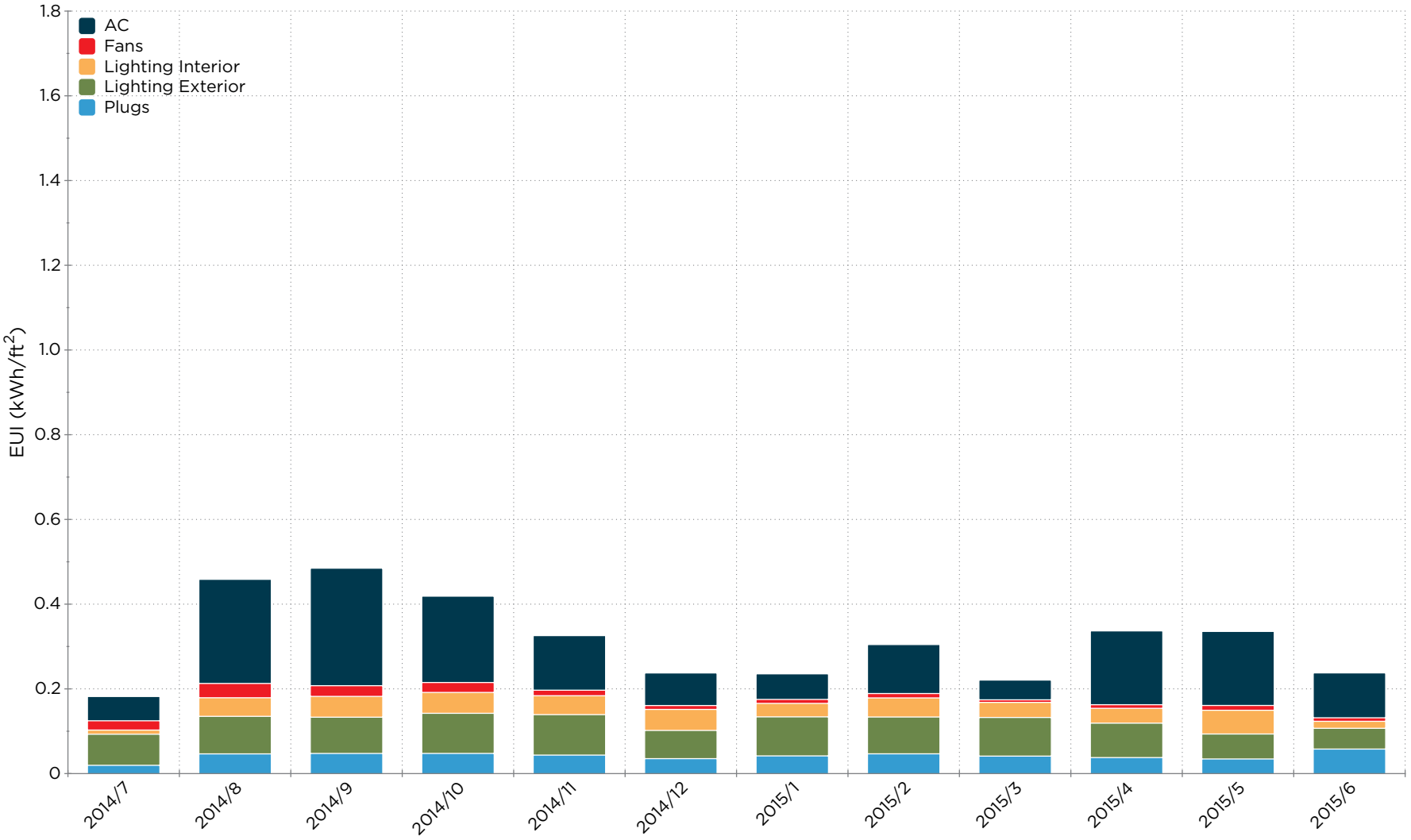


Monthly Energy Use Intensity by End Use: Kawaikini West

Description: Energy use intensity divided by end use for each month for KW West

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: AC energy use had the most variability across months compared with the rest of the end uses. For KW West, AC ranged from 57% in September to 21% in March.

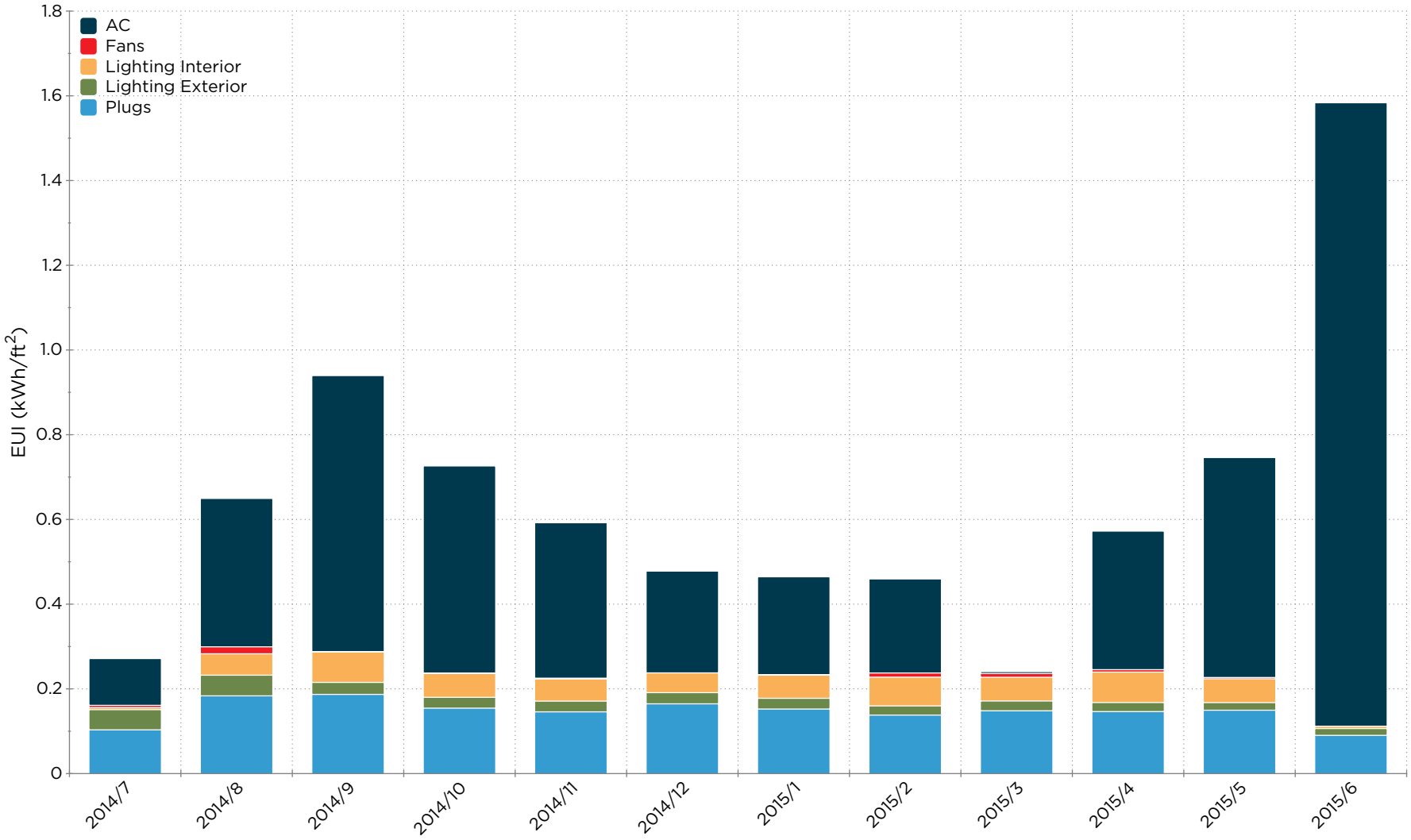


Monthly Energy Use Intensity by End Use: Ilima

Description: Energy use intensity divided by end use for each month for Ilima

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: During June 2015, the AC was left on continuously from 6/6/15-6/25/15. This 19 day event corresponded to 84% of the AC energy and 80% of the total energy consumed for June.

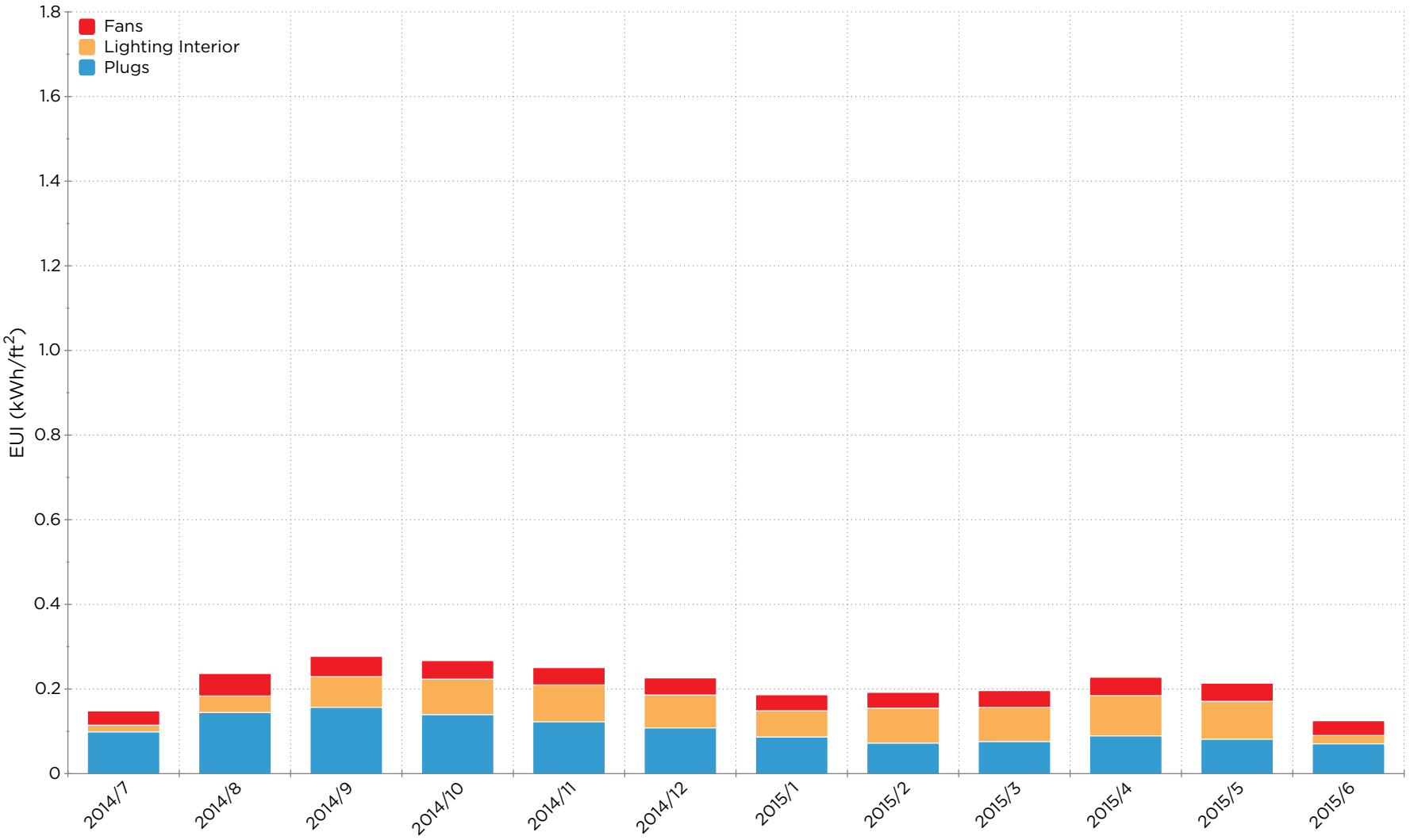


Monthly Energy Use Intensity by End Use: Ewa P6

Description: Energy use intensity (EUI) divided by end use for each month for P6

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: Plug energy use consumed 37% (February 2015) to 66% (July 2014) of the monthly EUI values

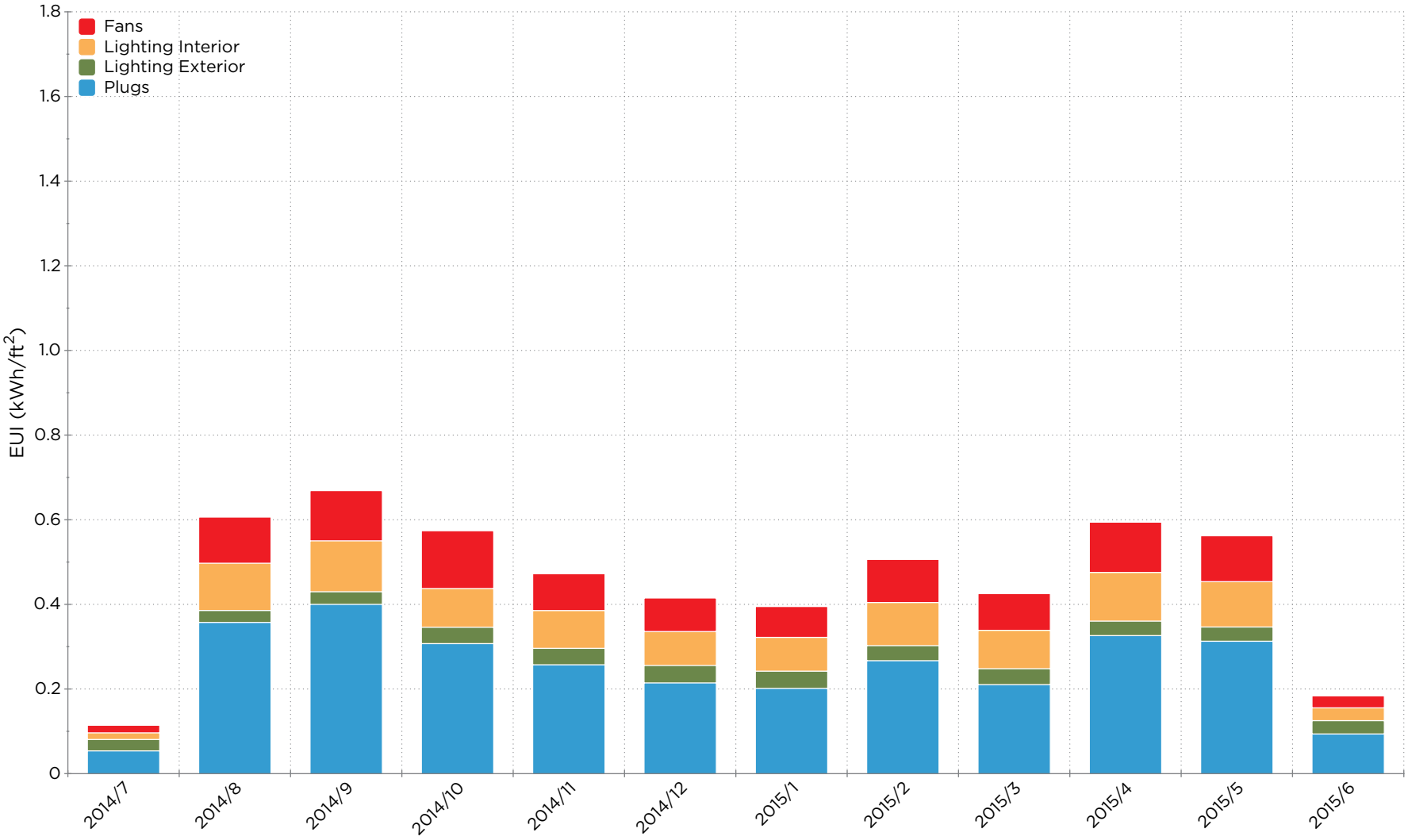


Monthly Energy Use Intensity by End Use: Ewa P1

Description: Energy use intensity divided by end use for each month, for P1. P1 has two window AC units that are not metered as a separate end use. Therefore, the plugs category contains the energy use for the two window AC units.

Findings: During the school year months of August to May, September 2014 had the largest EUI which was 71% above the least energy intensive month of January 2015.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

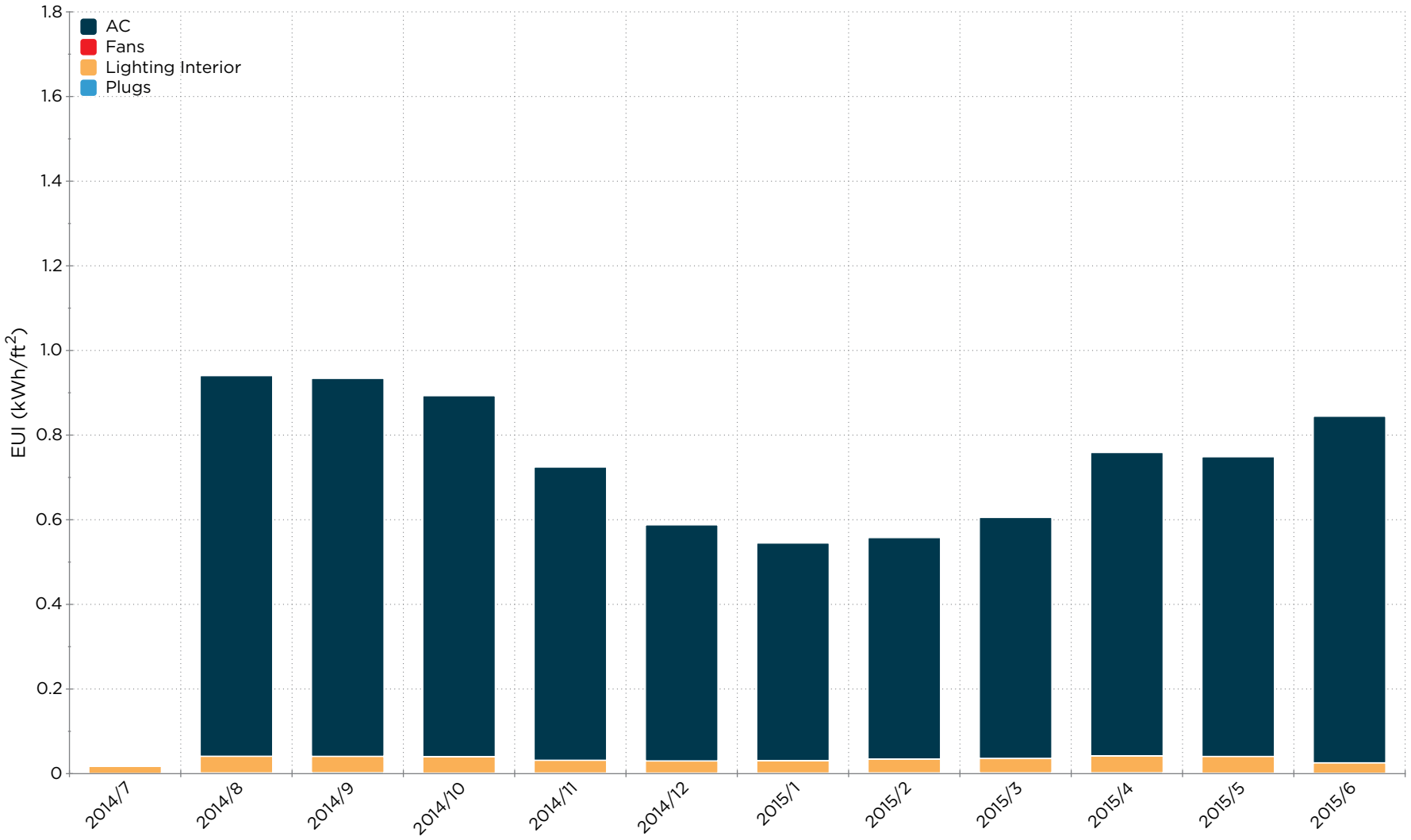


Monthly Energy Use Intensity by End Use: Ewa D36

Description: Energy use intensity separated by end use for each month for D36. The air conditioning in D36 is a central system shared with 3 other classrooms. The AC energy was extrapolated[1] for 7/1/14-6/30/15 based on measured data from 11/12/15-11/20/15. The AC is programmed to run from 6am to 6pm during weekdays.

Findings: Excluding July, AC accounted for 97% (August 2014) to 94% (January-March 2015) of the total energy use intensity for each month.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



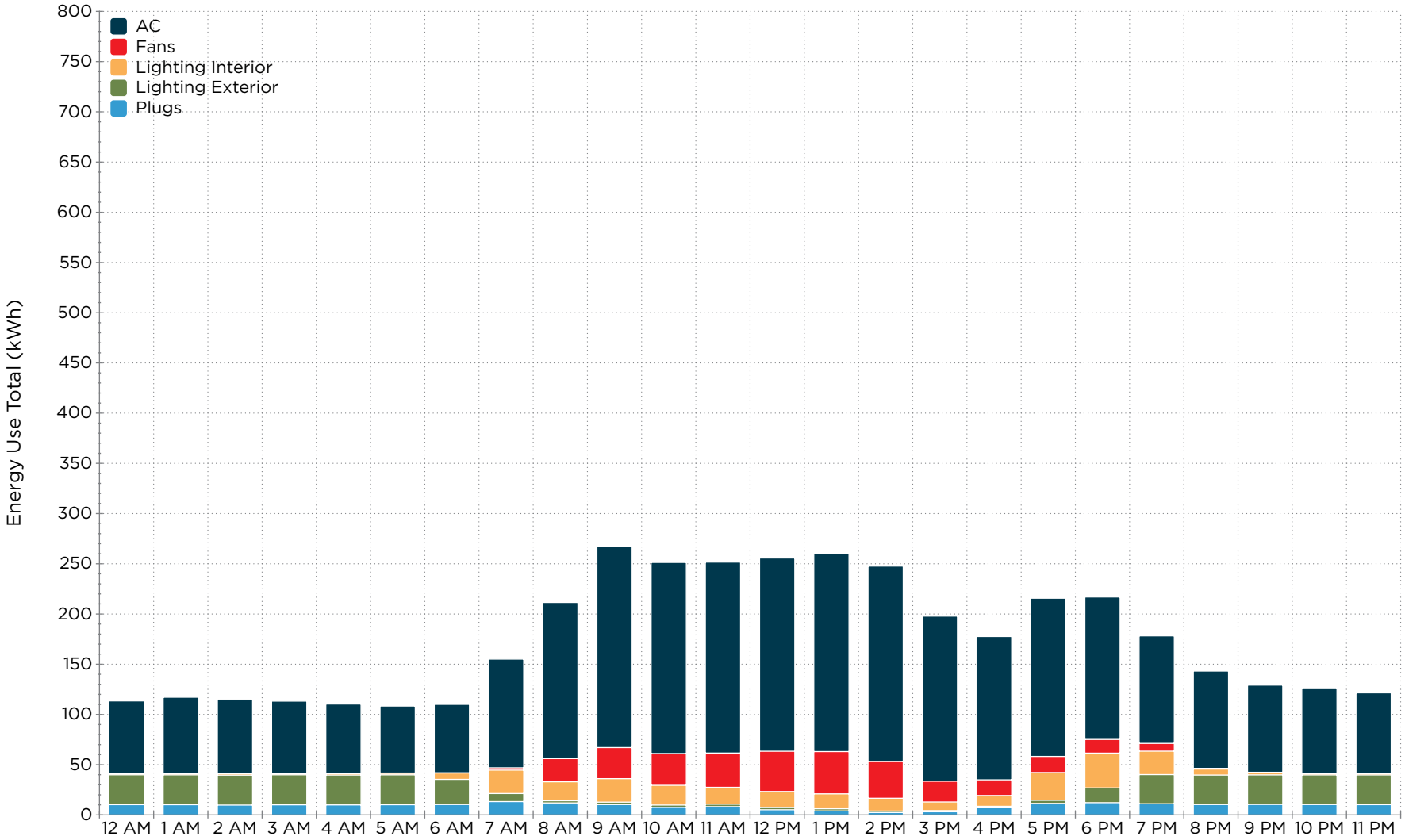
1: Additional information on the D36 extrapolation methodology can be found on the Methodology Section

Hourly Total Energy by End Use: Kawaikini East

Description: Average hourly school day energy use divided by end use for KW East. The fan coil unit in the split system AC was malfunctioning between 10/17/13 - 2/27/15.

Findings: The hour with the greatest amount of fan energy use was between 1pm - 2pm. Of all the fan energy use, 64% occurred during school hours of 8am to 2pm.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

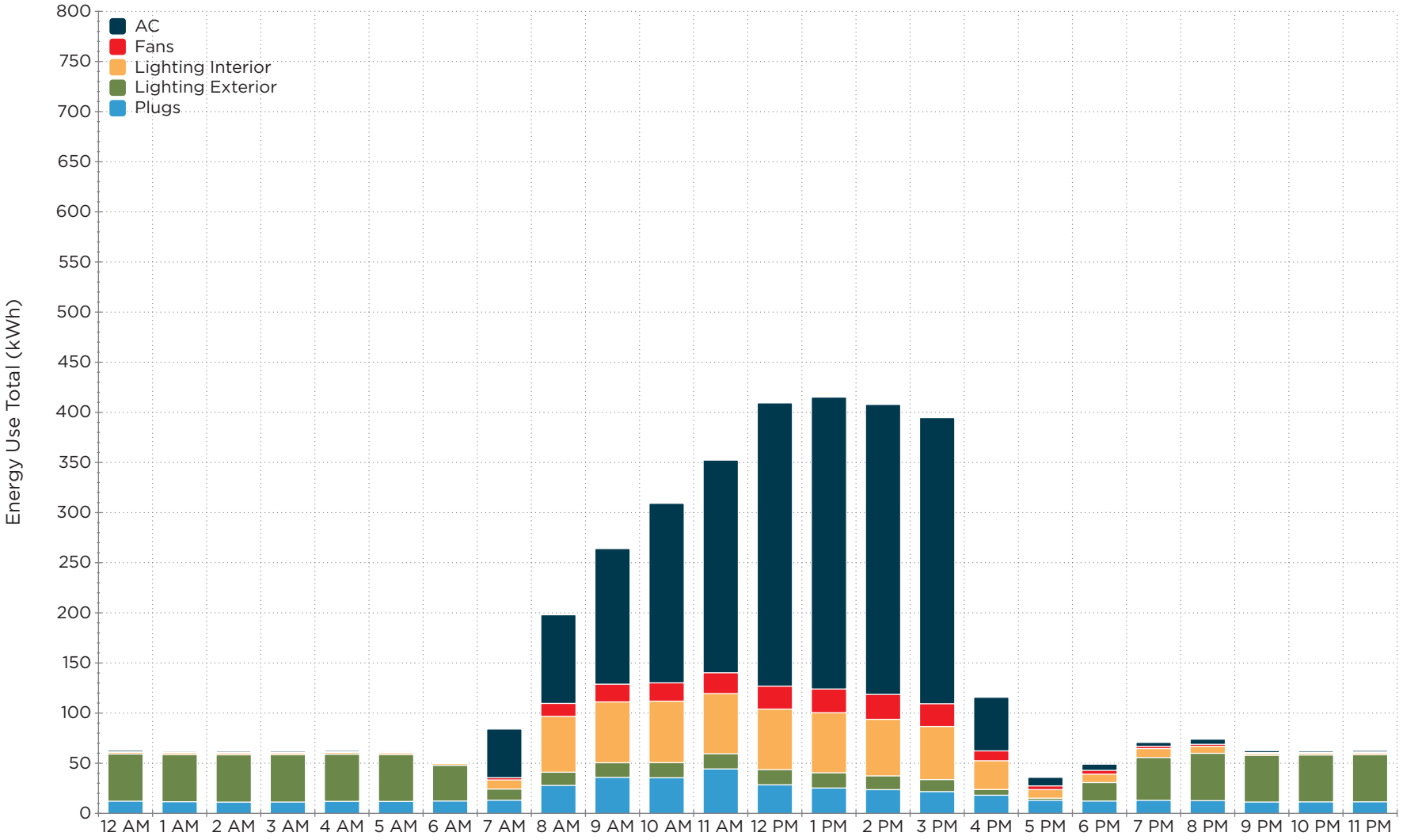


Hourly Total Energy by End Use: Kawaikini West

Description: Average hourly school day energy use divided by end use for KW West

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: The morning hours (8am - 12pm) used 37% less total energy than in the afternoon (12pm - 4pm).

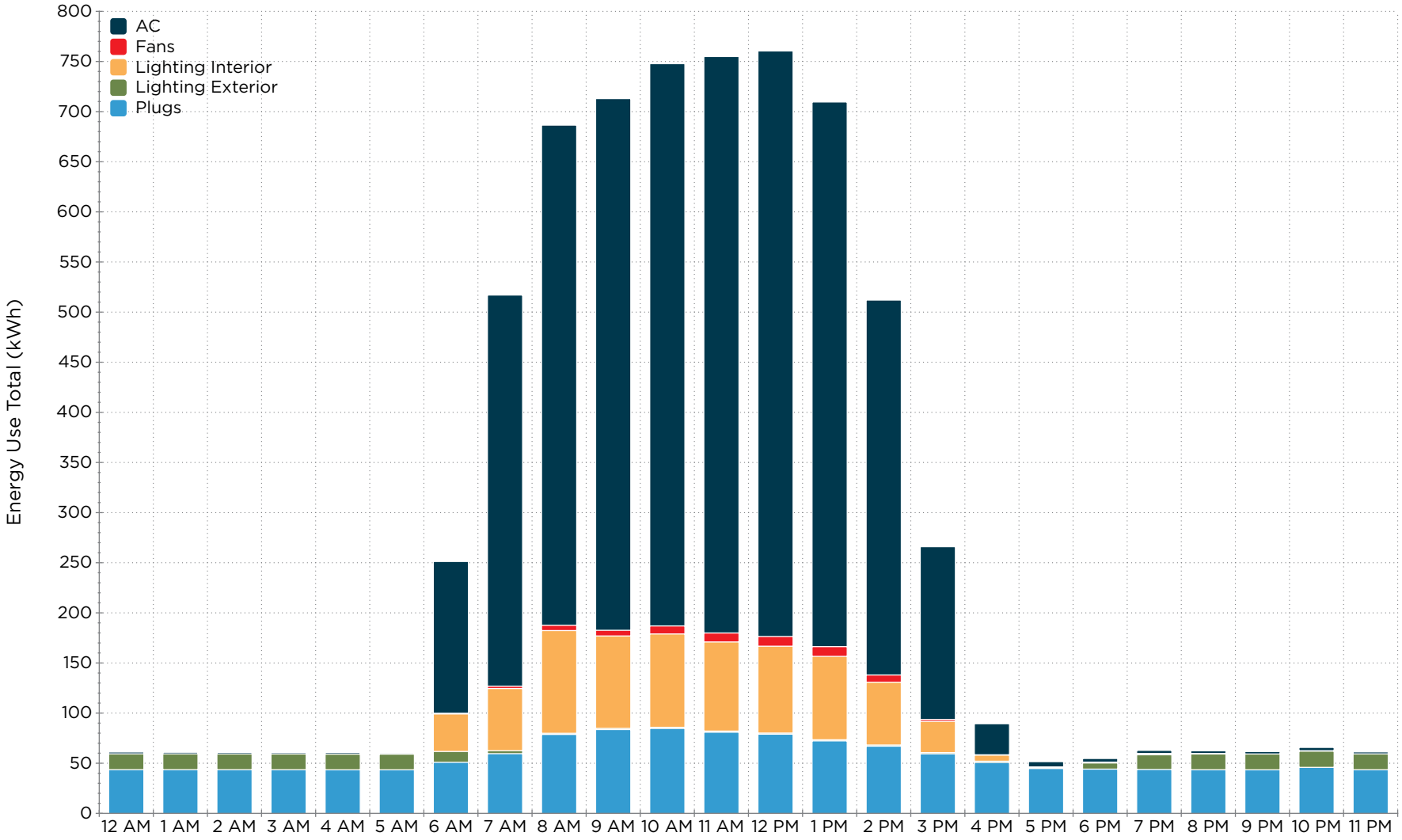


Hourly Total Energy by End Use: Ilima

Description: Average hourly school day energy use divided by end use for Ilima

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: The hour between 12pm - 1pm had the greatest amount of total energy use, and also the greatest amount of AC energy use. AC energy use accounted for 77% of the total energy during that hour.

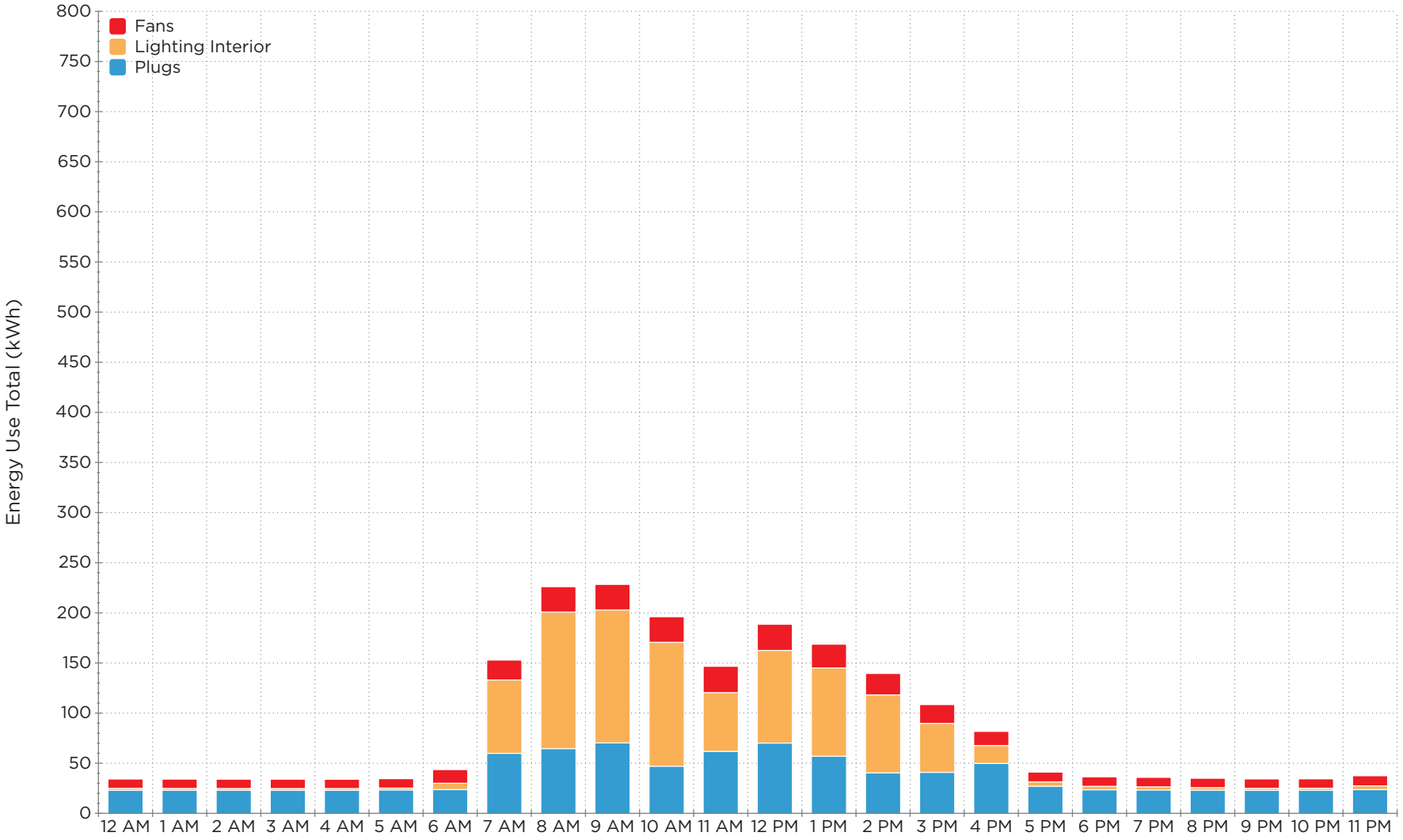


Hourly Total Energy by End Use: Ewa P6

Description: Average hourly school day energy use divided by end use for P6

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: The three hours with the greatest amount of total energy use were between 8am - 11am. These three hours accounted for 31% of the total energy use throughout the day. During these three hours, interior lighting accounted for 59% of the total energy use.

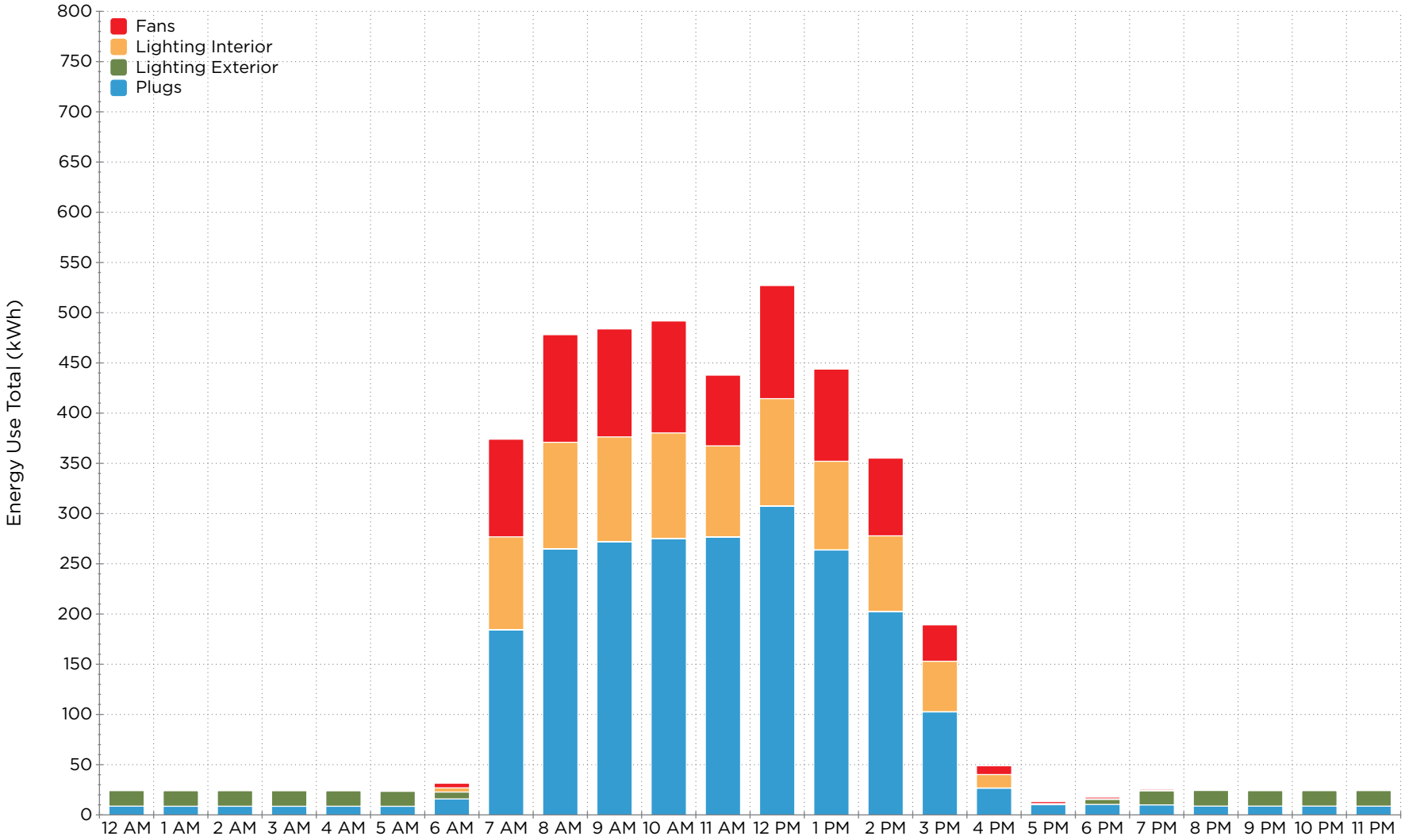


Hourly Total Energy by End Use: Ewa P1

Description: Average hourly school day energy use divided by end use for P1. P1 has two window air conditioning units that are not metered as a separate end use. Therefore, the plug load contains the energy use for the two window air conditioning units.

Findings: Of the total energy use throughout the day, 86% occurred between 7am - 3pm. During that period, plugs accounted for 57% of the total energy use.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

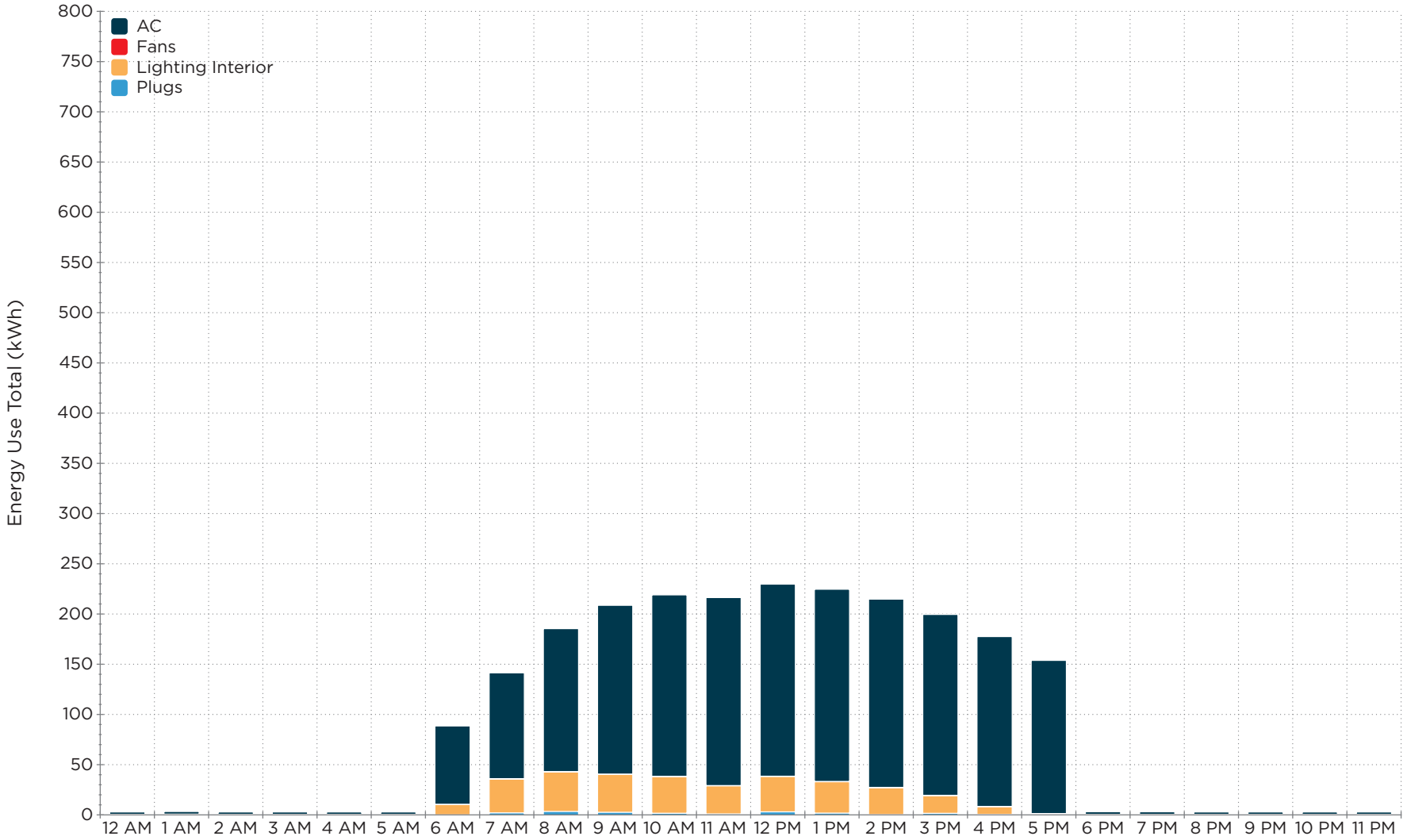


Hourly Total Energy by End Use: Ewa D36

Description: Average hourly school day energy use divided by end use for D36. The air conditioning in D36 is a central system shared with 3 other classrooms. The AC energy was extrapolated[1] for 7/1/14-6/30/15 based on measured data from 11/12/15-11/20/15. The AC is programmed to run from 6am to 6pm on weekdays.

Findings: The hour with the greatest interior lighting energy use occurred between 8am - 9am. During this hour, interior lighting accounted for 21% of the total energy use.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



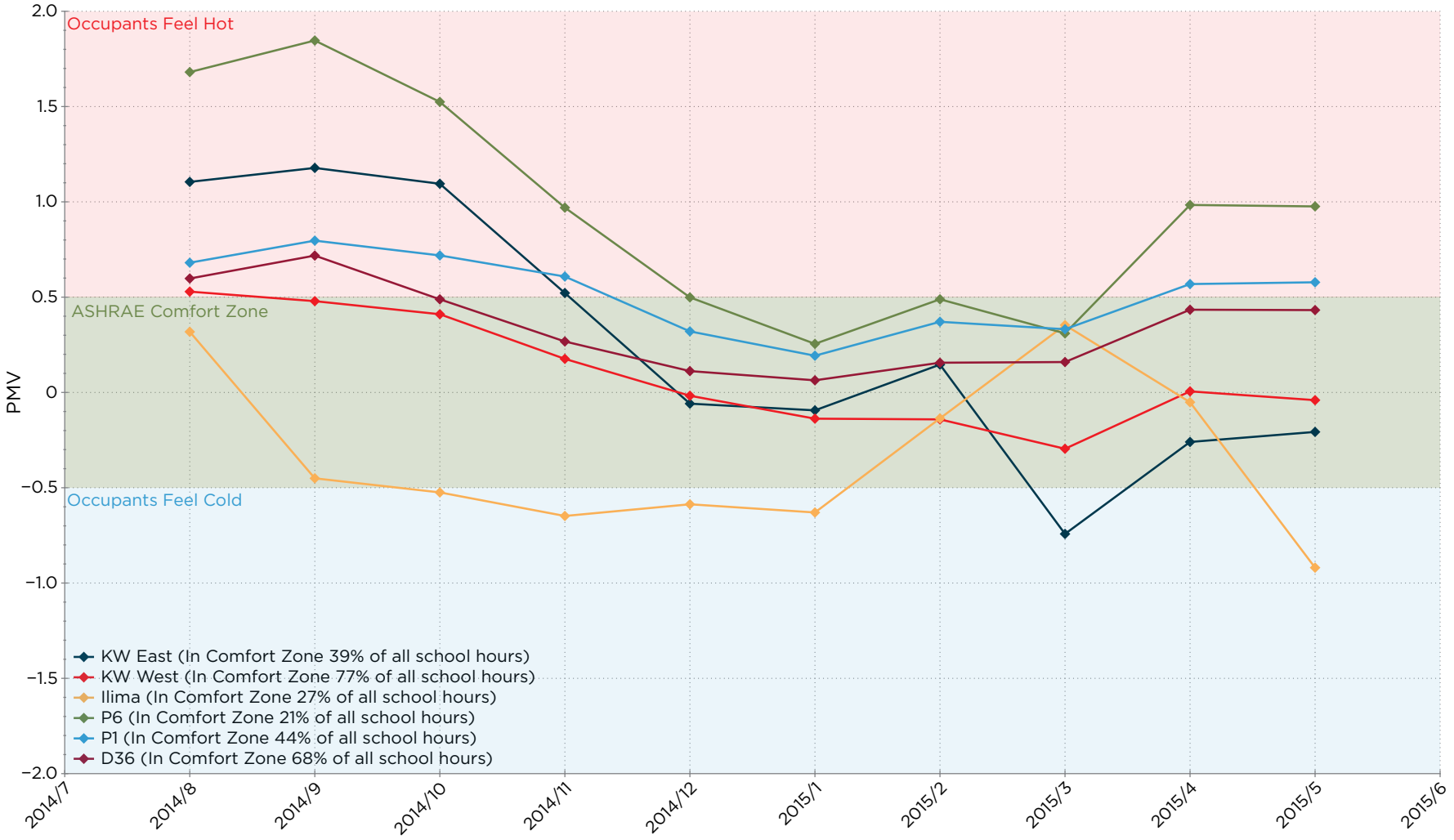
1: Additional information on the D36 extrapolation methodology can be found on the Methodology Section.

Monthly Average PMV Scores by School Hours

Description: Average monthly PMV[1] scores from school hours only for each classroom

Findings: KW West had 77% of all school hours within the ASHRAE Comfort Zone which was the highest across all classrooms. In contrast, P6 was the lowest at 21% of school hours within the Comfort Zone. While Ilima has identical construction to KW West, Ilima over cooled the classroom resulting in 27% of all school hours within the Comfort Zone.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours



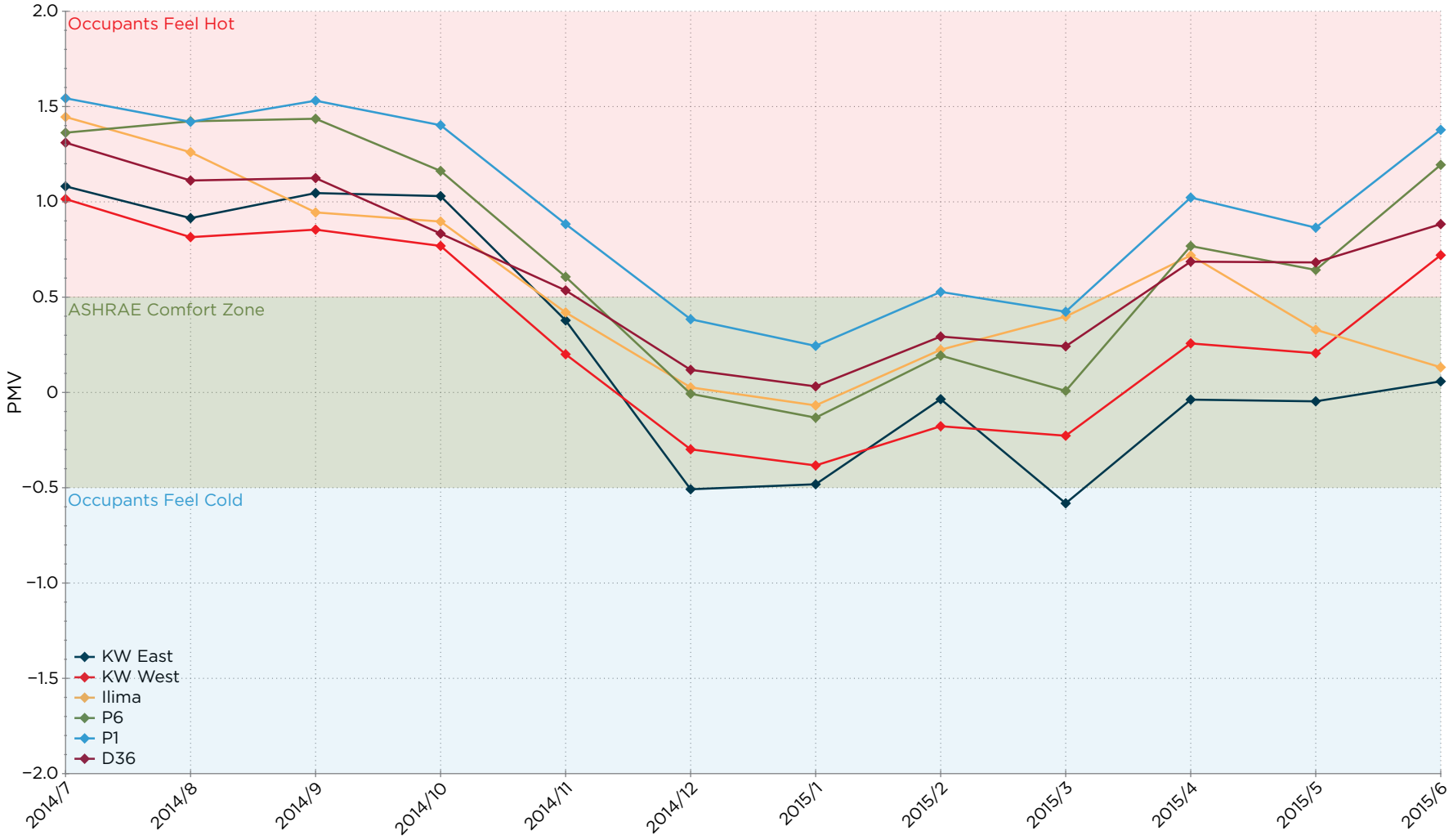
1: Additional information on PMV can be found on the Methodology Section

Monthly Average PMV Score by Non-School Hours

Description: Average monthly PMV[1] scores from non-school hours only for each classroom

Findings: When classrooms were unoccupied, the PMV values across the months had a similar profile. P1 had the highest average PMV score across months.

Study Period: 07/01/2014 - 06/30/2015
Days: Non-School Days
Hours: Non-School Hours



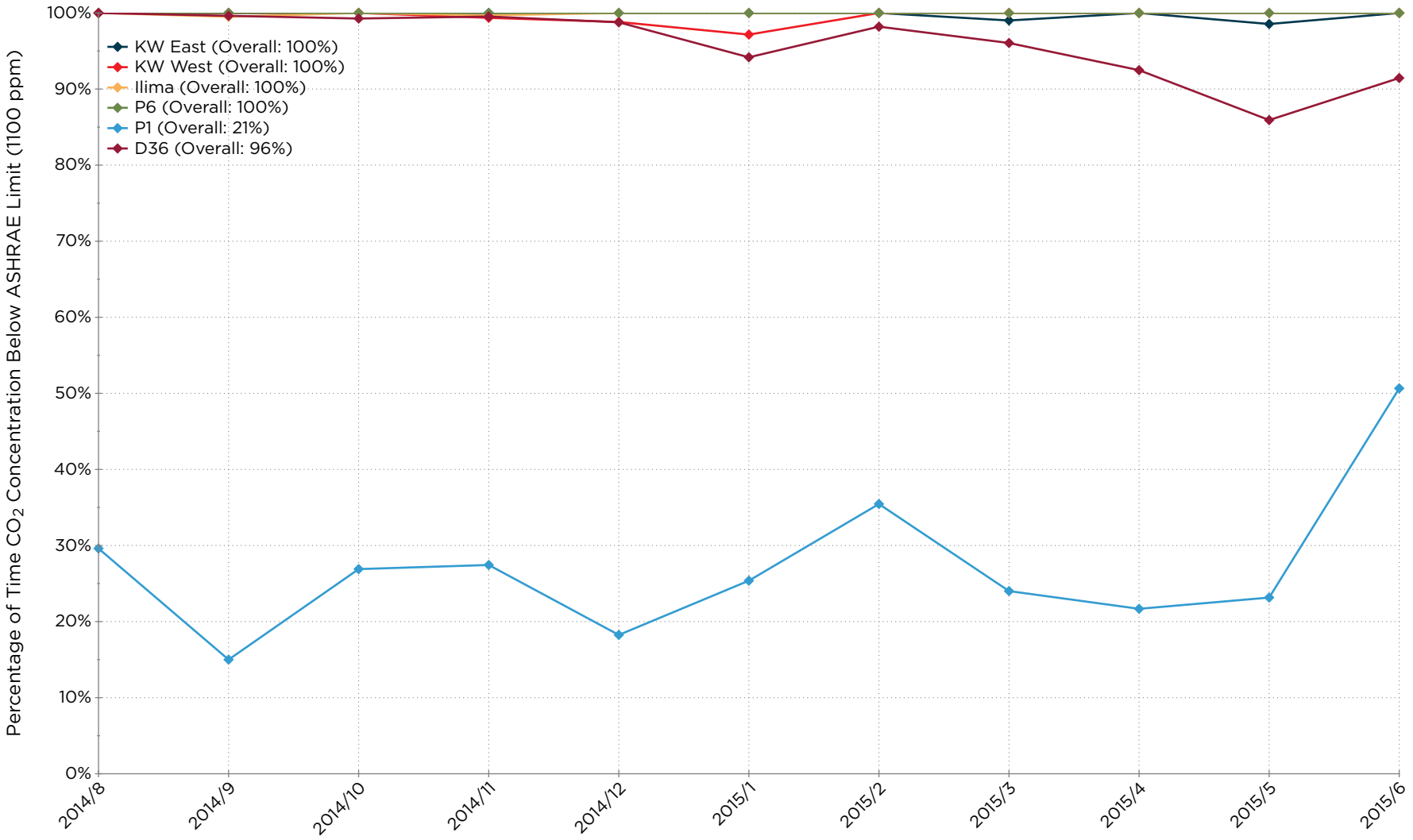
1: Additional information on PMV can be found on the Methodology Section

Monthly Air Quality, CO_2, Below ASHRAE Limit by Percent

Description: The percentage of school hours when the CO_2 concentration was below the ASHRAE limit for adequate air circulation (1100 ppm) for each month and each classroom.

Findings: P1 had CO_2 concentrations below the acceptable threshold of 1100 ppm for only 27% of school hours across all months. September had the lowest percentage of school hours with CO_2 concentrations under the ASHRAE limit 15% for P1.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

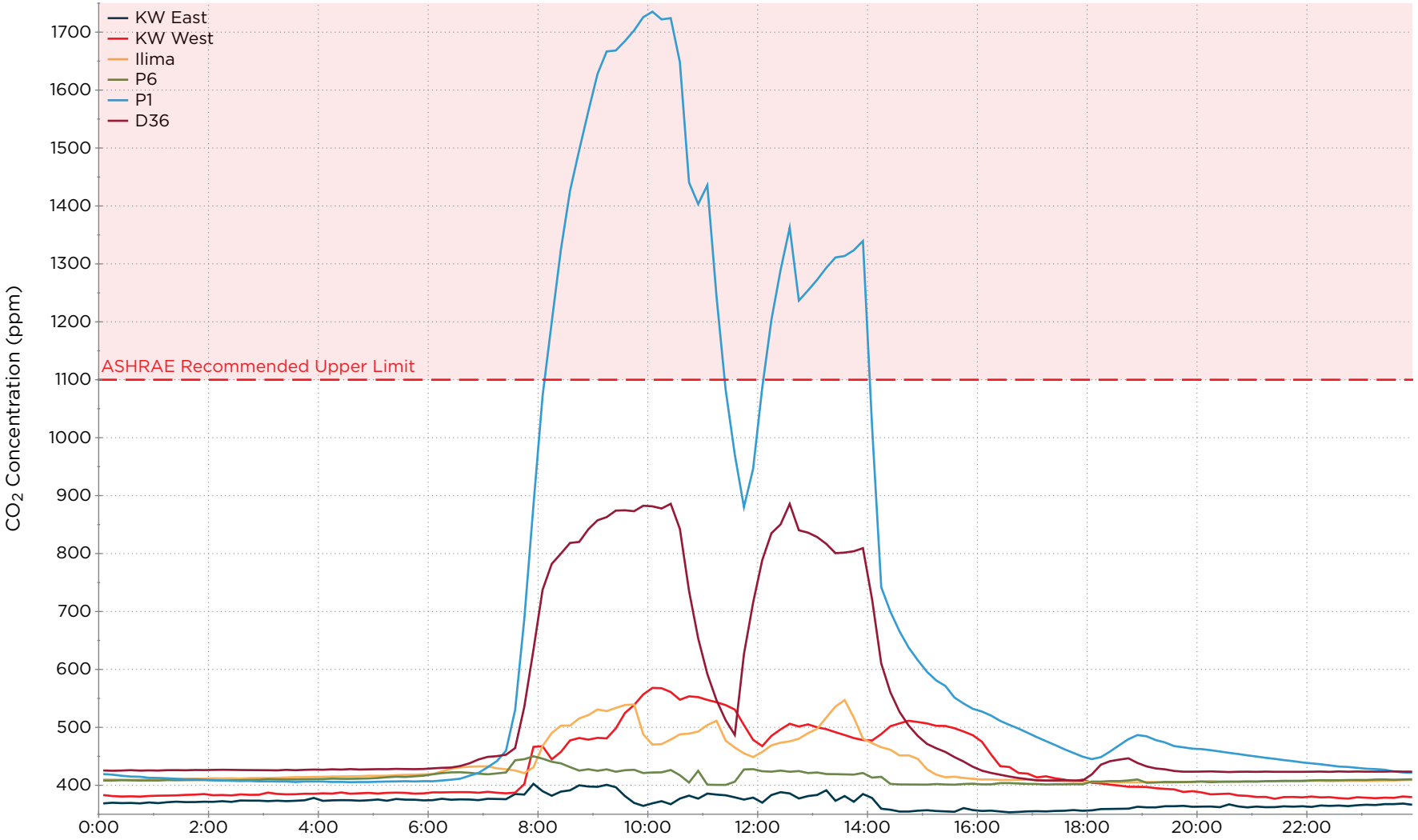


Hourly Average August Air Quality, CO_2, Concentrations

Description: Daily profiles of CO_2 concentration for school days in August. August was chosen due to the fact that it was a hot month when AC was used in the classrooms.

Findings: P1 had average CO_2 levels above the ASHRAE CO_2 threshold in August for the majority of the school hours (between 8:07 am - 11:24 am and 12:06 pm - 2:02 pm).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

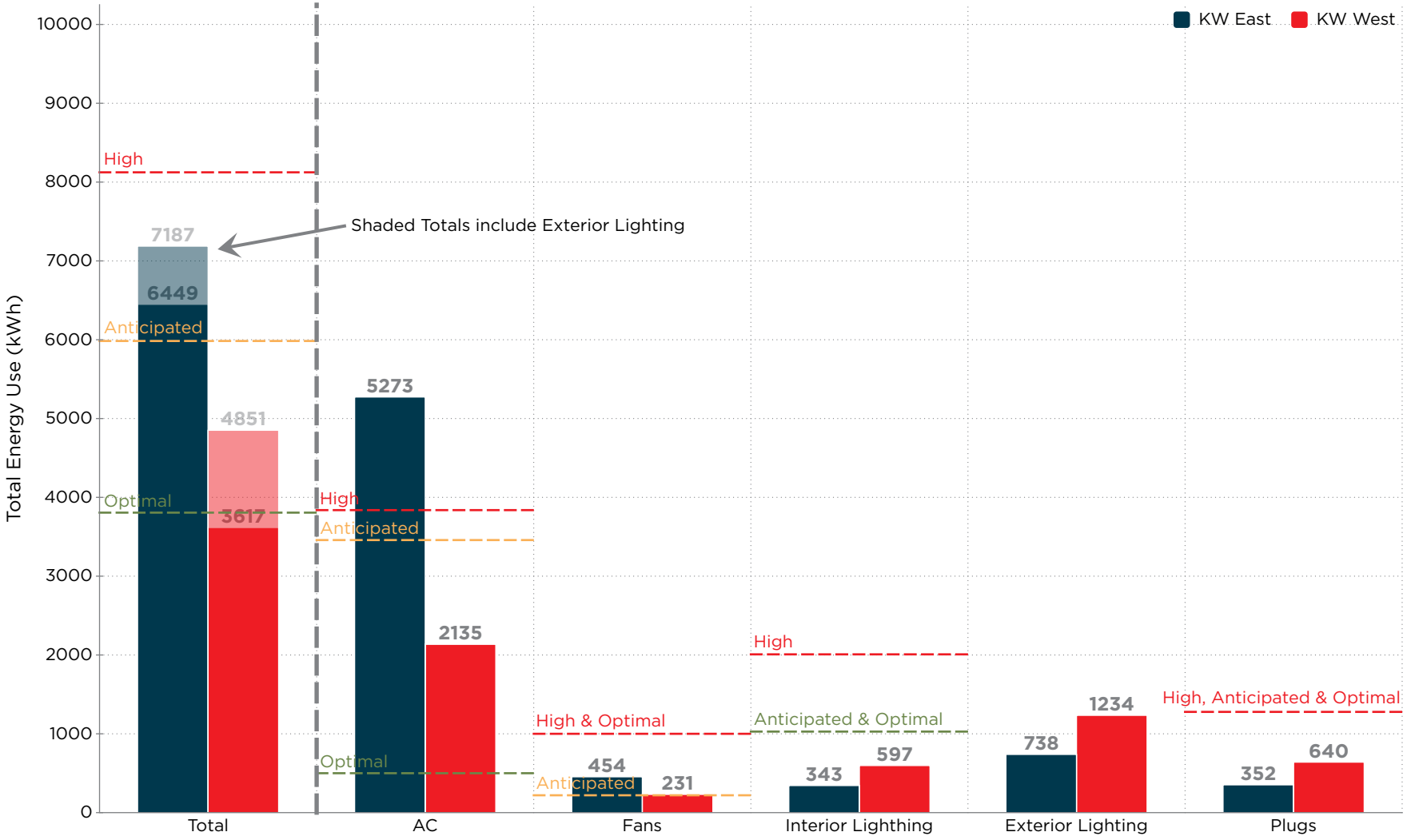


Annual Total Energy Use Actual vs. Modeled: Kawaikini East and West

Description: Kawaikini energy models from the Phase II ONR Report are compared to measured values across energy end uses. Exterior lighting was included in the energy modeling but estimated as "0." Model scenarios are optimal (low), anticipated (medium) and high. More information on model scenarios can be found in the Methodology section.

Findings: Overall, KW East consumed 20% more than "Anticipated" while KW West consumed 19% less than "Anticipated." KW East used 37% more AC energy than the "High" modeling scenario.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

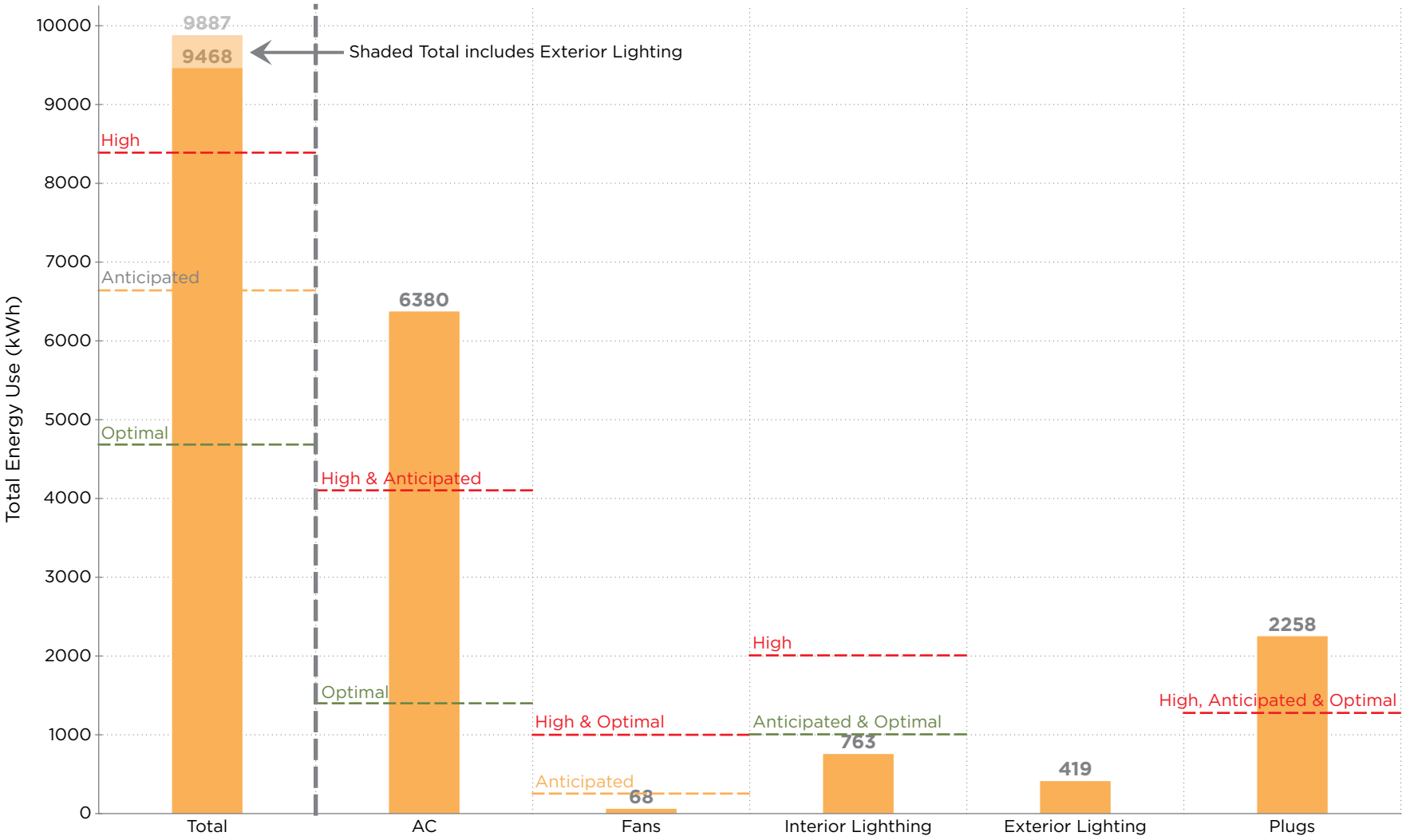


Annual Total Energy Use Actual vs. Modeled: Ilima

Description: Ilima energy models from the Phase II ONR Report are compared to measured values across energy end uses. Exterior lighting was included in the energy modelling but estimated as "0." Model scenarios are optimal (low), anticipated (medium) and high. More information on model scenarios can be found in the Methodology section.

Findings: Overall, Ilima consumed 18% more energy than the "High" modeling scenario. On the system level, both AC and plugs overshot their "High" model predictions by 55% and 77%, respectively.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

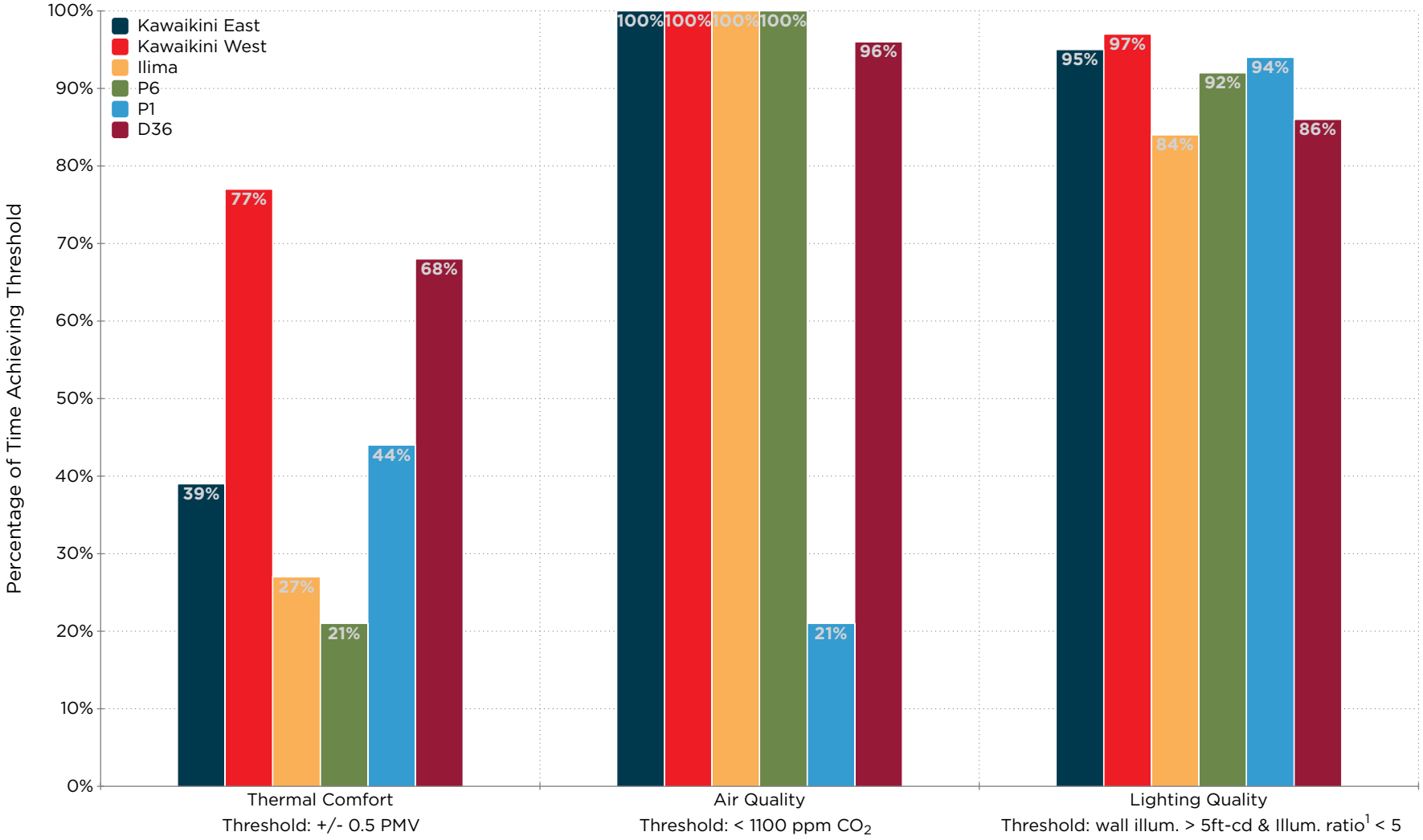


Annual Indoor Environmental Quality Comparison to Standards

Description: All six classrooms were compared with the percentage of time interior environment and lighting thresholds were met.

Findings: On average, the Test Platforms (KW East, KW West. Ilima, & P6) had 15% less time within the thermal comfort zone, had 41% more time with acceptable air quality and 2% more time with acceptable lighting conditions compared to Traditional classroom (P1 &. D36)

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours



1: Illuminance ratio is wall ft-cd/ surface ft-cd

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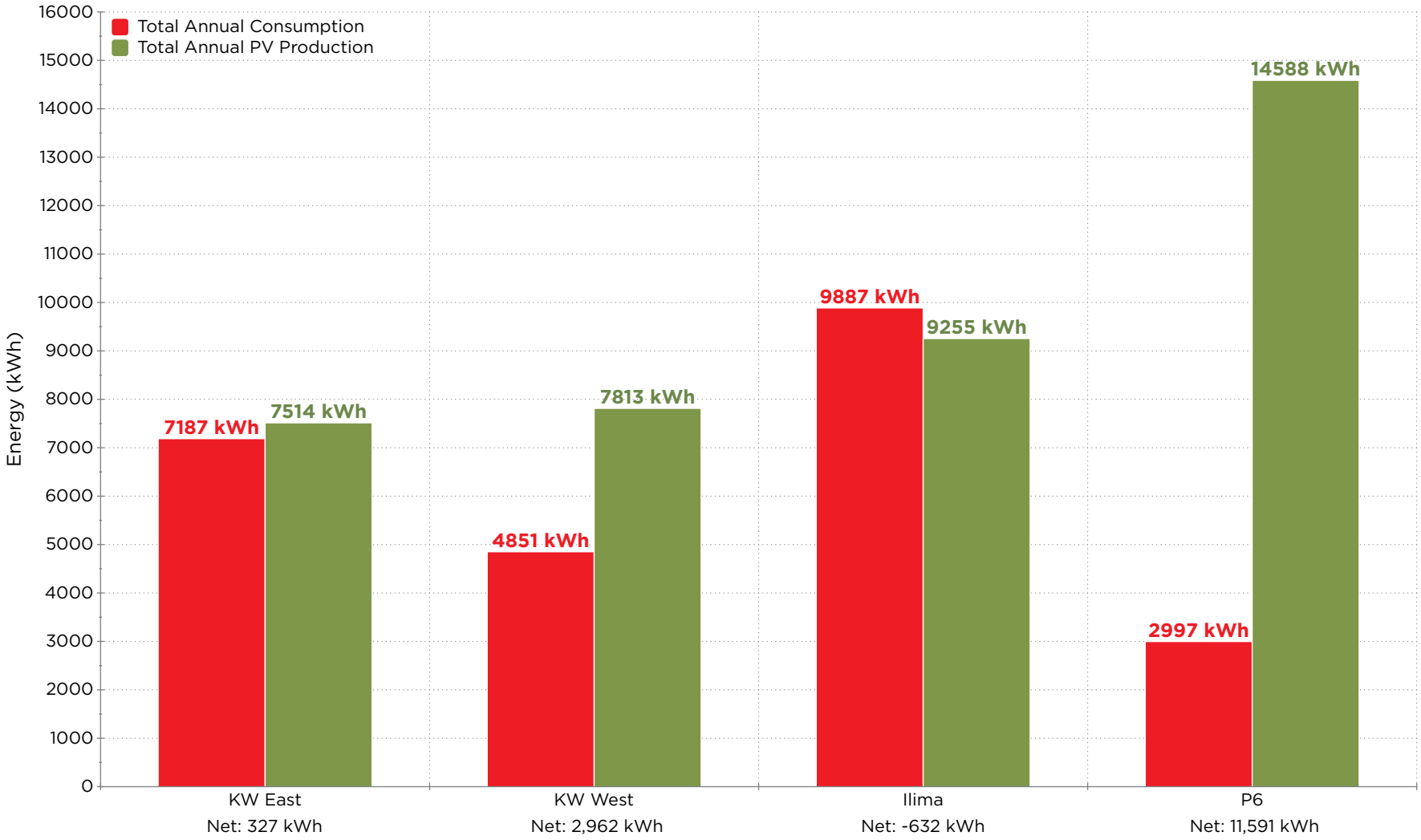
Annual Net Zero Energy Comparison

Description: These charts show the annual electricity consumption, PV electricity production and the net difference across the four classrooms with PV systems.

Findings: While Ilima and KW East & West have the same PV system size, Ilima's system produced more electricity. Ilima was the only classroom to not achieve energy neutrality on an annual basis, due to its high energy consumption. Ewa P6's PV generated the most electricity and consumed the least. Ewa's PV system capacity (12.32kW) is 2.3x bigger than the other 3 systems (5.24 kW).

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



Annual PV Model Prediction Versus Actual PV Production

Description: The modeled PV results are based on the anticipated PV performance modeled scenario[1].

Kawaikini East and West

	Task 1 Report & Phase 2 ONR PV Model Prediction	KW East PV Actual Production	KW West PV Actual Production
System Size (kW)	9.8 (total)	5.24	5.24
Module Make/Model	First Solar FS-265 Panels & SunPower 230 Panels	Solar Frontier SF-165-S & Mitsubishi PV-MLE260HD	Panasonic/Sanyo VBHN220A A01 & Mitsubishi PV-MLE260HD
PV Panel Type(s)	Thin Film & Monocrystalline	Thin Film & Monocrystalline	Hetero-junction & Traditional Monocyrstalline
Annual Electricity Generated (kWh/yr)	11,968	7,514	7,813

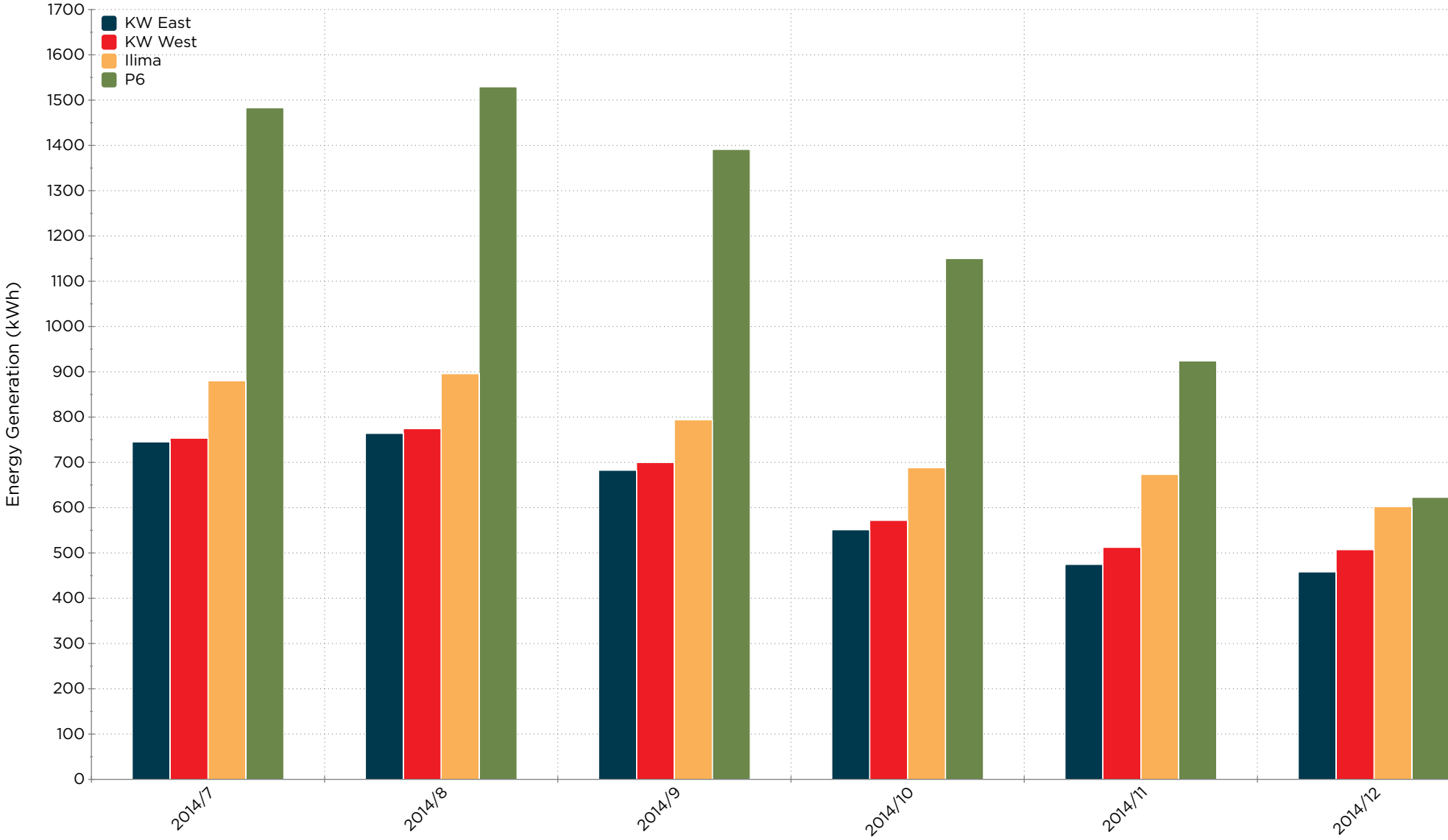
Ilima

	Phase 2 ONR Report PV Model Prediction	Ilima PV Actual Production
System Size (kW)	5.0	5.24
Module Make/Model	First Solar FS-265 Panels & SunPower 230 Panels	Solar Frontier SF-165-S & Mitsubishi PV-MLE260HD
PV Panel Type(s)	Thin Film & Monocrystalline	Thin Film & Monocrystalline
Annual Electricity Generated (kWh/yr)	6,641	9,255

1: Based on the ONR Phase 2 Report

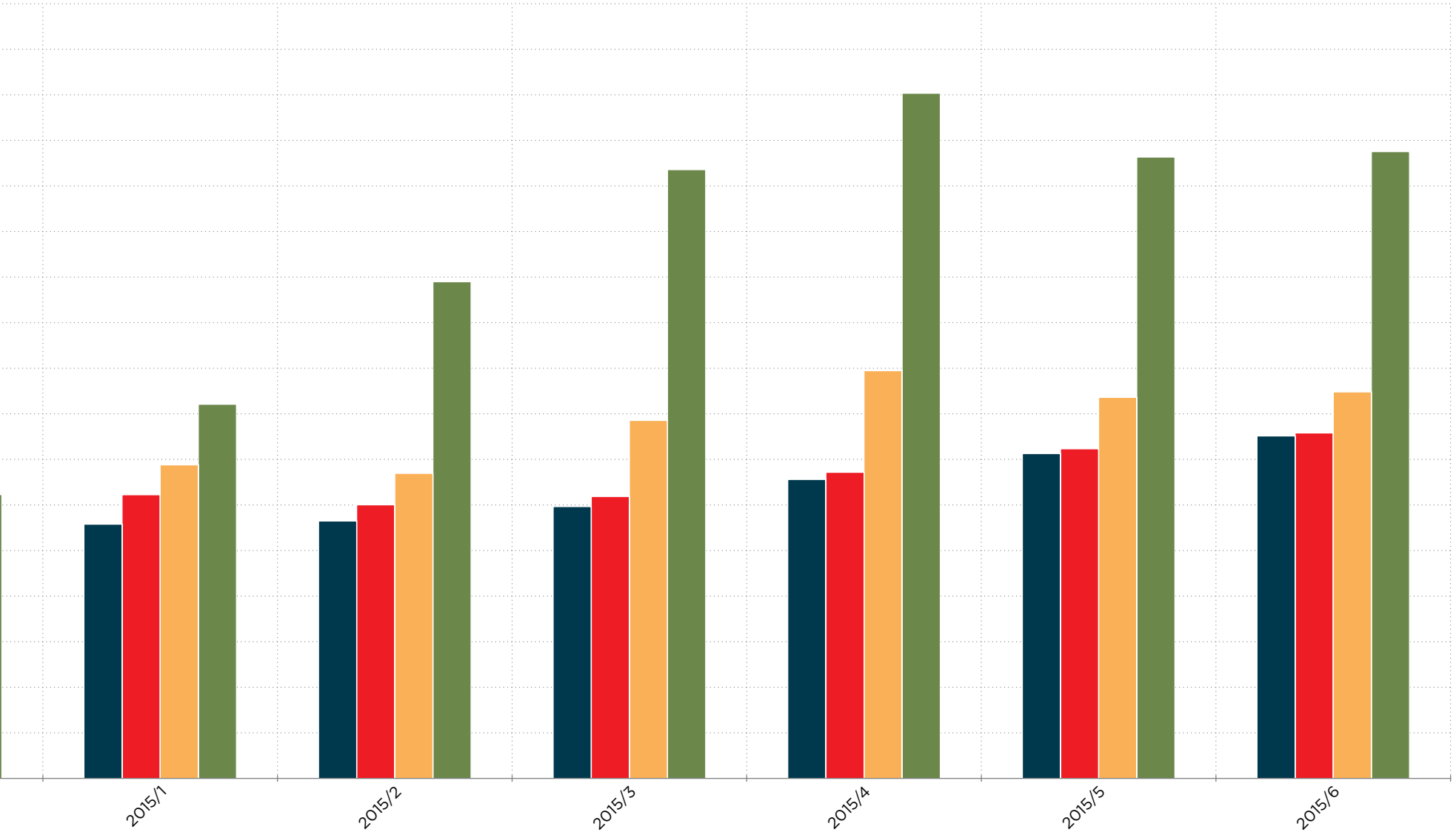
Monthly PV Total Energy Generation

Description: Monthly totals of energy generated by PV systems, for each of the four classrooms with PV systems.



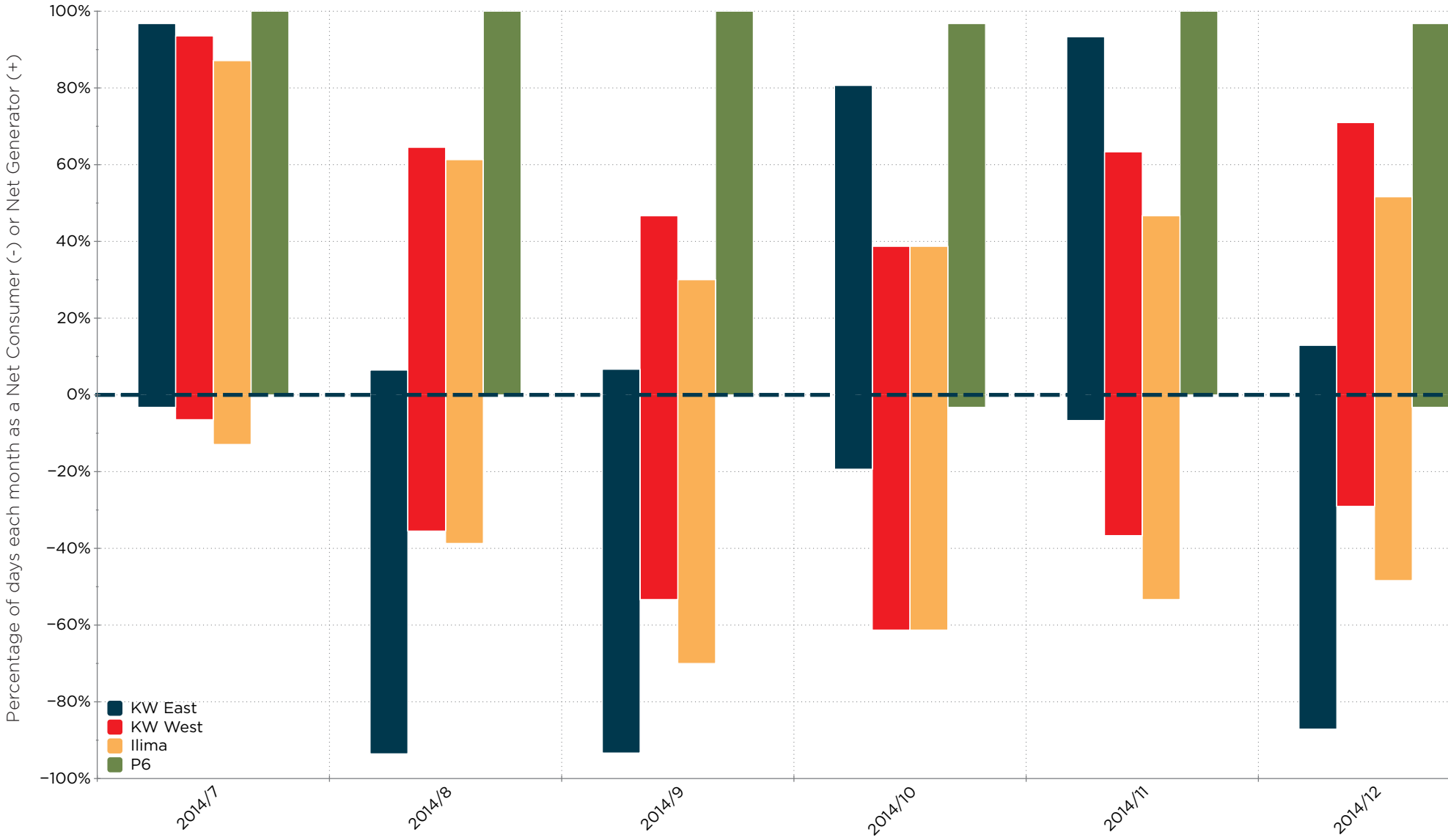
Findings: For the Kawaikini and Ilima PV systems, the total electricity production decreased by 40% in December from peak production in August. P6 saw a 60% decline in production from August to December.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



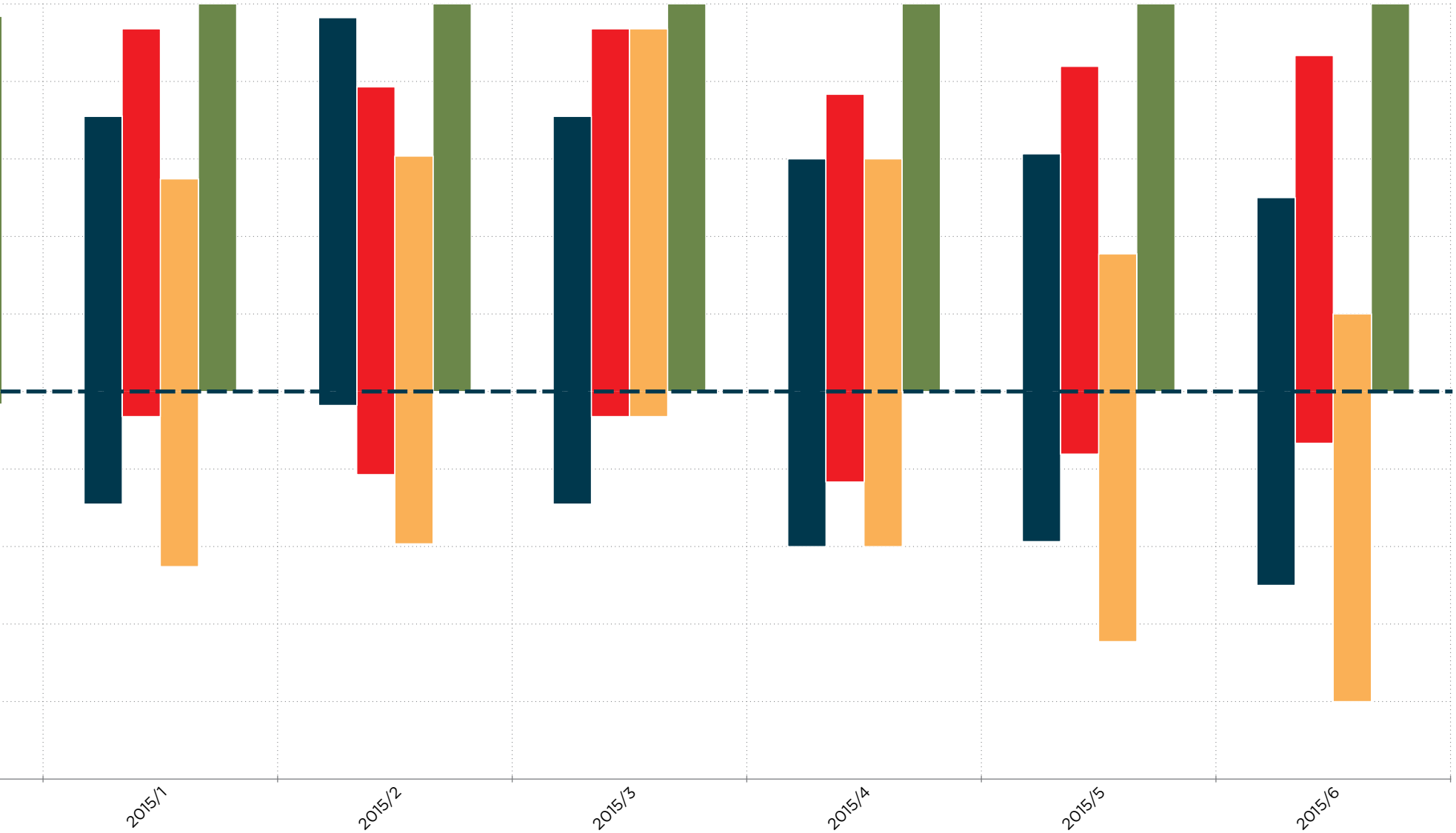
Monthly Net Zero Energy Comparison by Percent

Description: The percentage of days each month with net energy generation (positive) and net energy consumption (negative)for each of the four classrooms with PV systems.



Findings: In February, KW East had 96% of days that were a Net Generator (i.e. generated more electricity than consumed). but in August 93% were Net Consumer (i.e. consuming more electricity from the electrical grid than generated by on-site renewables). Therefore, KW East had the largest swing between Net Positive and Net Negative days among the classrooms.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

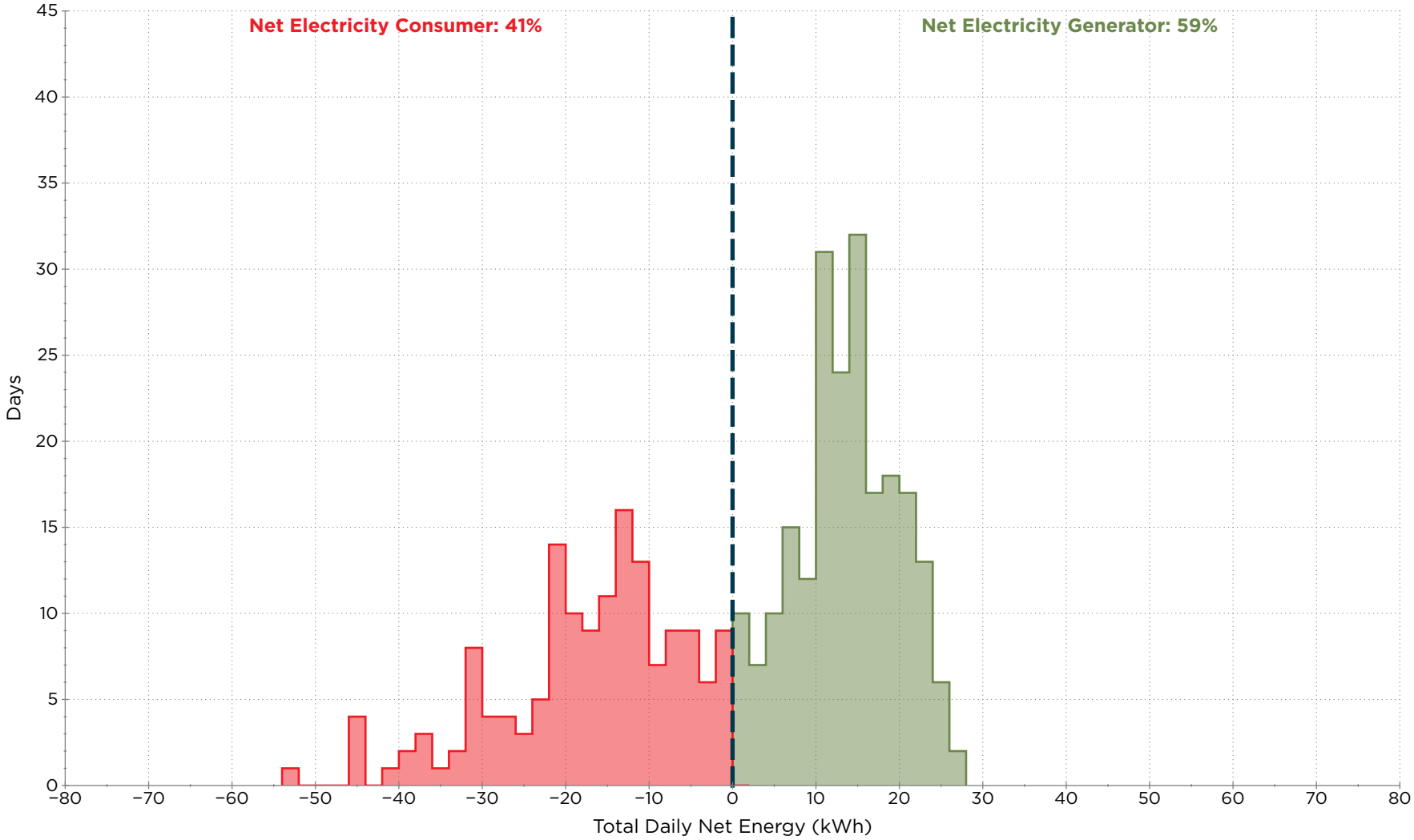


Daily Net Zero Energy Comparison: Kawaikini East

Description: The chart shows the number of days across the year between total daily net energy intervals at KW East. Total daily net energy is calculated by total electricity generated in a day minus total electricity consumed in a day. Net generator days produced more electricity than consumed. Net consumer days used grid electricity in addition to on-site generation to meet demand.

Findings: KW East had 59% of days through the year where more electricity was produced than consumed by the classroom.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



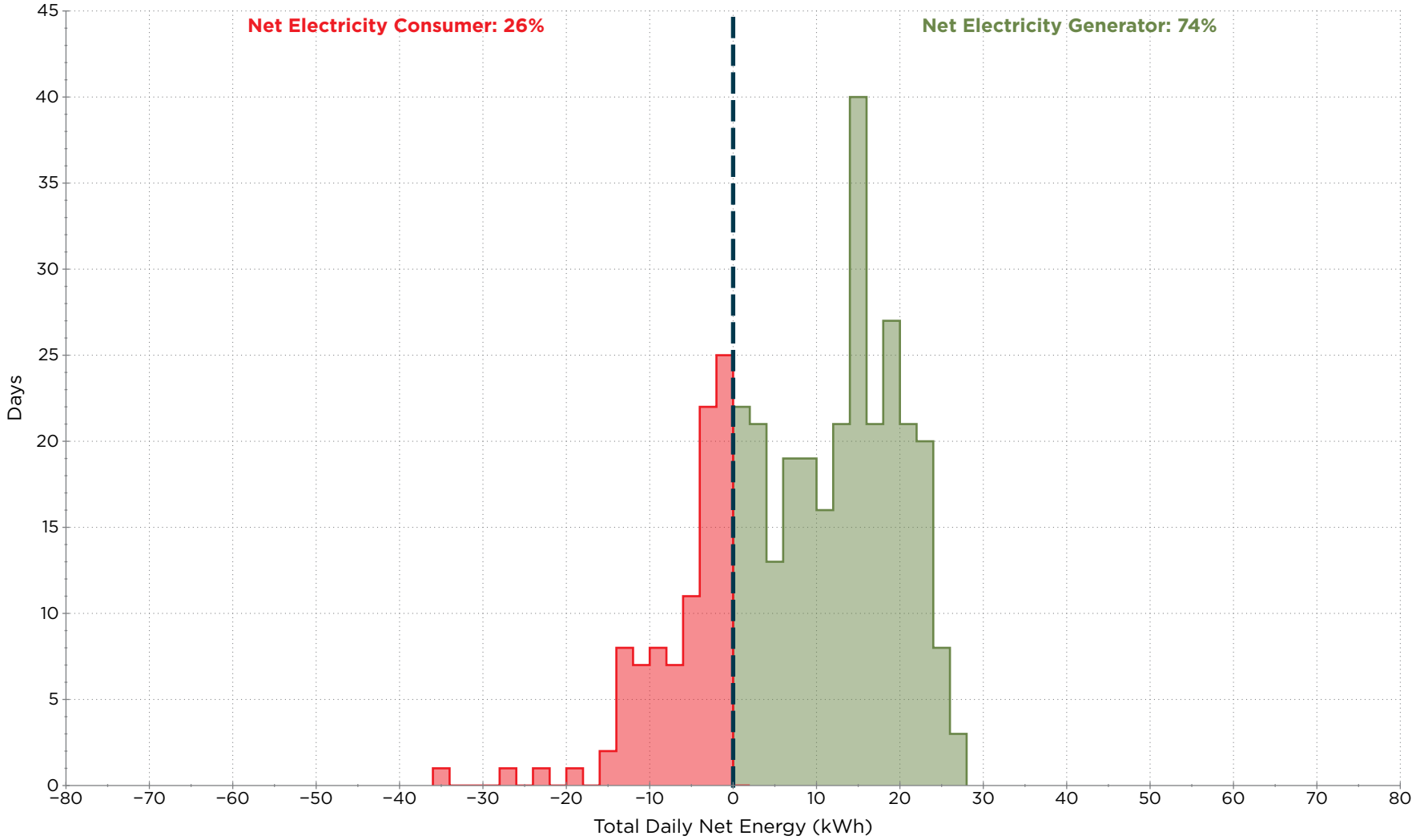
SUBAWARD NO: MA130005

Daily Net Zero Energy Comparison: Kawaikini West

Description: The chart shows the number of days across the year between total daily net energy intervals at KW West. Total daily net energy is calculated by total electricity generated in a day minus total electricity consumed in a day. Net generator days produced more electricity than consumed. Net consumer days used grid electricity in addition to on-site generation to meet demand.

Findings: KW West had 74% of days through the year where more electricity was produced than consumed by the classroom.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

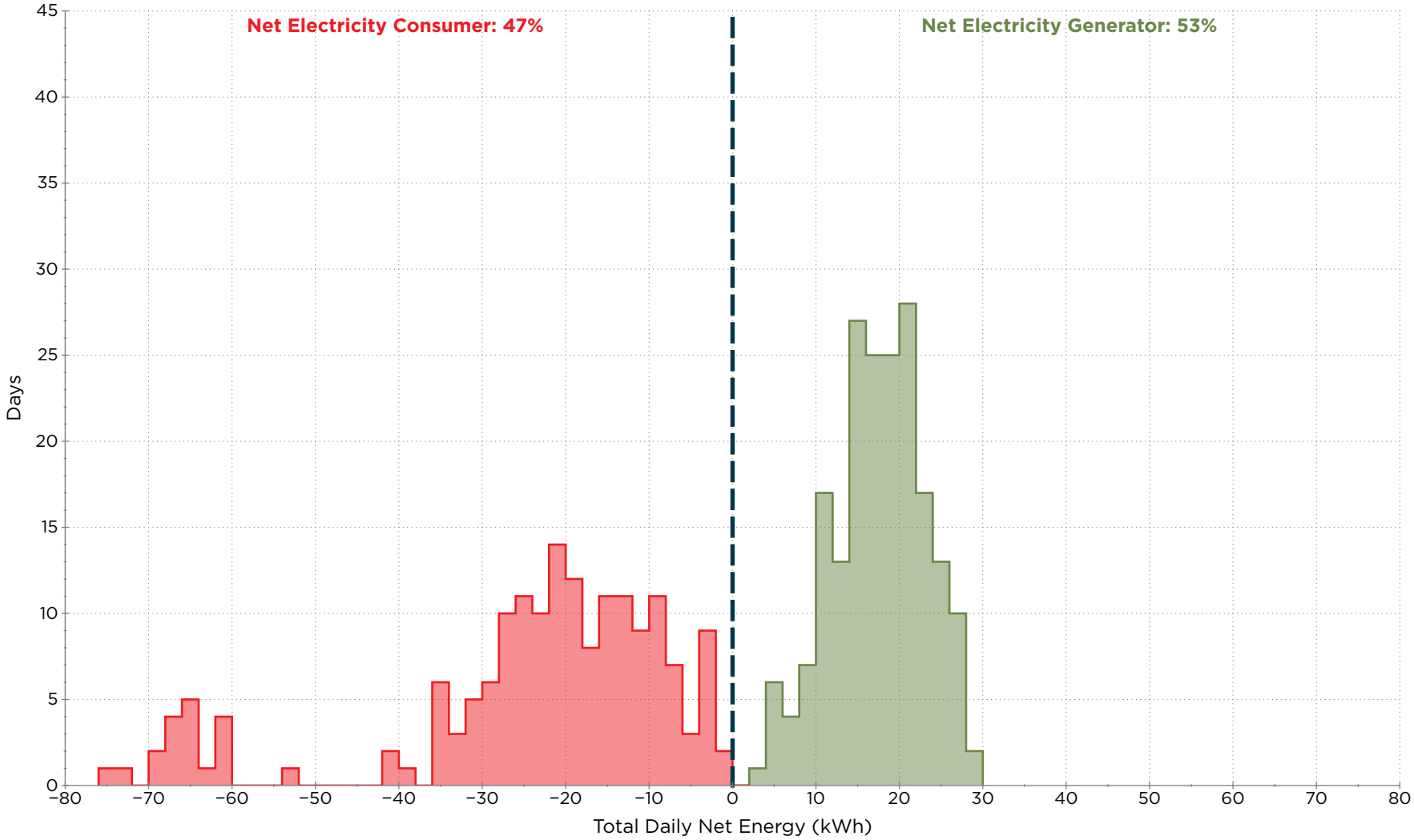


Daily Net Zero Energy Comparison: Ilima

Description: The chart shows the number of days across the year between total daily net energy intervals at Ilima. Total daily net energy is calculated by total electricity generated in a day minus total electricity consumed in a day. Net generator days produced more electricity than consumed. Net consumer days used grid electricity in addition to onsite generation to meet demand.

Findings: Ilima had 53% of days through the year where more electricity was produced than consumed by the classroom.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



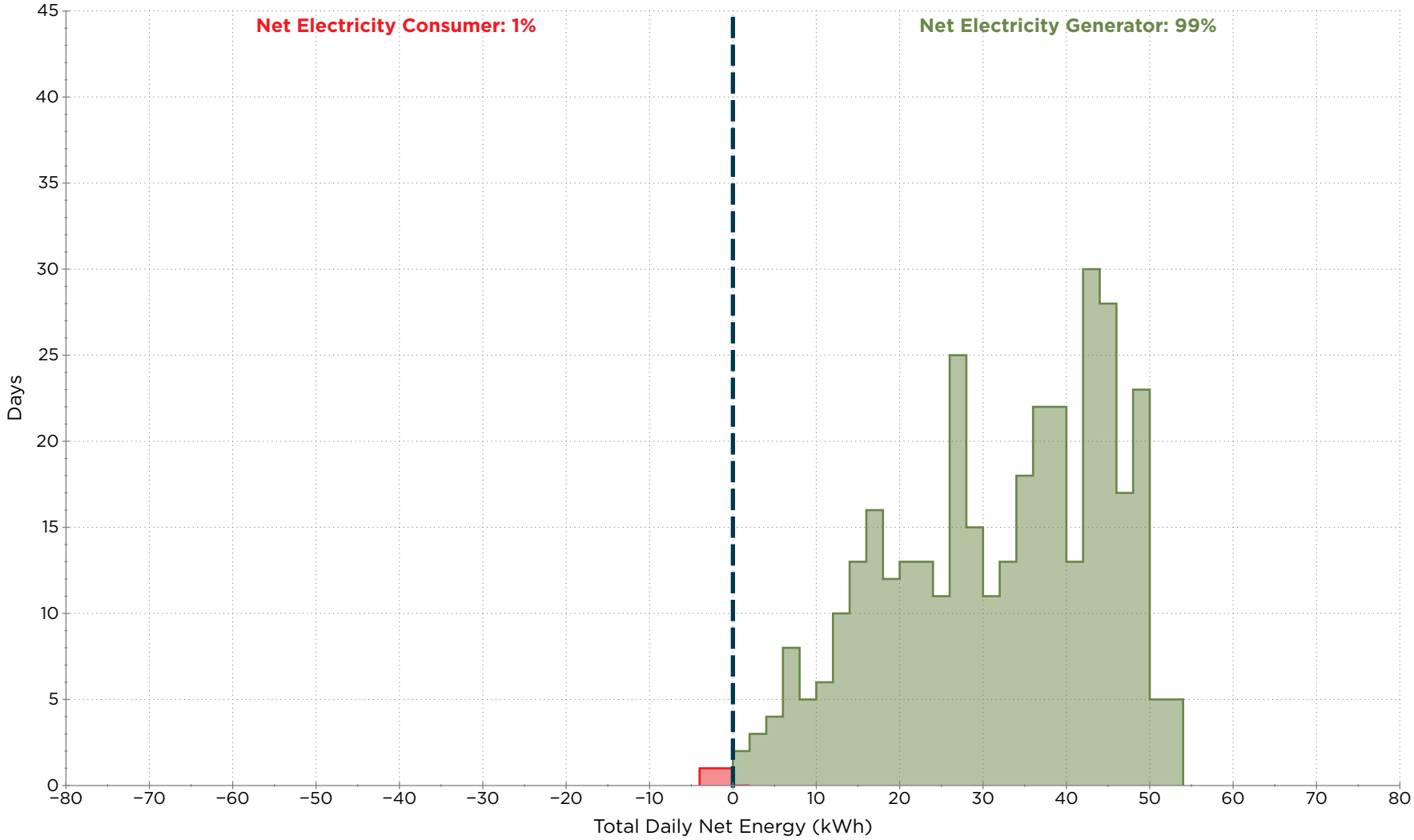
SUBAWARD NO: MA130005

Daily Net Zero Energy Comparison: Ewa P6

Description: The chart shows the number of days across the year between total daily net energy intervals at P6. Total daily net energy is calculated by total electricity generated in a day minus total electricity consumed in a day. Net generator days produced more electricity than consumed. Net consumer days used grid electricity in addition to onsite generation to meet demand.

Findings: P6 had 99% of days through the year where more electricity was produced than consumed by the classroom.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

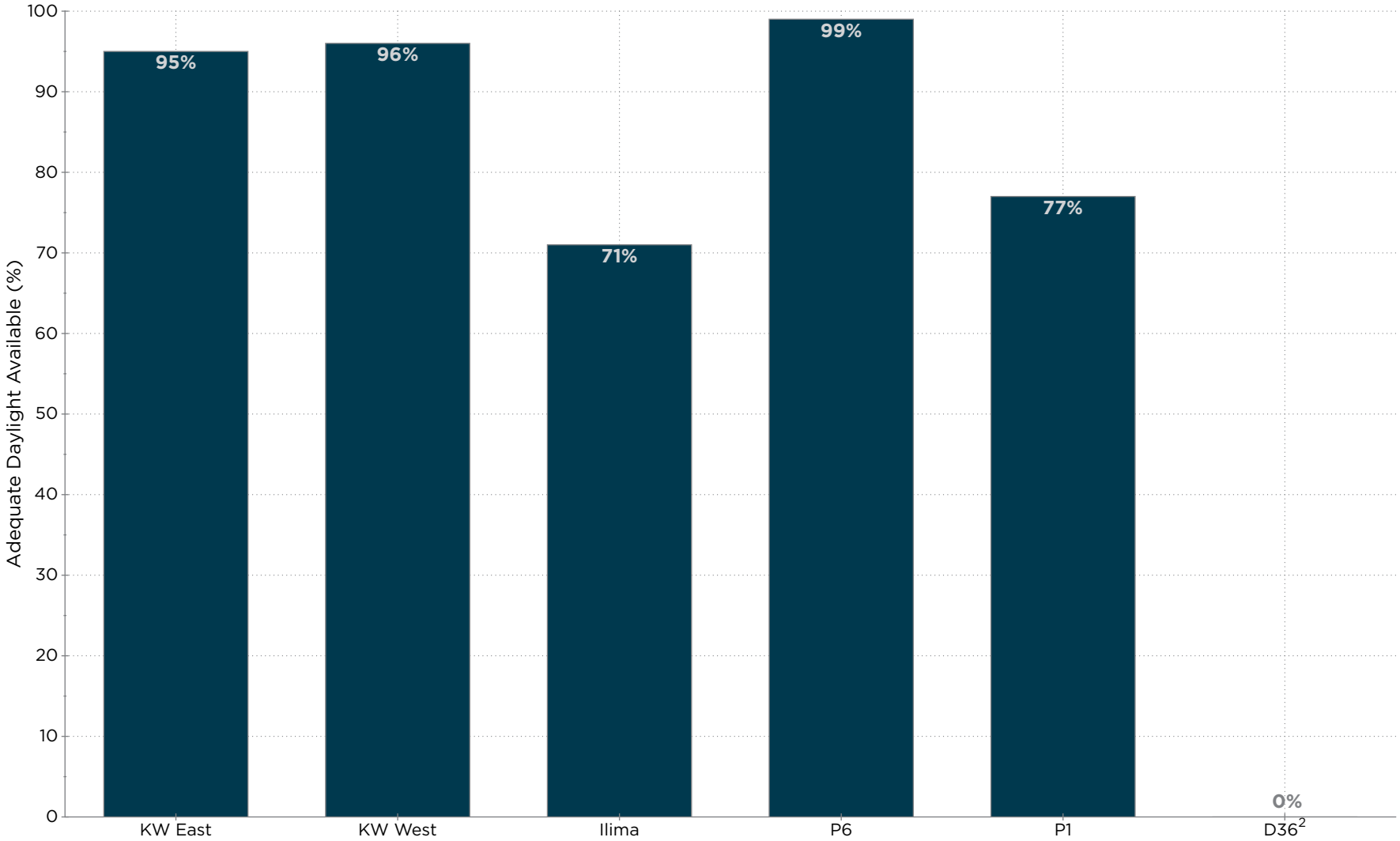


Annual Observed Daylight Availability in School Hours on Non-School Days

Description: The percentage of time daylight was adequate to meet interior lighting quality criteria[1].

Findings: On average, the KW East, KW West, and P6 Test Platforms had 58% more time daylight met lighting criteria compared to Traditional classrooms of P1 and D36[2]. While Ilima is the same physical structure and orientation as KW East & West, occupants put newspaper on the front windows at Ilima for security reasons. Therefore, the percentage of time daylight met lighting quality criteria at Ilima was 25% less than KW West.

Study Period: 07/01/2014 - 06/30/2015
Days: Non-School Days
Hours: School Hours



1: Lighting quality: the average wall illuminance > 5 ft-cd and the illuminance ratio (wall illuminance/ surface illuminance) <5
2: D36 did have windows but the shades were often closed as seen in Section 3.

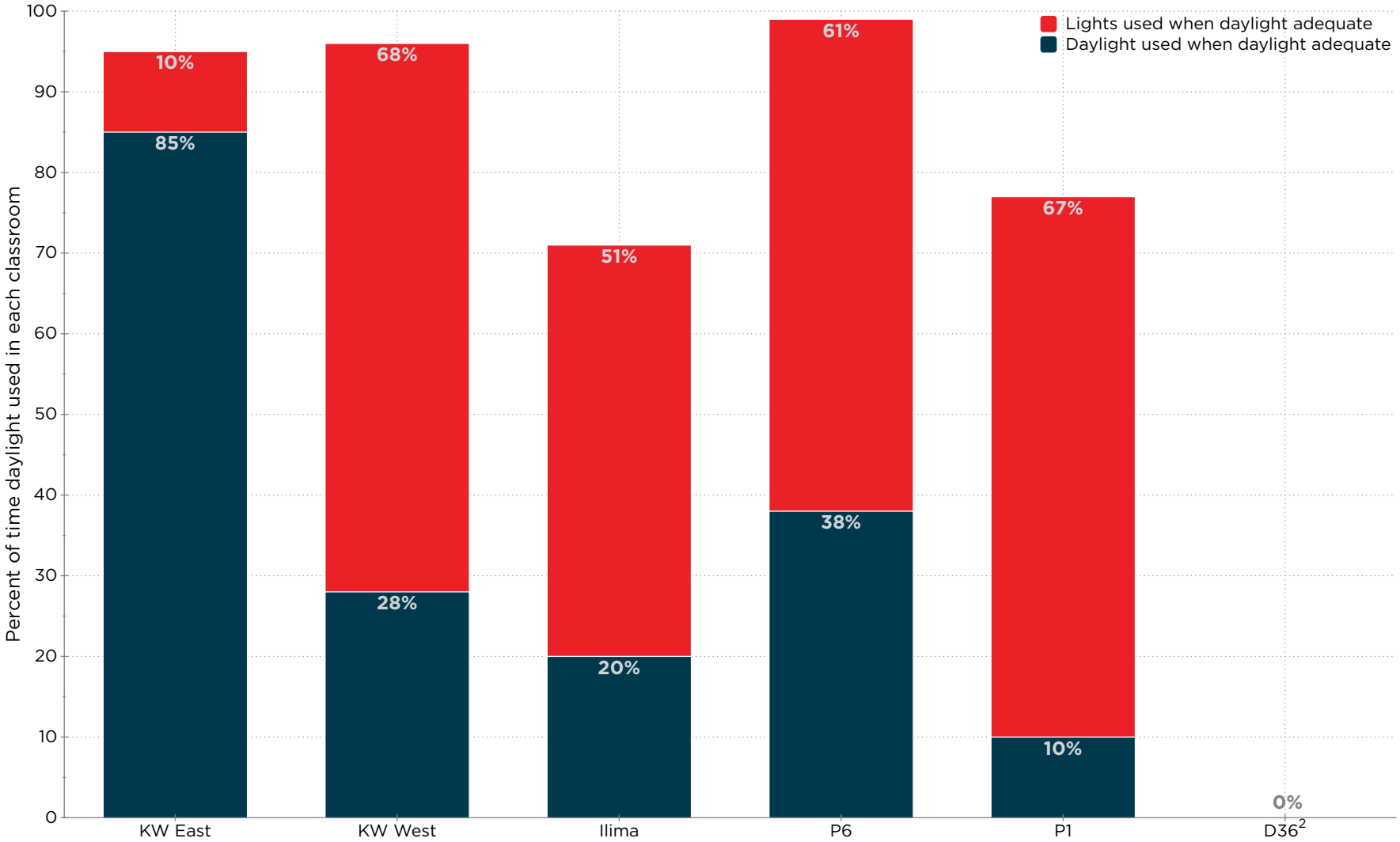
SUBAWARD NO: MA130005

Annual Daylight Use versus Daylight Opportunity

Description: The chart shows the percent of time the classroom used daylight or interior lights when natural daylight was adequate to meet lighting quality criteria[1].

Findings: Three out of four Test Platforms (i.e. KW East, KW West and P6) showed daylight capacity above 90% but only 1 used daylight above 50% uncovering a potential energy saving opportunity.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours



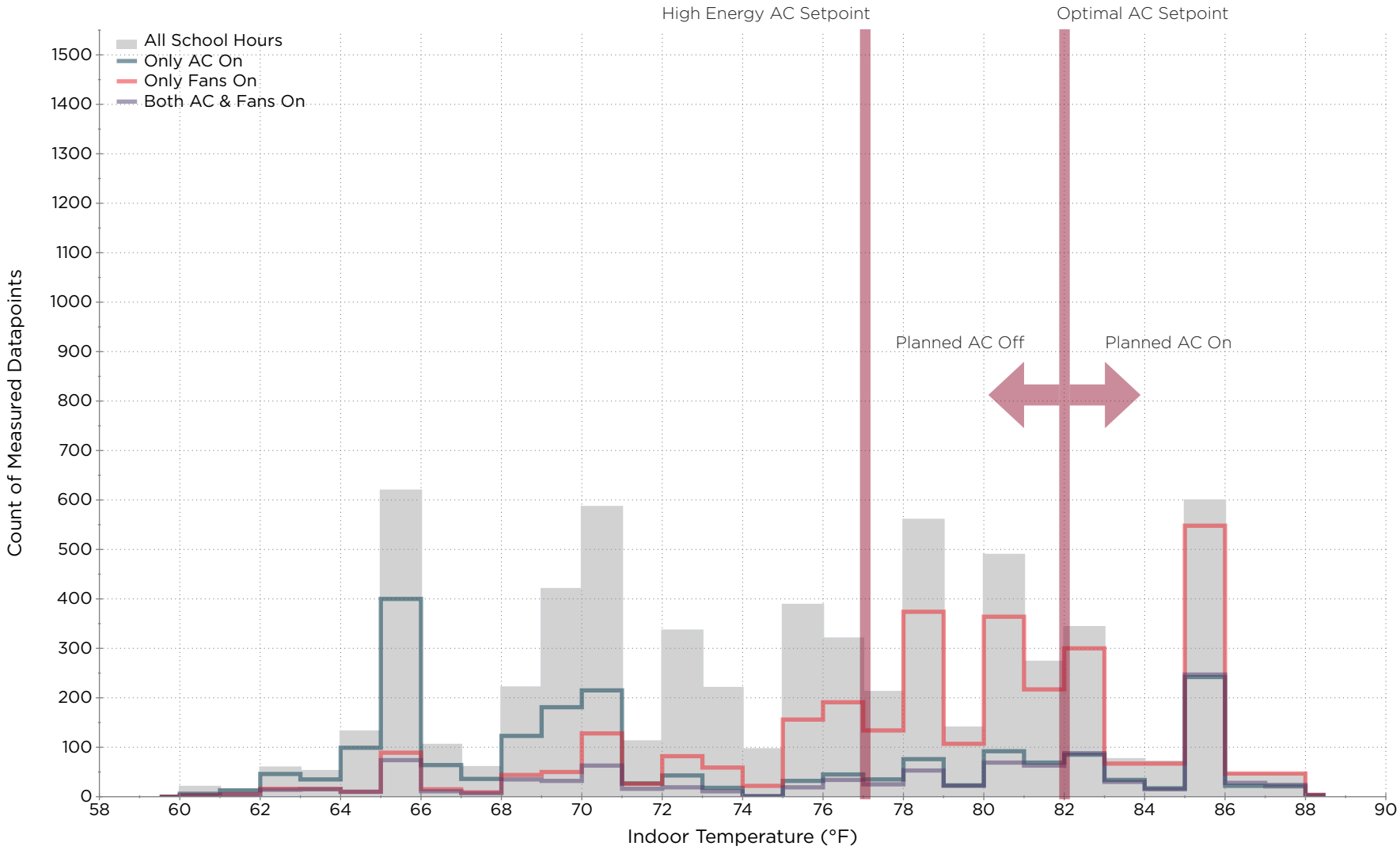
1: Adequate daylight is defined as when the average wall illuminance was greater than 5 ft-cd and the illuminance ratio (wall illuminance/ surface illuminance) was < 5
2: D36 did have windows but the shades were closed as seen in Section 3.

AC & Fan Usage vs. Indoor Temperature: Kawaikini East

Description: Chart depicts count of 15-min intervals where different Air Conditioning, Ceiling Fans, or both, were in use at different indoor temperatures. The gray area graph represents the total number of intervals available. The fan coil unit in the split system AC was malfunctioning between 10/17/13 - 2/27/15, which skewed the AC energy use intensities during that period.

Findings: 80% of AC use occurred below the optimal setpoint (82°F) and 60% below the "high-energy use" setpoint (77°F); AC was used more often than Fans below 77°F

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

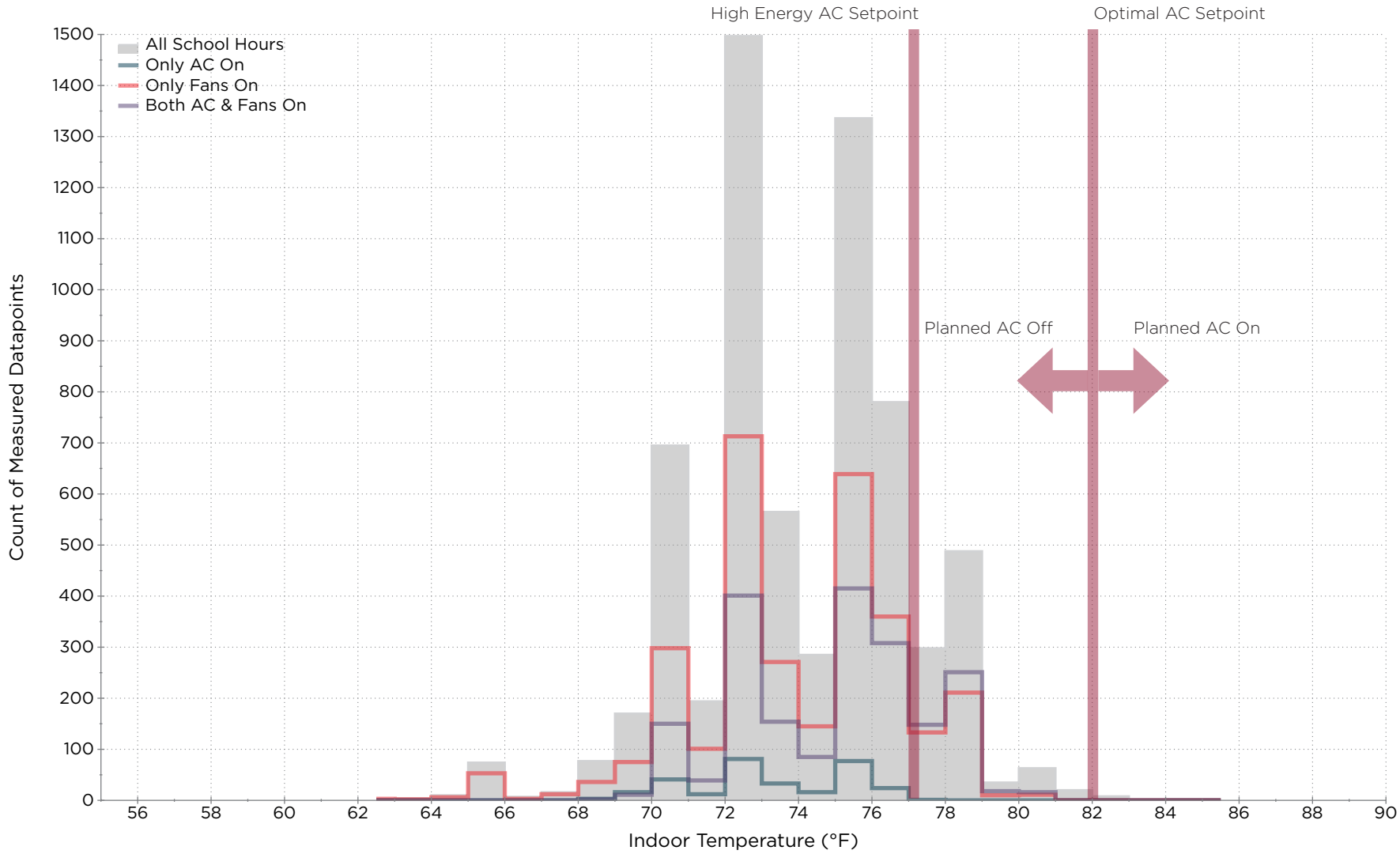


AC & Fan Usage vs. Indoor Temperature: Kawaikini West

Description: Chart depicts count of 15-min intervals where different Air Conditioning, Ceiling Fans, or both, were in use at different indoor temperatures. The gray area graph represents the total number of intervals available.

Findings: 100% of AC use occurred below the optimal setpoint and 80% below the "high-energy use" setpoint; Indoor temperatures in Kawaikini West only exceeded 82°F for 6 hours the whole year

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

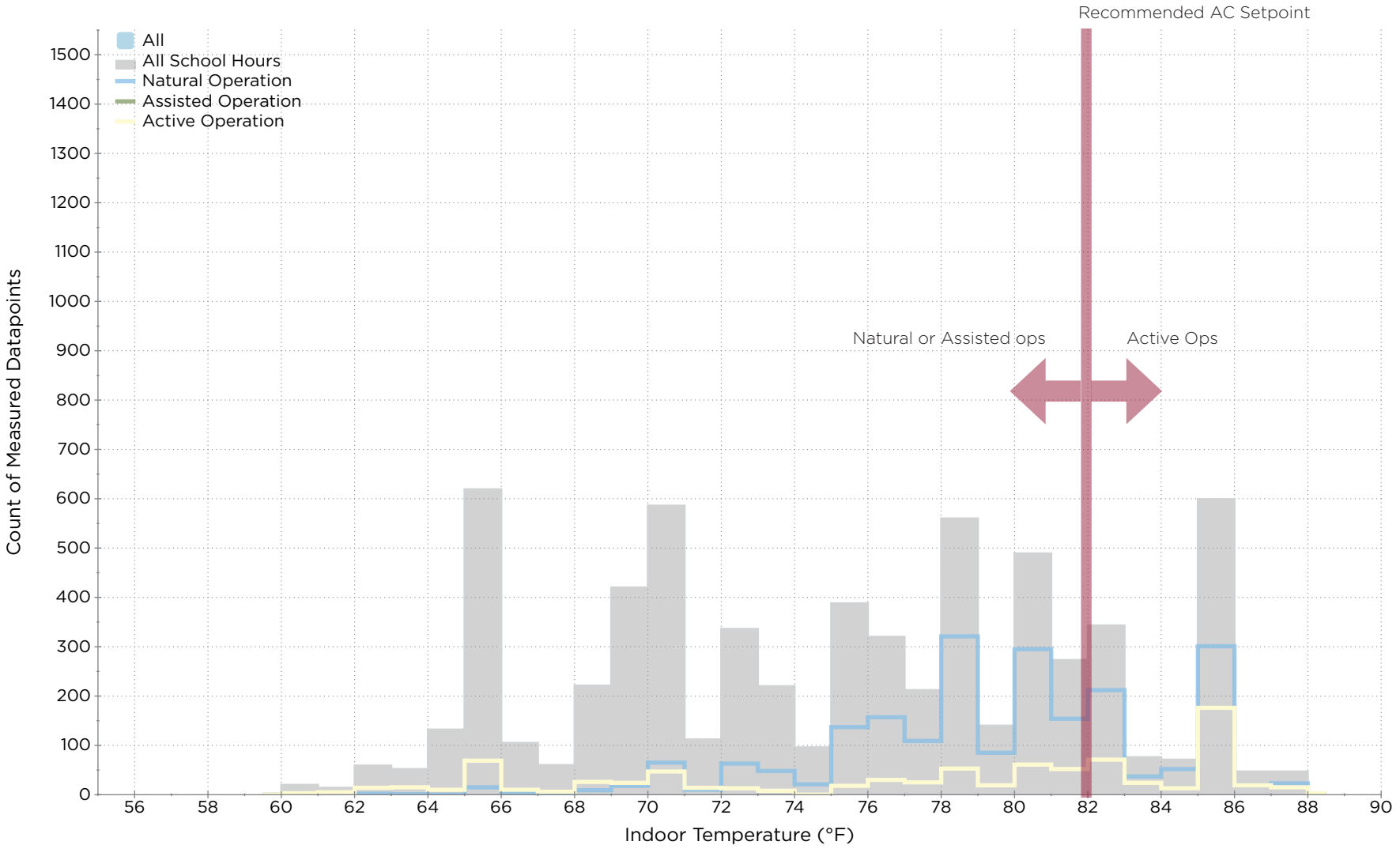


Mech. Operational Modes vs. Indoor Temperature: Kawaikini East

Description: Chart depicts count of 15-min intervals where different HVAC mechanical operational modes[1] were in use at different indoor temperatures. Natural Ops = Ceiling Fans Only. Assisted Ops = Ceiling fans + Exhaust Fans. Active Ops = Ceiling Fans + Air Conditioning. The fan coil unit in the split system AC was malfunctioning between 10/17/13 - 2/27/15, which skewed the AC energy use intensities during that period.

Findings: 60% of Active Operations occurred below the recommended Active Mode setpoint (< 82°F), and was only used 50% of the time during the hours when it was recommended (> 82°F)

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours



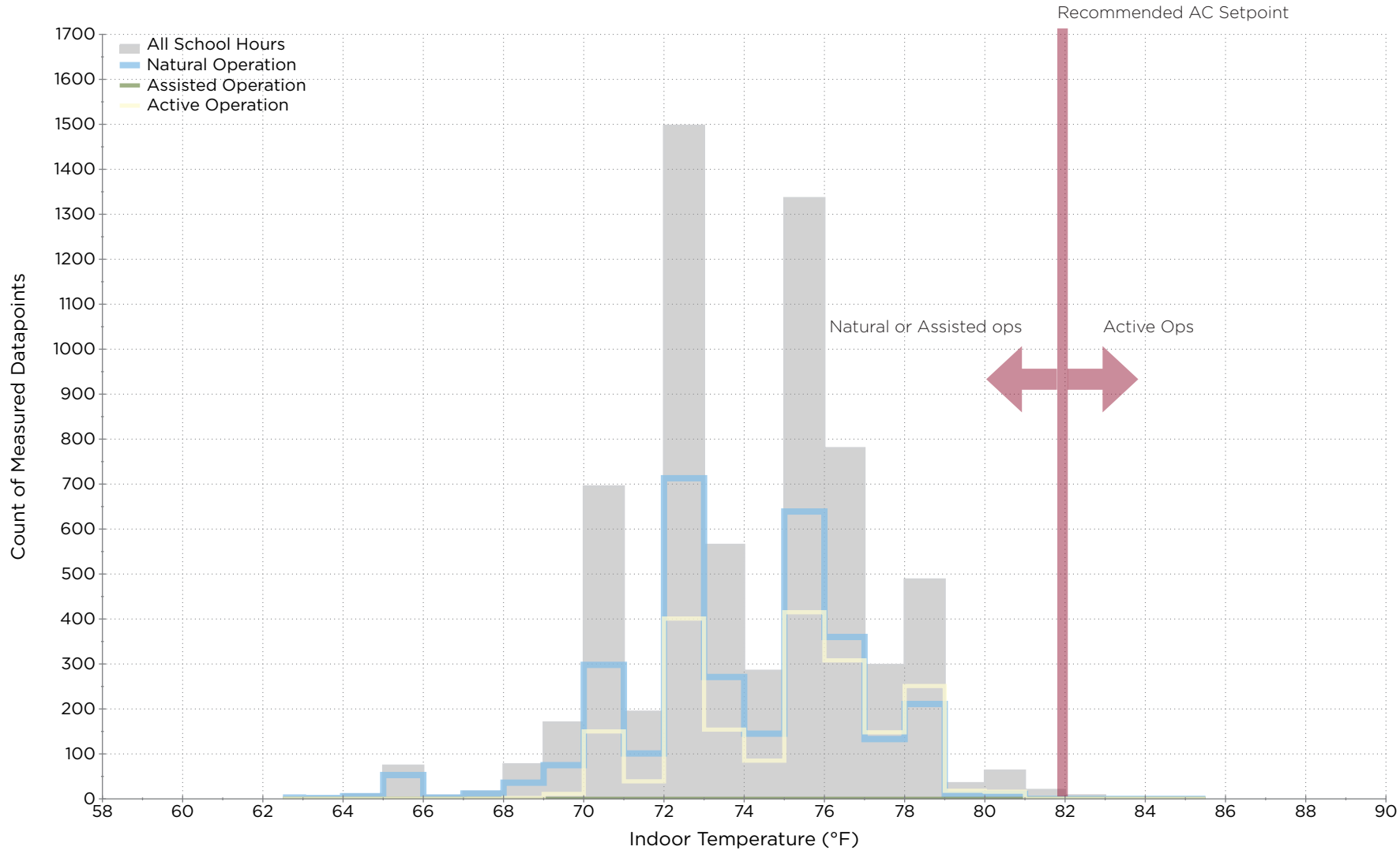
1: Reference: FROG Operations Guide 2012)

Mech. Operational Modes vs. Indoor Temperature: Kawaikini West

Description: Chart depicts count of 15-min intervals where different HVAC mechanical operational modes[1] were in use at different indoor temperatures. Natural Ops = Ceiling Fans Only. Assisted Ops = Ceiling fans + Exhaust Fans. Active Ops = Ceiling Fans + Air Conditioning.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

Findings: 100% of Active Operations occurred below the recommended Active Mode setpoint (< 82°F). and there were only 6 hours the whole year when Active Operations should have been used (> 82°F)



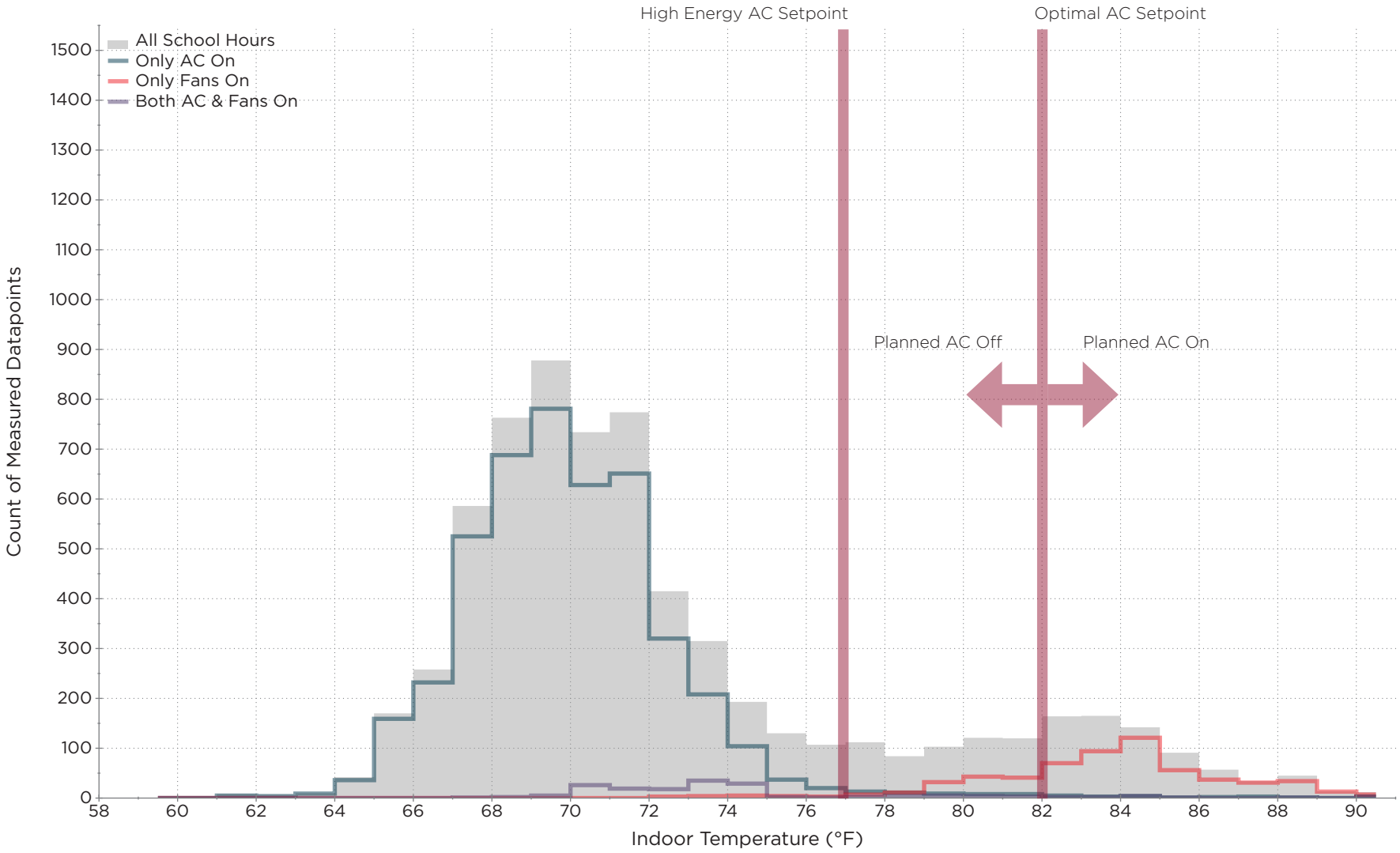
1: Reference: FROG Operations Guide 2012)

AC & Fan Usage vs. Indoor Temperature: Ilima

Description: Chart depicts count of 15-min intervals where different Air Conditioning, Ceiling Fans, or both, were in use at different indoor temperatures. The gray area graph represents the total number of intervals available.

Findings: 99% of AC use occurred below the optimal setpoint and 97% below the "High-energy use" setpoint

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

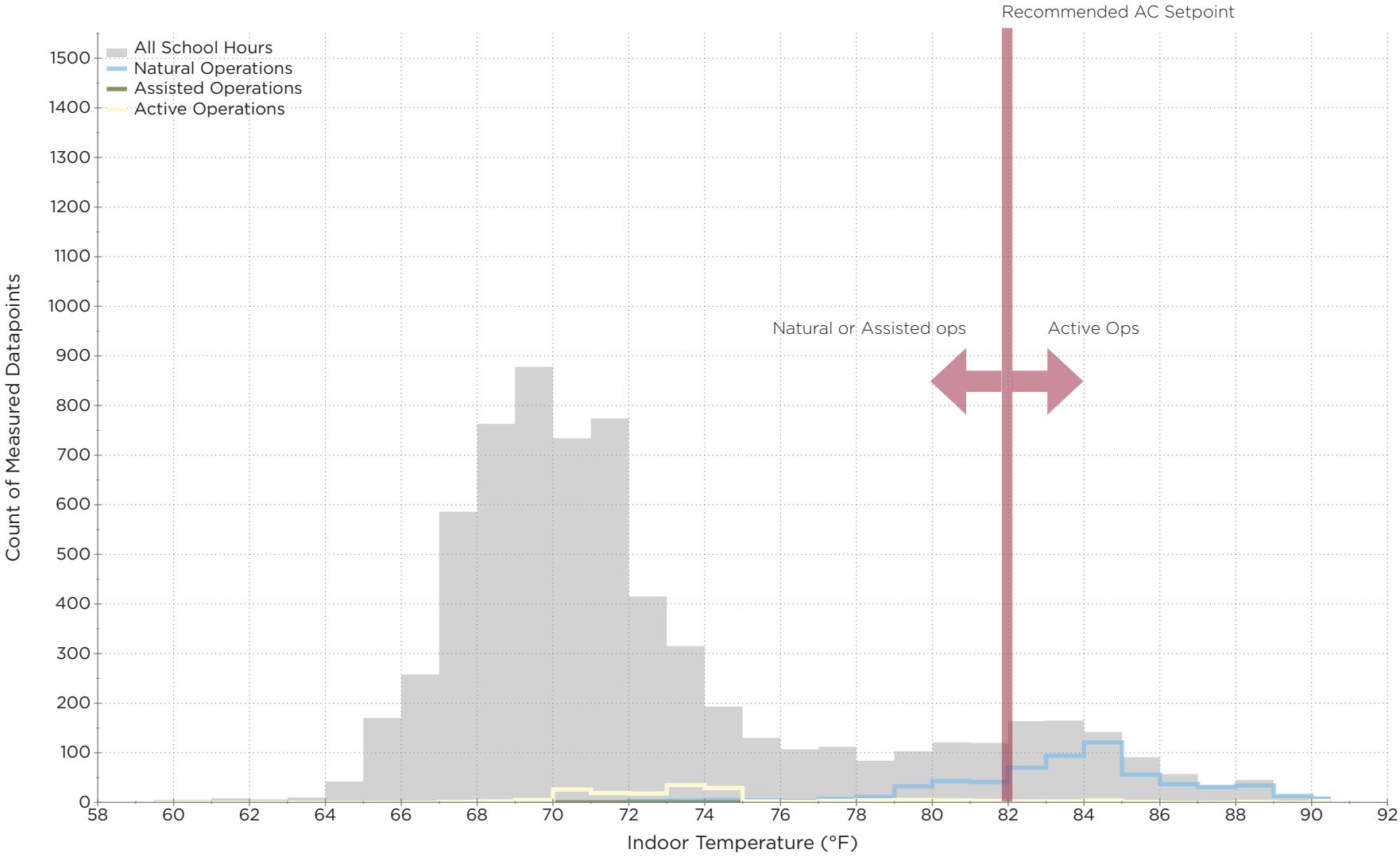


Mech. Operational Modes vs. Indoor Temperature: Ilima

Description: Chart depicts count of 15-min intervals where different HVAC mechanical operational modes[1] were in use at different indoor temperatures. Natural Ops = Ceiling Fans Only. Assisted Ops = Ceiling fans + Exhaust Fans. Active Ops = Ceiling Fans + Air Conditioning.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours

Findings: 85% of Active Operations occurred below the recommended Active Mode setpoint; Recommended operational modes were used less than 20% of the time



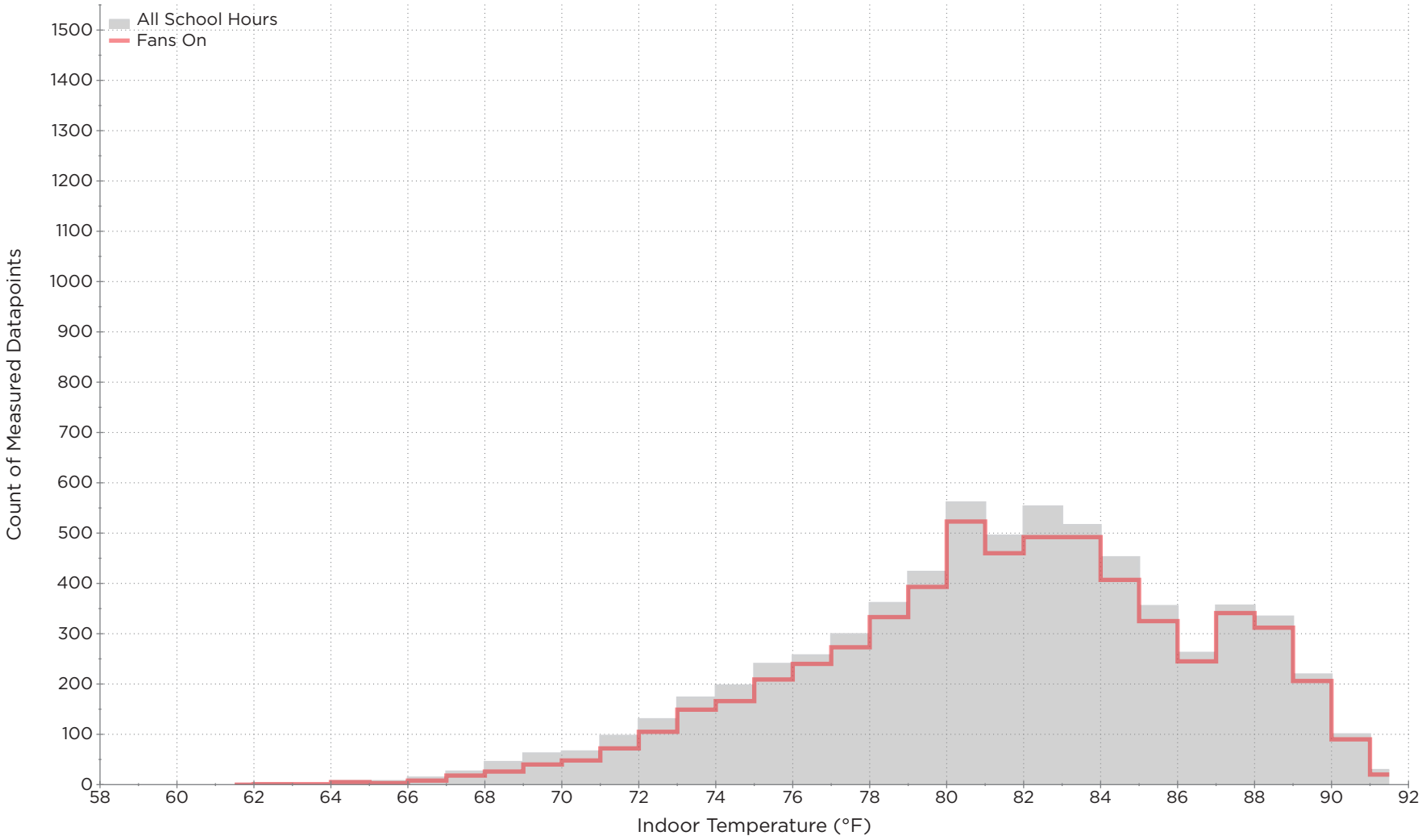
1: Reference: FROG Operations Guide 201

Fan Usage vs. Indoor Temperature: Ewa P6

Description: Chart depicts count of 15-min intervals where Ceiling Fans were on at different indoor air temperatures. The gray shading represents the total intervals available at each temperature.

Findings: Fans were used 95% of the total hours available across all indoor air temperatures

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

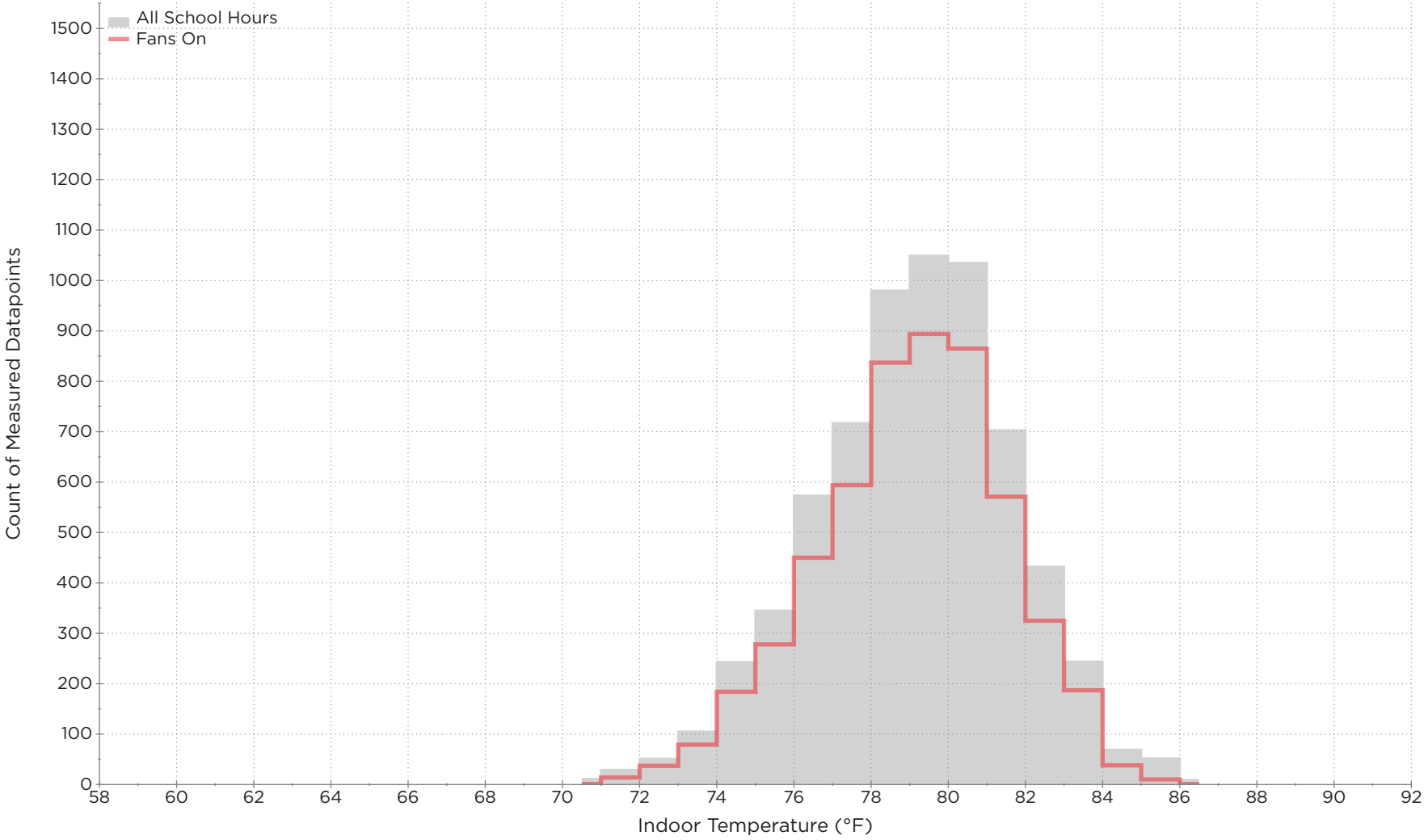


Fan Usage vs. Indoor Temperature: Ewa P1

Description: Chart depicts count of 15-min intervals where Ceiling Fans were on at different indoor air temperatures. The gray shading represents the total intervals available at each temperature.

Findings: Fans were used 90% of the total hours available across all indoor air temperatures

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

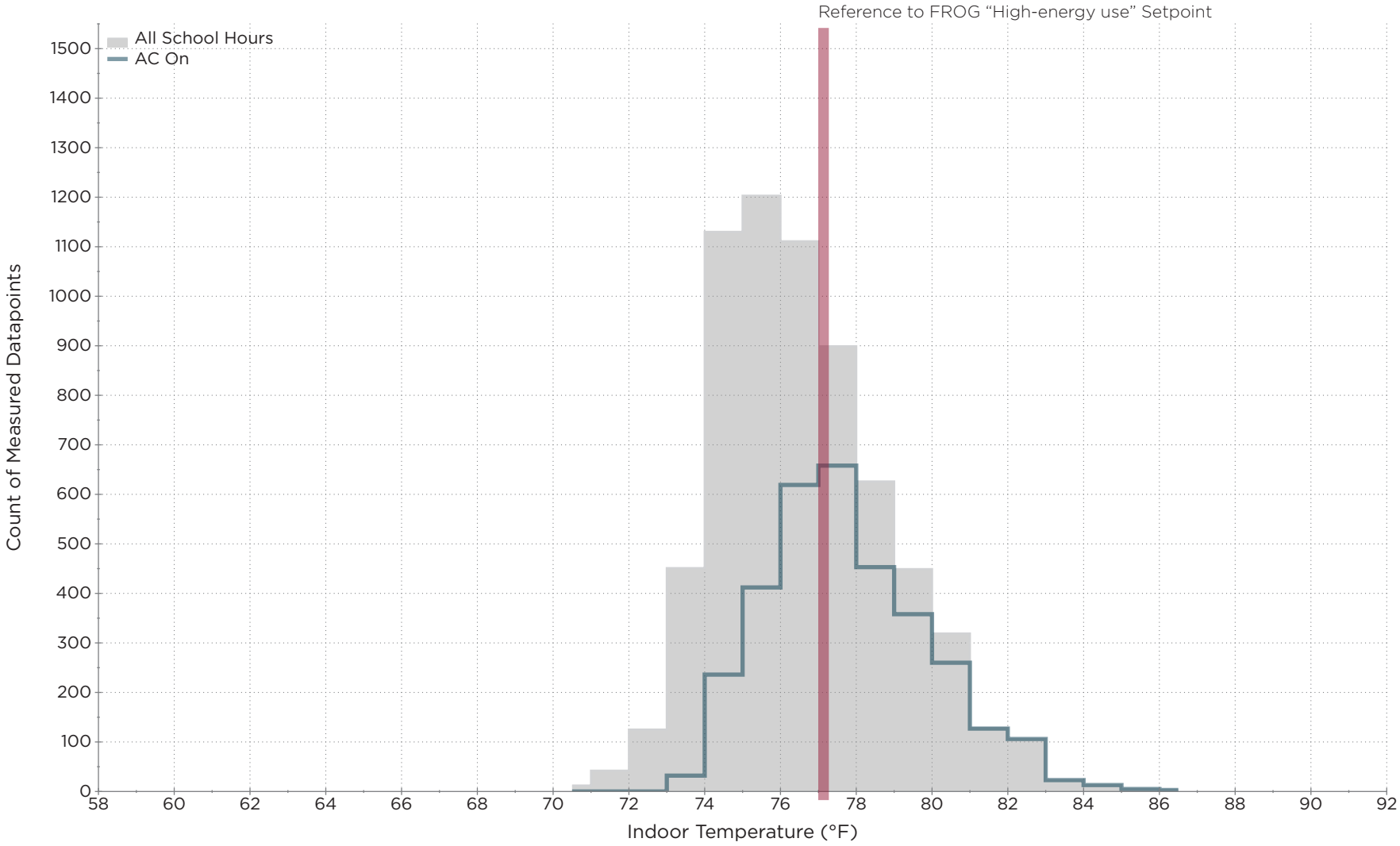


AC Usage vs. Indoor Temperature: Ewa D36

Description: Chart depicts count of 15-min intervals where Air Conditioning was used at different indoor air temperatures. The gray shading represents the total intervals available at each temperature.

Findings: AC was used below the FROG “High-Energy Use” setpoint 40% of the time

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: School Hours



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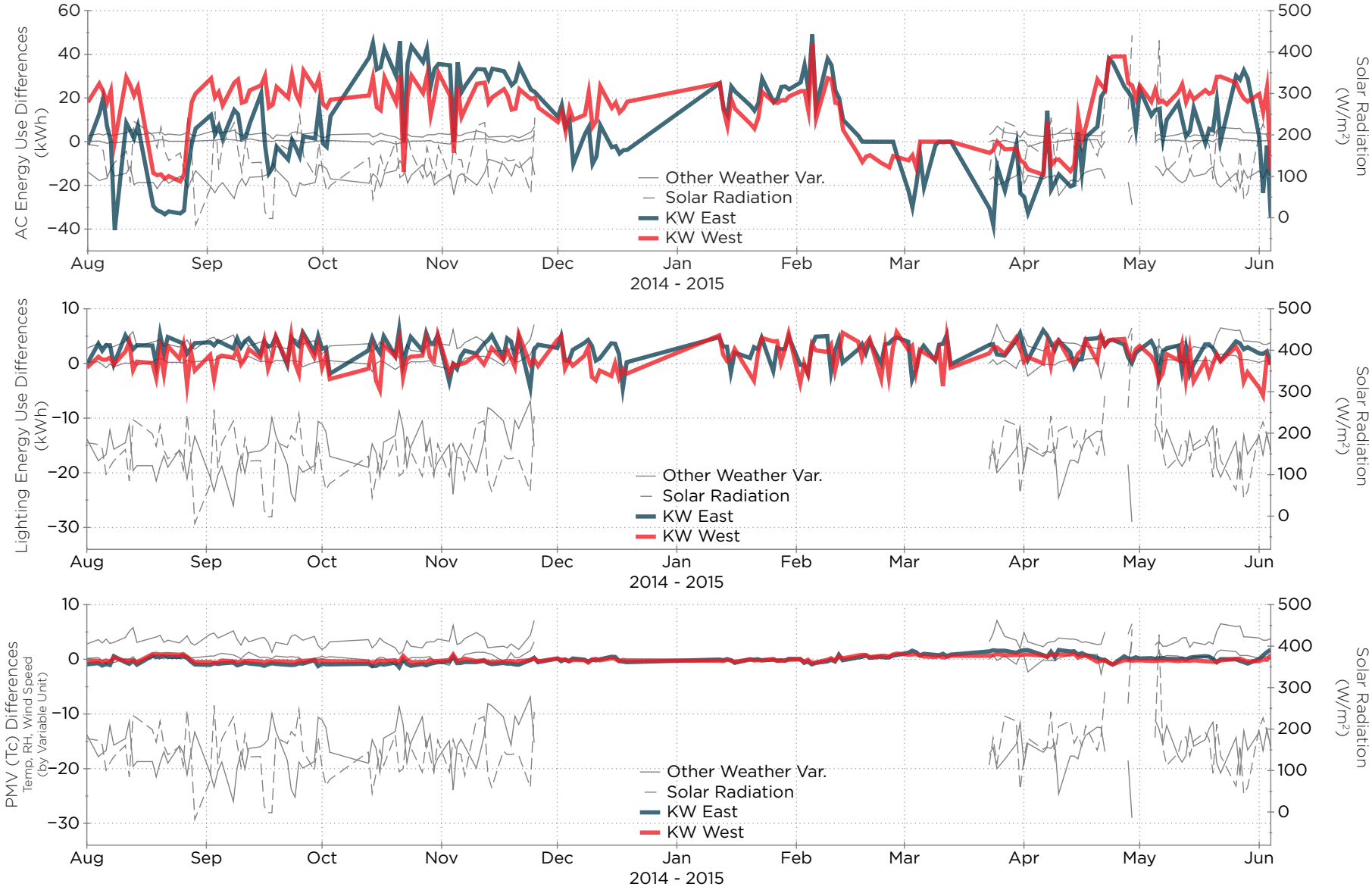
Daily Avg. Microclimate & Performance Differences: Lihu'e vs. Ewa Beach

Description: The charts depict differences in daily average weather variables (used to describe local microclimates) between Lihu'e and Ewa Beach as well as the differences in performance criteria (AC Energy, Lighting Energy, PMV) over the course of the study period. No weather information was collected for Lihu'e from 11/25/14 to 3/19/15 due to hardware issues.

Findings: Conditions and performance vary frequently and some measures vary more than others over time

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



SUBAWARD NO: MA130005

Description: The tables below detail key statistics calculated running a multiple linear regression model to determine differences in Air Conditioning Use (dependent variable) from differences in Microclimates (independent variables). Microclimate (Weather) variables included: Outdoor Air Temperature, Outdoor Relative Humidity, Wind Speed, and Solar Radiation.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: 0 of the 3 Performance Models showed statistically significant relationships with differences in microclimate (p-value < alpha) and less than 5% of the variation in performance could be explained by the model

Difference in AC Energy Use	
Multiple R	0.14
R Squared	0.02
# of Observations	75
P-Value	0.84
Significant	No

By Weather Variable Analyzed		
Variable	**Coefficient**	**P-Value**
Air Temperature	1.42	0.53
Relative Humidity	0.52	0.35
Wind Speed	-1.67	0.56
Solar Radiation	-0.01	0.82

Difference in Lighting Energy Use	
Multiple R	0.18
R Squared	0.03
# of Observations	75
P-Value	0.65
Significant	No

By Weather Variable Analyzed		
Variable	**Coefficient**	**P-Value**
Air Temperature	-0.21	0.13
Relative Humidity	-0.01	0.88
Wind Speed	-0.01	0.94
Solar Radiation	0.00	0.60

Difference in Thermal Comfort	
Multiple R	0.24
R Squared	0.06
# of Observations	75
P-Value	0.39
Significant	No

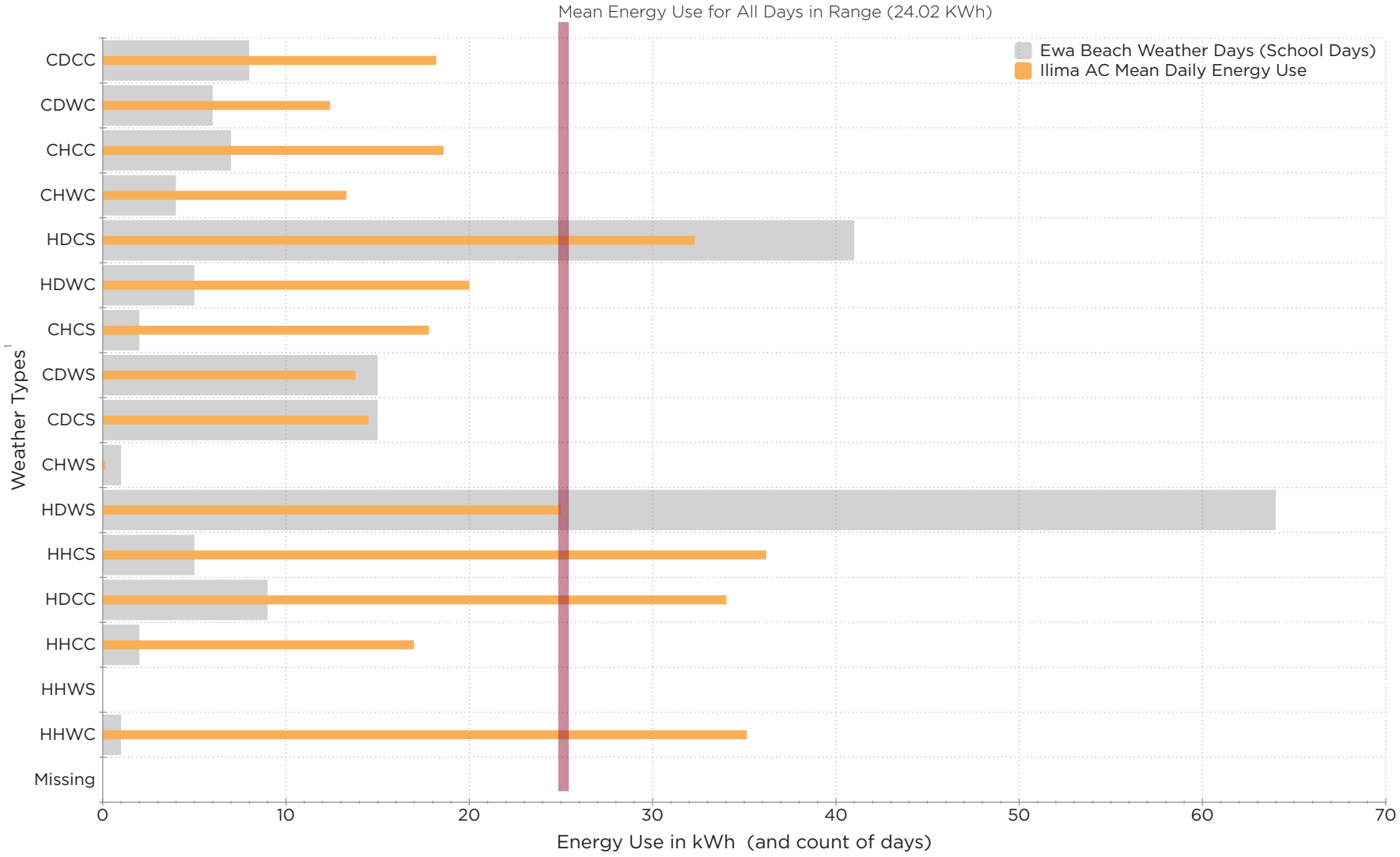
By Weather Variable Analyzed		
Variable	**Coefficient**	**P-Value**
Air Temperature	0.04	0.11
Relative Humidity	-0.00	0.75
Wind Speed	0.03	0.19
Solar Radiation	-0.00	0.82

Daily Weather Type vs. AC Energy Use: Ilima

Description: Chart depicts count of Weather Type[1] days (i.e. days that were Hot/Humid/Windy/Cloudy, etc.) and the associated AC Mean Daily Energy Use for those days expressed in Kilowatt-Hours.

Findings: Ewa Beach has two day types accounting for 58% of all days observed. Both day types are Hot, Dry, and Sunny, with the difference between the two being Windy vs. Calm. Of these days, the Windy days on average use less AC energy than the calm days.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



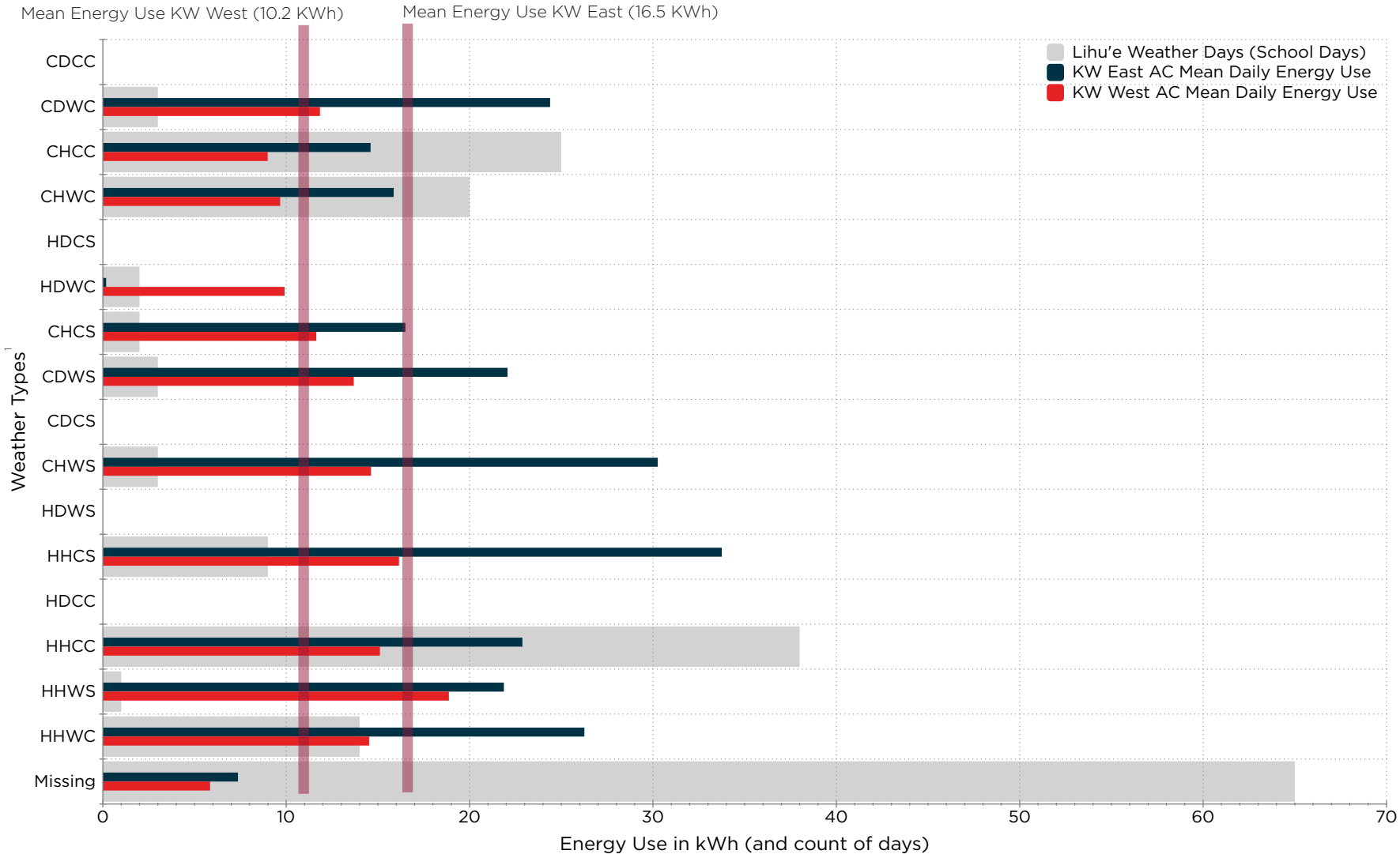
1: Weather Types are discussed in more detail in Section

Daily Weather Type vs. AC Energy Use: Kawaikini East and West

Description: Chart depicts count of Weather Type[1] days (i.e. days that were Hot/Humid/Windy/Cloudy, etc.) and the associated AC Mean Daily Energy Use for those days expressed in Kilowatt-Hours.

Findings: Lihue has three day types accounting for 68% of all days observed (65 days are missing data). All three day types are Humid and Cloudy. The Hot & Humid day averages 64% greater mean AC energy use than the cold and humid day, while controlling for Calm and Cloudy conditions.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



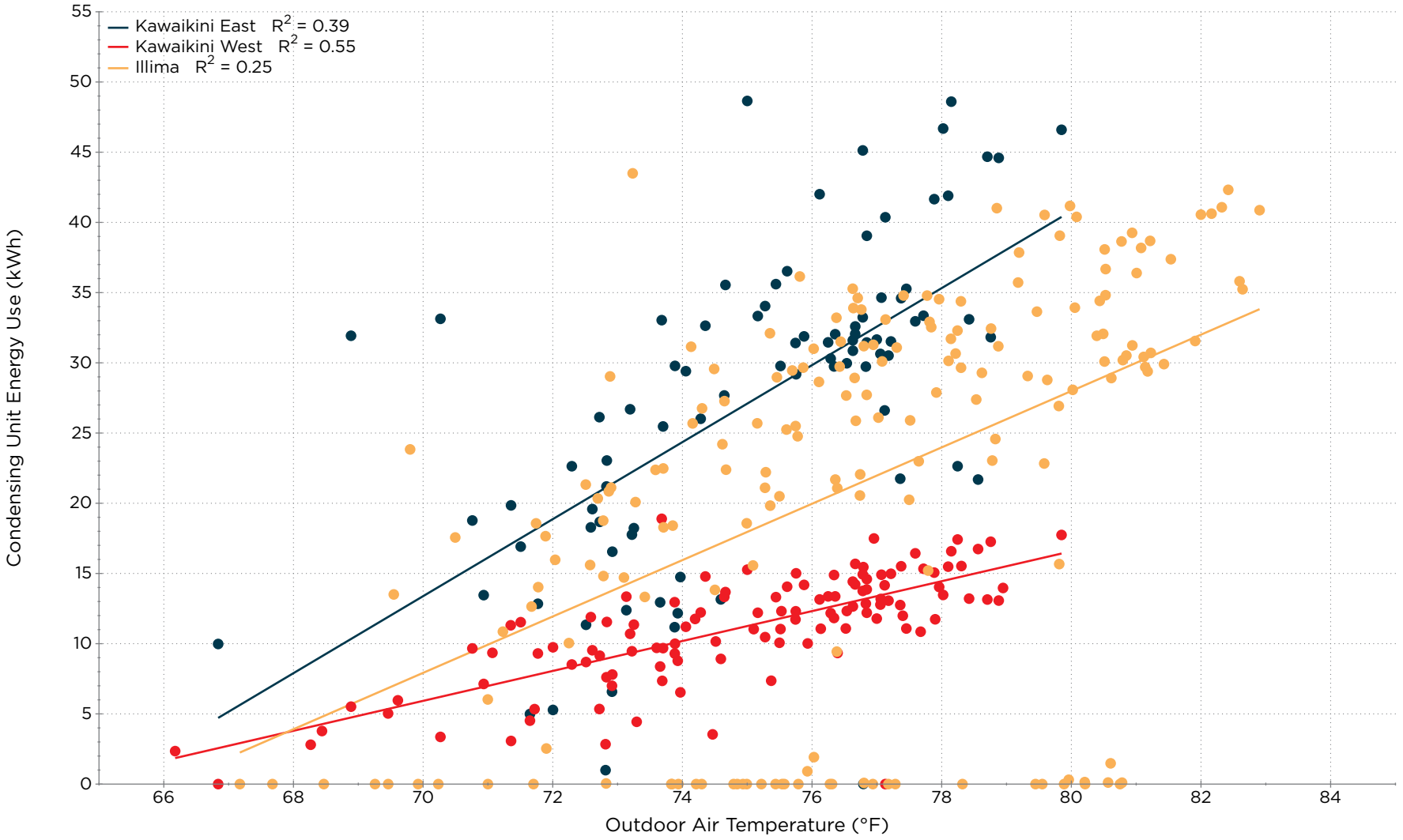
1: Weather Types are discussed in more detail in Sectio

Daily Average Outdoor Air Temperature vs. Daily AC Energy Use

Description: Correlation scatter plots of daily average outdoor air temperature vs. daily sums of condensing unit energy use (approximate for AC energy use), for the three Frog classrooms.

Findings: HVAC (condensing unit only) energy has a moderate correlation (i.e. $0.2<R^2<0.6$). with outdoor air temperature across platforms.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



Relationship between AC Energy Use and Weather Conditions

Description: The tables below detail key statistics calculated running a multiple linear regression model to determine Air Conditioning Use (dependent variable) from Weather data (independent variables). Weather variables included: Outdoor Air Temperature, Outdoor Relative Humidity, Wind Speed, and Solar Radiation.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: 2 of the 3 FROG Test Platforms showed statistically significant relationships with Weather (p-value < alpha), with the models able to explain 50-69% of the measured variation in AC use

FIT EVALUATION: KAWAIKINI EAST	
Multiple R	0.71
R Squared	0.50
# of Observations	75
P-Value	4.68E-10
Significant	Yes

BY WEATHER VARIABLE ANALYZED			
Variable	**Coefficient**	**P-Value**	**Significant**
Air Temperature	0.44	0.63	No
Relative Humidity	1.44	0.00	Yes
Wind Speed	2.90	0.18	No
Solar Radiation	0.21	2.14E-08	Yes

FIT EVALUATION: KAWAIKINI WEST	
Multiple R	0.82
R Squared	0.69
# of Observations	75
P-Value	5.36E-17
Significant	Yes

BY WEATHER VARIABLE ANALYZED			
Variable	**Coefficient**	**P-Value**	**Significant**
Air Temperature	1.14	1.18E-09	Yes
Relative Humidity	0.00	0.96	No
Wind Speed	-1.18	0.003	Yes
Solar Radiation	0.02	1.8E-04	Yes

FIT EVALUATION: ILIMA	
Multiple R	0.29
R Squared	0.08
# of Observations	75
P-Value	0.17
Significant	No

BY WEATHER VARIABLE ANALYZED			
Variable	**Coefficient**	**P-Value**	**Significant**
Air Temperature	1.26	0.17	No
Relative Humidity	-0.46	0.30	No
Wind Speed	-5.00	0.07	No
Solar Radiation	-0.02	0.46	No

alpha = 0.05 for all tests

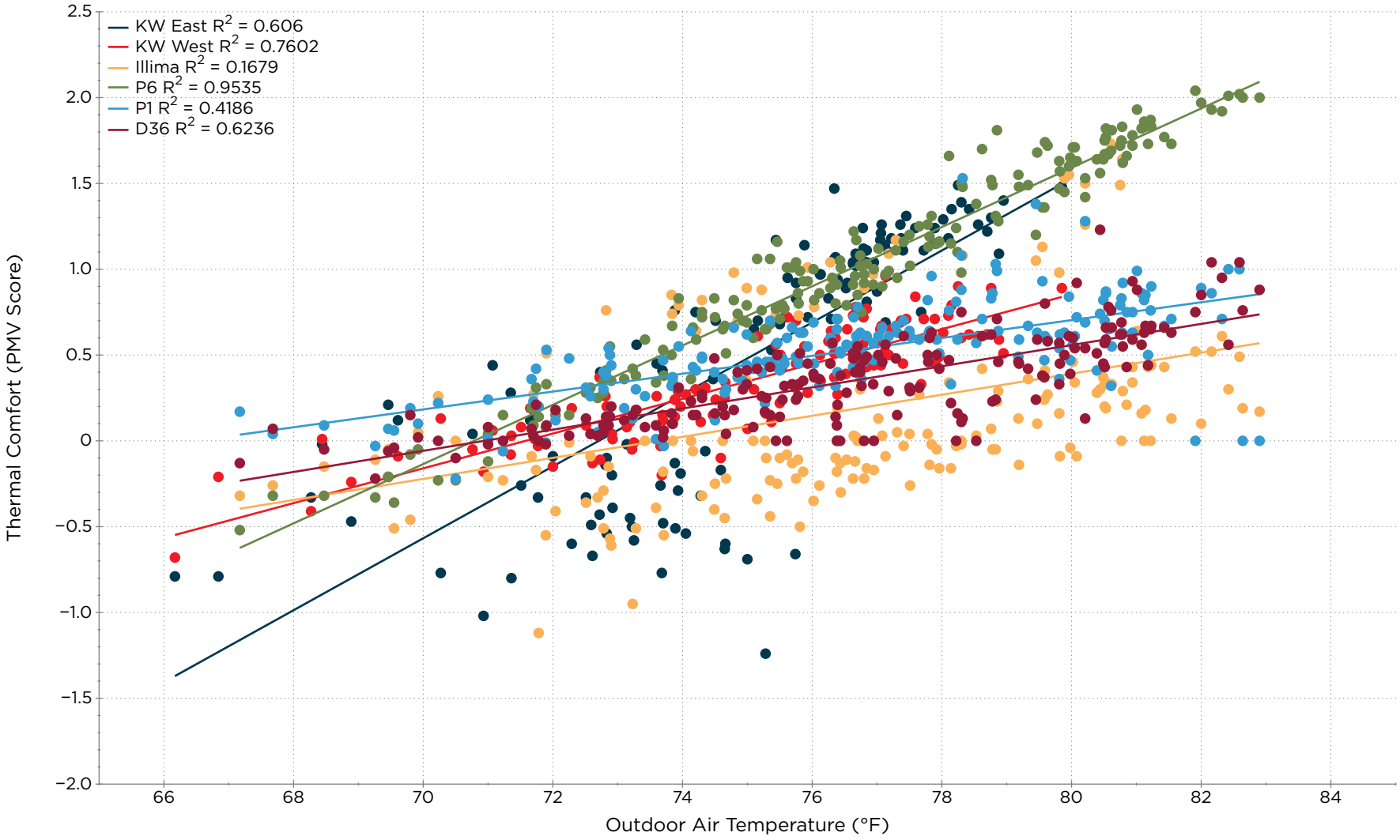
Differences in R2 between tables and charts is due to sample size differences and impacts of multiple variables

Average Outdoor Temperature vs. PMV (Thermal Comfort)

Description: Correlation scatter plots of daily average outdoor air temperature vs. daily average PMV (Thermal Comfort) scores, for the three Frog classrooms.

Findings: Ewa P6 shows the highest relationship with outdoor air temperature with an $R^2 = 0.95$ while Ilima FROG appears to have the lowest connection to outdoor air temperature $R^2 = 0.17$

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



Relationship between PMV and Weather Conditions

Description: The tables below detail key statistics calculated running a multiple linear regression model to determine PMV (dependent variable) from Weather data (independent variables). Weather variables included: Outdoor Air Temperature, Outdoor Relative Humidity, Wind Speed, and Solar Radiation.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: 6 of the 6 classrooms showed statistically significant relationships with Weather (p-value < alpha) with 3 of the 4 models able to explain more than 85% of the measured variation in PMV (Thermal Comfort)

KW EAST

Multiple R	0.94
R Squared	0.89
# of Observations	75
P-Value	3.76E-32
Significant	Yes

Variable	Coefficient	P-Value	Significant
Air Temperature	0.13	3.77E-23	Yes
Relative Humidity	0.01	0.07	No
Wind Speed	-0.04	0.07	No
Solar Radiation	0.002	5.96E-06	Yes

KW WEST

Multiple R	0.90
R Squared	0.81
P-Value	4.03E-24
Significant	Yes

Air Temperature	0.06	3.01E-10	Yes
Relative Humidity	0.02	1.36E-05	Yes
Wind Speed	0.05	0.02	Yes
Solar Radiation	0.002	3.50E-09	Yes

ILIMA

Multiple R	0.52
R Squared	0.27
P-Value	1.68E-04
Significant	Yes

Air Temperature	0.09	0.004	Yes
Relative Humidity	0.04	0.01	Yes
Wind Speed	0.16	0.08	No
Solar Radiation	0.002	0.01	Yes

P6

Multiple R	0.96
R Squared	0.91
P-Value	1.66E-36
Significant	Yes

Air Temperature	0.16	3.44E-32	Yes
Relative Humidity	0.009	0.018	Yes
Wind Speed	-0.08	5.70E-04	Yes
Solar Radiation	0.00	4.1E-05	Yes

P1

Multiple R	0.38
R Squared	0.14
P-Value	0.026
Significant	Yes

Air Temperature	0.04	0.029	Yes
Relative Humidity	0.003	0.731	No
Wind Speed	-0.04	0.423	No
Solar Radiation	-0.001	0.030	Yes

D36

Multiple R	0.73
R Squared	0.53
P-Value	7.13E-11
Significant	Yes

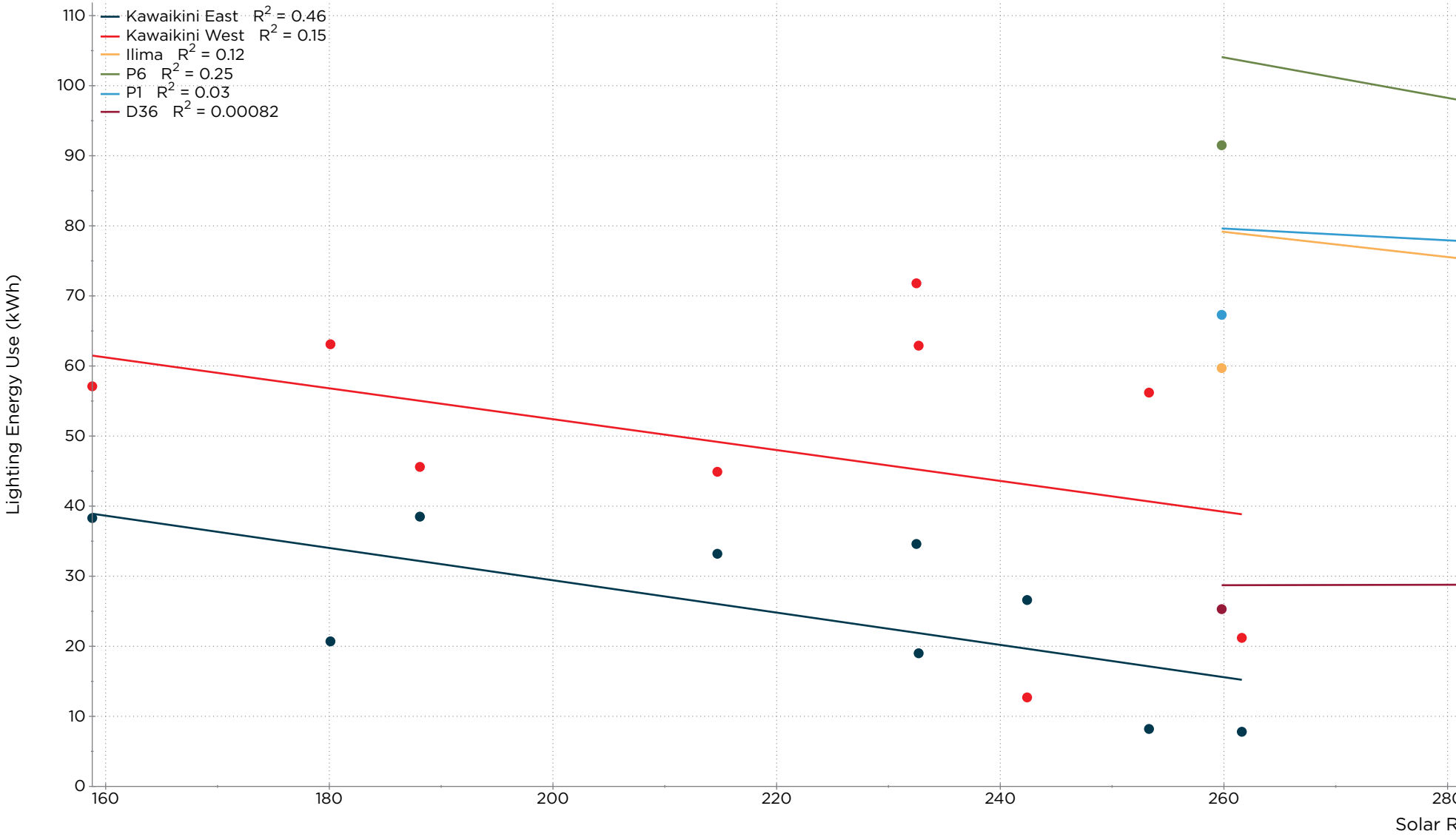
Air Temperature	0.06	7.62E-06	Yes
Relative Humidity	-0.006	0.30	No
Wind Speed	-0.06	0.11	No
Solar Radiation	0.001	0.006	Yes

alpha = 0.05 for all tests

Differences in R2 between tables and charts is due to sample size differences and impacts of multiple variables

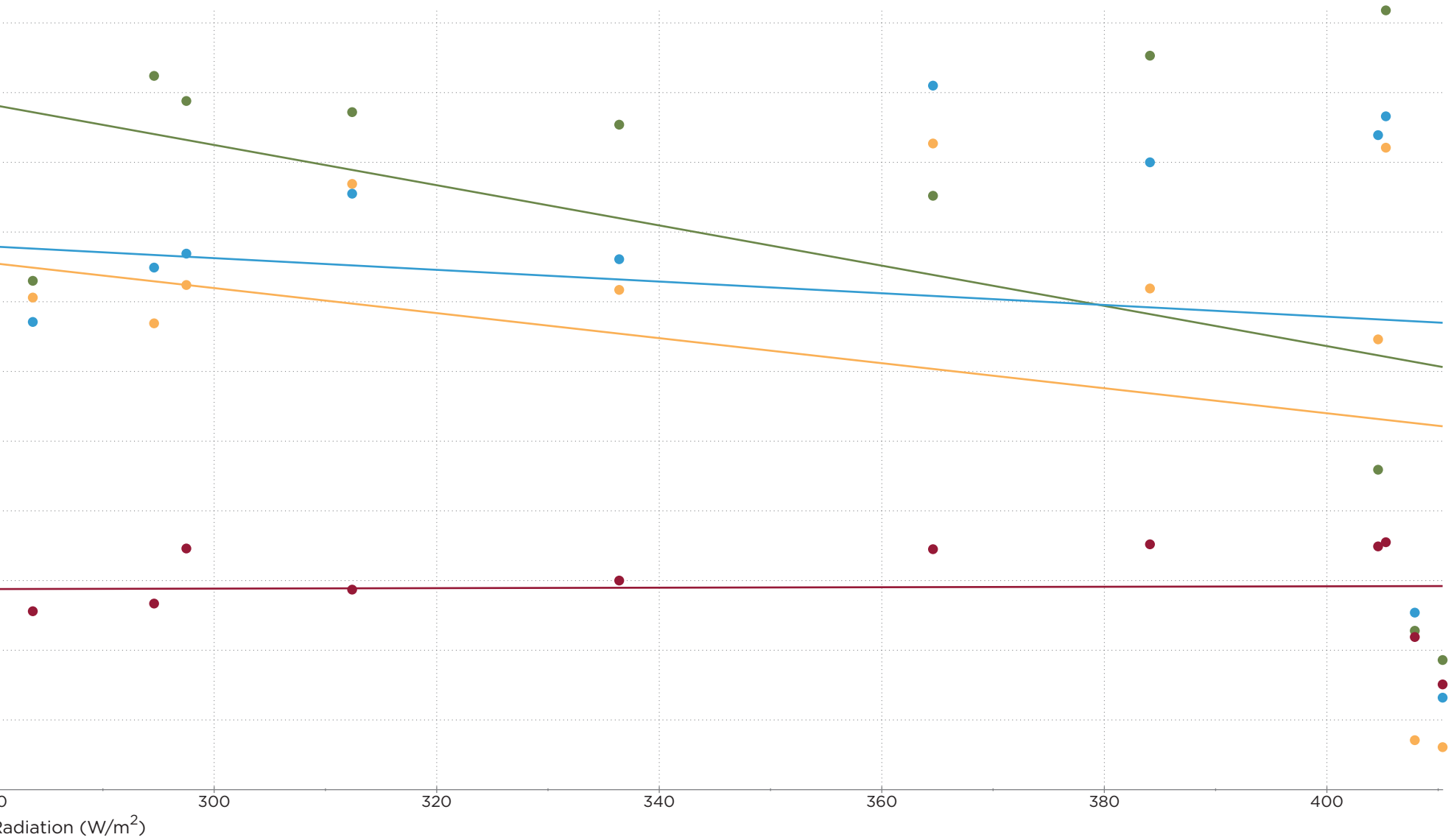
Monthly Lighting Energy Use Related to Solar Radiation

Description: Correlation scatter plots of monthly average solar radiation vs. monthly sums of interior lighting energy use for each classroom.



Findings: Kawaikini East and P6 have the strongest correlation with an R^2 of 0.46 and 0.25 respectively between lighting use and solar radiation. In contrast, Traditional classrooms (i.e. D36 and P1) have almost no linear relationship with correlation coefficients of 0.00082 and 0.03 respectively.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours



Relationship between Lighting Energy Use and Solar Radiation

Description: The tables below detail key statistics calculated running a multiple linear regression model to determine Light Energy Use (dependent variable) from Weather data (independent variables). Weather variables included: Outdoor Air Temperature, Outdoor Relative Humidity, Wind Speed, and Solar Radiation.

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Findings: 4 of the 6 classrooms showed statistically significant relationships with Weather (p-value < alpha), however, none of the models were able to explain more than 21% of the measured variation in lighting use

KW EAST

Multiple R	0.46
R Squared	0.21
# of Observations	75
P-Value	0.002
Significant	Yes

Variable	Coefficient	P-Value	Significant
Air Temperature	-0.20	0.05	Yes
Relative Humidity	-0.02	0.68	No
Wind Speed	0.20	0.37	No
Solar Radiation	-0.01	0.06	No

KW WEST

Multiple R	0.24
R Squared	0.06
P-Value	0.38
Significant	No

Air Temperature	0.07	0.54	No
Relative Humidity	-0.05	0.34	No
Wind Speed	-0.45	0.11	No
Solar Radiation	-0.006	0.16	No

ILIMA

Multiple R	0.14
R Squared	0.02
P-Value	0.83
Significant	No

Air Temperature	-0.10	0.31	No
Relative Humidity	-0.00	0.98	No
Wind Speed	-0.16	0.59	No
Solar Radiation	0.003	0.40	No

P6

Multiple R	0.39
R Squared	0.15
P-Value	0.019
Significant	Yes

Air Temperature	-0.39	0.027	Yes
Relative Humidity	0.003	0.96	No
Wind Speed	-0.46	0.37	No
Solar Radiation	-0.003	0.52	No

P1

Multiple R	0.37
R Squared	0.14
P-Value	0.035
Significant	Yes

Air Temperature	-0.12	0.17	No
Relative Humidity	-0.04	0.32	No
Wind Speed	-0.34	0.17	No
Solar Radiation	0.01	0.02	Yes

D36

Multiple R	0.37
R Squared	0.14
P-Value	0.03
Significant	Yes

Air Temperature	-0.036	0.26	No
Relative Humidity	-0.007	0.66	No
Wind Speed	-0.071	0.46	No
Solar Radiation	0.002	0.007	Yes

alpha = 0.05 for all tests

Differences in R2 between tables and charts is due to sample size differences and impacts of multiple variables

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DESCRIPTION

Section 7 provides a summary of the contract and exploratory research questions including findings, interpretation and future work. In addition, energy saving recommendations are outlined for each classroom.

7

Discussion & Recommendations

Discussion and Future Work	126
Energy Saving Measures	130

Discussion and Future Work - Contract Questions

Below summarizes the key study questions, corresponding findings and suggests additional research areas:

RESULTS

1. How do Test Platform performances compare to Traditional classrooms and to each other?

Finding

Test Platforms, on average, delivered 15% more comfort per energy consumed than Traditional classrooms.

Interpretation

It is not clear exactly why Test Platforms outperformed Traditional classrooms; and in fact, not all test platforms did outperform traditional classrooms. But with microclimate not a significant factor in the performance differences, the FROG Test platforms did demonstrate the potential for superior performance when considering comfort delivered per EUI.

2. Do Test Platforms perform as predicted by models?

Finding

Compared to the "Anticipated" model scenario, FROG Test Platforms' total energy consumption varied from +20% to -19% overall and by individual system from +77% to -72%.

Interpretation

Analyzing HVAC, Fan, and Lighting system operations compared to indoor and outdoor variables suggested that buildings were not operated per recommended operating guidelines. And since system usage didn't correspond with weather or consistent hourly schedules, it appears that the variability was likely due to user preference.

FUTURE STUDY

COMPARING COMFORT DELIVERED PER UNIT OF ENERGY

Approach

Comfort delivered per EUI helped connect the Energy and IEQ performance criteria, preventing buildings that used less energy with a minimum comfort level, and vice versa, from becoming the ideal. We recommend expanding the COMF/EUI metric to additional indoor environmental quality parameters in order to benchmark building performance more holistically.

Possible Research Questions

How does COMF/EUI change over time when different energy conservation programs are implemented?

What is the variation in COMF/EUI across building stock and how does that influence future investment decisions?

INPUTTING USER BEHAVIOR AND PREFERENCE

Approach

Accurate models depend on accurate assumptions for all drivers of system use. Building/system and weather characteristics are well studied, but occupant behaviors are generally unknown. Study occupants values and environmental preferences towards energy and comfort to more accurately model user demands.

Possible Research Questions

By knowing user values and preferences, can models better predict energy consumption?

Which energy conservation strategies are better aligned with which user preferences?

3. Do all classrooms perform within established guidelines (as per ASHRAE Standard 55 and 62.1)?

Finding

Test Platforms, on average, had 15% less time within the thermal comfort zone, had 41% more time with acceptable air quality and 2% more time with acceptable lighting conditions compared to Traditional Classrooms.

Interpretation

Test Platforms performed only slightly better on overall indoor environmental quality (IEQ) than traditional classrooms mostly due to superior performance in Lighting and Air Quality. While one of the FROG Test Platforms achieved the highest IEQ score overall, the other three Test Platforms underperformed compared to the Traditional classrooms. With building system operations controlled by users, perception of comfort may be different than calculated, leading to differences.

DEFINING COMFORT ACROSS CULTURAL NORMS

Approach

Understanding comfort differences across populations is crucial to setting design standards. We recommend gathering user satisfaction data from a range of occupants and operating environments to compare the levels of perceived comfort to calculated comfort based on ASHRAE or other guidelines. Results could be used to determine appropriate guideline adjustments.

Possible Research Questions

What are perceived comfort ranges in Hawaii classrooms and how does it compare to ASHRAE's thermal comfort model?

Can the same level of perceived comfort be achieved with other heat abatement solutions besides air conditioning?

Discussion and Future Work - Exploratory Questions

Below summarizes the key study questions, corresponding findings and suggests additional research areas:

RESULTS

1. How well did Test Platforms achieve "energy-neutrality"?

Finding

3 of 4 Test Platforms achieved energy neutrality or better on an annual basis.

Interpretation

The Kawaikini FROGs achieved Zero Net Energy (ZNE) by having a combined energy use approx. 15% below the "Anticipated" modeled consumption amount (excluding exterior lighting) and energy production above the Anticipated amount, as planned. Ilima FROG, however, produced more energy than its "High" estimate but consumed even more. P6 achieved ZNE by producing 3.9x the energy it consumed.

2. How do the classrooms compare in use of natural daylighting?

Finding

3 of 6 classrooms showed daylight capacity above 90% during school hours but only 1 platform achieved more than 50% utilization of that daylight potential.

Interpretation

Interior lights were often used when natural daylight was sufficient, which led to excess energy use, especially when buildings with dimming capabilities kept lights on at full power. This behavior could have resulted from, in part, occupant norms and/or lack of education on what sufficient daylight levels look like.

FUTURE STUDY

IMPROVING ADHERENCE TO HIGH-PERFORMANCE OPS

Approach

All classrooms have days that are close to achieving energy-neutrality but require a small amount (~1-5 kWh) of grid electricity. The need for grid electricity could be eliminated by either better adhering to the high-performance building operations manual for each building or otherwise implementing further energy efficiency or conservation initiatives.

Possible Research Questions

How can building operations better adhere to high-performance guidelines when occupants have access to controls?

Can net zero energy be achieved at a school level in Hawaii while maintaining a high level of occupant comfort?

TESTING PERCEIVED ADEQUATE LIGHTING

Approach

Survey occupants on perception of lighting levels and visual comfort when they are engaging in a range of activities to determine whether or not they can independently establish when lighting levels are sufficient, testing at what point occupants will adjust their lighting environment.

Possible Research Questions

How do people's perceptions of adequate light levels compare to calculated values?

How important are external views to feeling comfortable in a space?

3. How do the local weather and differences in microclimate impact classroom operations and performance?

Finding

Differences in microclimates did not reveal statistically significant relationships. Individual classrooms did exhibit moderate weather performance relationships.

Interpretation

Of the three performance criteria modeled by weather variables, only PMV exhibited a statistically significant relationship across FROG platforms in both Lihu'e and Ewa Beach. However, the % variation explained and the significance lowered when looking at these variables as potential reasons for differences in performance between platforms in Lihu'e and Ewa Beach. Given the lack of consistency in building system operations measured from system usage, it appears user preference influenced performance more than local weather did.

4. How do the classrooms compare against national averages for Energy Use Intensity (EUI)?

Finding

5 of 6 classrooms had lower EUIs than the top quartile of national schools; Kawaikini West and Ewa P6 had EUIs 37% and 58% lower, respectively

Interpretation

These 6 Hawaiian classrooms are already considered high-performing from a national EUI perspective; however, the national benchmarks don't account for differences in climate and other variables that may not make the benchmarks as useful as local comparisons, or comparisons to schools with similar operating requirements. Additionally, most national benchmarks are based on whole schools and not classrooms, so the exact benchmarking was approximated in this study and should be refined.

CONNECTING BUILDING SYSTEMS TO WEATHER

Approach

Install some classrooms with automated systems to adjust to varying outdoor and indoor conditions. In other classrooms, train occupants on how to optimally control the building.

Possible Research Questions

Compared to a building automation system, how well can educated occupants manage a building's operations?

Does an automated building lead to improved energy use performance while also satisfying occupants?

LOCALLY DEFINED BENCHMARKS

Approach

Comparing classroom energy use across a portfolio is useful for understanding performance context and potential. Analyze information on energy consumption, space use and program schedule for all Hawaii Department of Education's schools.

Possible Research Questions

What is the HIDOE's EUI benchmark by classroom type, school type, microclimate, and even academic performance?

How can the HIDOE benchmark be used for improved decision making within the Hawaii ecosystem?

Energy Saving Measures Specific to Issues in Classrooms

One to two key problems for each classroom are described followed by energy saving measures to address the problem.

System	Name	KW East	KW West
		1. The condensing unit was broken for 16 months before it was noticed and fixed. 2. 80% of AC use occurred below the optimal setpoint.	1. KW West had approximately double the amount of energy used for exterior lights than KW East. 2. 68% of the time interior artificial lights were used instead of daylight
All	Occupant Education	Educate the building occupants and maintenance staff on the operating procedures.	
	Building Automation System (BAS)		
	Energy Dashboard	An energy dashboard could alert maintenance staff to problems with equipment.	
HVAC	Cooling Setpoints		
	Demand Control Ventilation		
	Night Flushing		
Interior Lighting	Daylight Sensors		Daylight sensors could turn off interior lights when daylight is sufficient.
Exterior Lighting	Lighting Motion Sensors		Exterior lights could be triggered by motion sensors instead of always on at night.
Plug Loads	Energy Star Equipment		
	Smart Power Strips		

	Ilima	Ewa P6	Ewa P1	Ewa D36
	1. Air conditioning was used most of the time possibly due to manually operated windows and louvers. In addition, the space was over cooled.	1. P6 consumed 49% and 32% of the total classroom energy on plug loads and interior lights respectively.	1. Plug loads account for 54% of total classroom energy use. 2. 79% of school hours had CO_2 concentrations above the ASHRAE limit of 1100ppm.	1. The HVAC system is run from 6am to 6pm during weekdays regardless of occupancy. 2. Windows are covered preventing daylight into the space.
	The BAS could auto control the louvers and windows to open when advantageous. Also, the BAS could prevent the space from being over cooled.			The BAS could raise and lower blinds to control for glare or security concerns.
				Use specific cooling setpoints to turn on/off the HVAC system
			Demand control ventilation would bring in fresh outside air to replace high CO_2 air.	
	Night flushing removes inside heat with cool night air.			
		Daylight sensors could turn off interior lights when daylight is sufficient.		
		Ensure all equipment is Energy Star certified.	Ensure all equipment is Energy Star certified.	
		Smart power strips turn off equipment when not in use.	Smart power strips turn off equipment when not in use.	

Applicable Energy Saving Measures

Below are a broader list of energy saving recommendations worth considering for each classroom.

System	Name	Description
All	Occupant Education	Educate occupants and custodians on how to operate the buildings as intended
	Building Automation System	Install a building automation system so classrooms can respond to weather changes automatically
	Energy Dashboard	Install an energy dashboard to display how much energy is being used by various systems
	Custodial Operations	Implement daytime custodial services
	Wall/Roof Insulation	Retrofit the roof and walls with additional insulation
	Retro-commissioning	Conduct retro-commissioning to ensure all systems are working as intended
HVAC	Cooling Setpoints	Restrict the HVAC setpoint temperatures so that space cooling is only allowed above a certain temperature
	Demand Control Ventilation	Implement demand control ventilation for the HVAC system to bring outside air into a classroom based on occupancy
	Cool Roofs	Retrofit the roof to use a white membrane which reflects the solar radiation and decreases the heat flux through the roof
	Night Flushing	Open windows/louvers at night to allow cool air into the classroom
Interior Lighting	Daylight Sensors	Install daylight sensors which turn off lights when there is sufficient daylight
	Lighting Motion Sensors	Install motion sensors to turn on lights when motion is detected
	Lighting Controls	Install lighting controls to regulate lighting quality for specific tasks or situations
	Efficient Lighting	Upgrade to more efficient lighting
Exterior Lighting	Daylight Sensors	Install daylight sensors which turns off lights when there is sufficient daylight
	Lighting Motion Sensors	Install motion sensors to turn on/off lights when motion is detected
	Efficient Lighting	Upgrade to more efficient lighting
Ceiling Fans	Energy Star Equipment	Purchase Energy Star ceiling fans
Plug Loads	Energy Star Equipment	Require computers, stand-alone fans, printers, microwaves, and window AC units to be Energy Star certified
	Smart Power Strips	Use energy saving, smart power strips to cut off electricity to equipment when not in use

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DESCRIPTION

Section 8 provides descriptions of benchmarks, calculations, energy demand estimates, assumptions, limitations and references used to create the graphs in this report.

8

Methodology

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Benchmarks

	Name	Value (Criteria)	Source	Pages
ENERGY	**National average: US K-12 schools (Electricity Use)**	10 kWh/ft^2	Touchstone Energy Project / US Energy Consumption Data reported by Energy Star	22-23
ENERGY	**Top Quartile: US K-12 Schools (Electricity Use)[1]**	6 kWh/ft^2	US EPA Energy Star Building Manual: 10. Facility Types: K-12 Schools	22-23
WEATHER	**Typical Meteorological year 3 for Honolulu Airport and Lihu'e airport**	Monthly Max/Min Temperature and Relative Humidity from 1991-2005	National Renewable Energy Laboratory	40-41
WEATHER	**Multiple Linear Regression Model Parameters**	alpha = 0.05 p-value < alpha for statistical signif. R^2 > 0.60 moderate; > 0.80 strong	MKThink Internal	116-122
INDOOR ENVIRONMENT	**Predicted Mean Vote (PMV)**	+/- 0.5 PMV	ASHRAE Standard 55 - 2013	12-13, 80-81, 86
INDOOR ENVIRONMENT	**CO_2 Threshold, ASHRAE Recommended Limit**	1100ppm	ASHRAE Standard 62.1 Technical FAQ #35	12-13, 20-21, 82-83, 86
INDOOR ENVIRONMENT	**Air Supply**	Plenum air temperature is within +/- 10 deg F of the supply air temperature	MK Internal Reference	Appendix
INDOOR ENVIRONMENT	**Lighting Quality**	illuminance > 5 ft-cd, Illuminance ratio (wall ft-cd/ surface ft-cd) < 5	Task 1 Report: Planning and Specification	98-99
INDOOR ENVIRONMENT	**Active Operations AC Setpoint (Optimal AC Setpoint)**	82°F	ONR Phase II Report / FROG 2013 Operations Guide	100-108
INDOOR ENVIRONMENT	**High-Energy Use AC Setpoint**	77°F	ONR Phase II Report	100-101 104,108

1: This benchmark was calculated from the US EPA Energy Star report which showed the Top Quartile of K-12 schools had an EUI of ~48,000BTU/SF annually. This number included both electrical and non-electrical energy; thus, to extract the electrical portion a ratio of 41% of the total BTU was used based on statistics calculated from the Touchstone Energy Cooperatives' school initiatives' report (10kWh of 24.65kWh, or 41%, of EUI was from electrical loads). The resultant was then rounded to the nearest whole number for ease of comparison.

Calculations

	Name	Description	Pages
ENERGY	**D36 Air Conditioning Modeling**	Ewa D36 received a new central air conditioning (AC) system which serves all 4 classrooms at the beginning of the FY14/15 school year. Since the new AC system was installed during the middle of the study, detailed energy monitoring was not part of the installation. The AC unit runs from 6am to 6pm Monday-Friday and is off the remaining hours. To obtain AC energy use, data were collected from 11/12/15-11/20/15 and used to extrapolate energy use for 7/1/2014-6/30/2015. The measured data were recorded in 5 minute intervals and used to get a regression equation between outside air temperature (from Weather Underground) and AC energy use. This regression equation was used to estimate AC energy use for the rest of the study period. AC Energy (kWh) from 6am to 6pm M-F = 0.0084 x Outside Air Temp in F - 0.5273 AC Energy use for all other hours = 0.0025 kWh	12-15, 20-23, 55-67, 73, 79, 108
INDOOR ENVIRONMENT	**Indoor Environmental Quality (IEQ)**	IEQ is the percentage of time when the following three environmental conditions are simultaneously met: - PMV value is within the ASHRAE Comfort Zone (-0.5 ≤ PMV value ≤ 0.5) - CO_2 concentration is below the ASHRAE threshold for adequate ventilation (1100 ppm) - wall illuminance exceeds 5 ft-cd and the illuminance ratio stays below 5	12-15
	Predicted Mean Vote (PMV)	PMV is an index that predicts people's thermal comfort in conditioned spaces on a scale created by ASHRAE where -3 is cold, 0 is neutral, and +3 is hot. The index is calculated using six parameters: interior temperature, relative humidity, wind speed, mean radiant temperature, metabolic rate, and clothing value.	12-13, 80-81, 86
	Daylight Analysis	The daylight analysis determined the percent of time during school hours (8am-2pm) that daylight could potentially meet lighting quality requirements. The daylight analysis included three key steps: 1. Minimum Solar Radiation Threshold: For all classrooms on non-school days during 8am - 2pm when lights were off (i.e. lighting power consumption was below 0.02W), each time stamp was characterized by lighting quality and solar radiation values. For any given solar radiation level, the probability of achieving the lighting quality threshold was developed (e.g. at 350 W/m^2, the interior illuminance levels had a 30% chance of meeting the lighting quality threshold). The solar radiation level corresponding to a 60% probability of achieving the lighting quality standard using a 25 interval moving average was used as the minimum threshold. Therefore, the minimum solar radiation thresholds were: KW East - 157 W/m^2, KW West - 139 W/m^2, Ilima - 617 W/m^2, P6 - 102 W/m^2, P1 - 536 W/m^2, D36 - 0 W/m^2 2. Daylight Capacity: The minimum solar radiation threshold was then applied to solar radiation values recorded on school days during school hours. Timestamps above the minimum solar radiation threshold meant daylight could meet the lighting quality standards. Daylight capacity is the number of timestamps with sufficient daylight compared to all timestamp instances. 3. Daylight Use: Daylight use occurred when the lights were off and the solar radiation levels were above the minimum solar radiation threshold. Lights were assumed to be off when the lighting power consumption was below 0.02W.	
	Air Supply Performance	Performance of the air supply systems in the FROG Test Platforms was measured by finding the percentage of time the average of the three plenum temperatures was within 10 °F of the supply air temperature compared to all school hours when the AC system was turned on.	
WEATHER	**Weather - Performance Regressions**	Weather was defined by 4 meteorological variables (Air Temperature, Relative Humidity, Wind Speed, and Solar Radiation) which were used as the independent variables in a multiple linear regression model to fit selected, measured performance metrics (AC Energy Use, Lighting Energy Use, and PMV (Thermal Comfort). The data was tested for normal distributions and models were run using a default alpha of 0.05. Only one model was made for each test and no variables were dropped in the analysis after failing to meet tests of statistical significance (p-value < alpha (0.05)).	111-120

Energy Demand Modeling Estimates

Energy demand estimates for Kawaikini East, Kawaikini West and Ilima were developed in the Phase II ONR report. Three estimates were developed: High, Anticipated and Optimal. Plug loads were assumed to be the same in all classrooms, and exterior lighting was assumed to be zero for all classrooms. Two different sets of estimates were developed for Kawaikini and Ilima to take into account the differences in climate and sunlight.

High:
The High estimate assumes air conditioning is used above a set point of 77°F and interior lights are on for 100% of occupied hours (8am to 6pm). Ceiling fans are also used.

Anticipated:
The Anticipated estimate is a middle value between the High and Optimal estimates. Anticipated estimates assume daylighting is used but natural ventilation is not.

Optimal:
The optimal estimate assumes that each classroom is cooled by natural ventilation up until a thermostat setpoint of 82°F, at which point they switch from passive to active mode, closing the ventilation louvers or windows and turning on air conditioning. The optimal estimate also assumes that daylighting is used.

The following two tables show the energy demand modeling estimates for Kawaikini East & West and Ilima:

Kawaikini East & West (estimates are per classroom)

	High	Anticipated	Optimal
Air Conditioning	3,838 kWh/year	3,458 kWh/year	500 kWh/year
Fans	1,000 kWh/year	220 kWh/year	1,000 kWh/year
Lighting Interior	2,008 kWh/year	1,028 kWh/year	1,028 kWh/year
Plugs	1,278 kWh/year	1,278 kWh/year	1,278 kWh/year
Total	**8,124 kWh/year**	**5,984 kWh/year**	**3,806 kWh/year**

Source: Phase II ONR Report

Ilima

	High	Anticipated	Optimal
Air Conditioning	4,103 kWh/year	4,103 kWh/year	1,400 kWh/year
Fans	1,000 kWh/year	254 kWh/year	1,000 kWh/year
Lighting Interior	2,008 kWh/year	1,006 kWh/year	1,006 kWh/year
Plugs	1,278 kWh/year	1,278 kWh/year	1,278 kWh/year
Total	**8,389 kWh/year**	**6,641 kWh/year**	**4,684 kWh/year**

Source: Phase II ONR Report

Assumptions & Limitations

Assumptions (A) and limitations (L) listed below by category

	Type	Description
ENERGY	A	For comparisons of “lights on” vs “lights off”, any timestamp where interior lighting power was below 0.02kW was counted as “lights off.”
	L	The fan coil unit in Kawaikini East was malfunctioning between 10/17/13 - 2/27/15. However, the condensing unit worked during this period, and the building occupants never stopped powering on the AC system.
	L	Ilima had manually operable windows and louvers, but was air-conditioned most of the time due to bug and dust problems when opening the louvers.
	A	During 2/18/14 - 4/17/15, Ilima did not use air conditioning even when room temperatures were at 80 deg F or above. We assume the AC wasn’t broken but that it was a user preference.
	L	The air conditioning unit was left on at Ilima continuously from 6/6/15-6/25/15.
	L	In P1 there were two window AC units. Their AC energy use was included in the Plug Loads.
	A	D36 shares the same electric panel with 3 other classrooms. Therefore to find energy use values for D36 specifically, raw values from the panel were divided by 4.
	L/A	In D36, year 1 had a window AC unit. Year 2 had central AC. AC energy was extrapolated for 7/1/2014-6/30/2015 based on measured data from 11/12/15-11/20/15. The central AC runs from 6am to 6pm on weekdays
WEATHER	L	No data was collected from the Lihu’e weather station between 11/25/14-3/19/15 due to a malfunctioning sensor.
	A	The Ewa weather station was used to represent weather conditions for the Ilima FROG Test Platform, as Ilima Intermediate and Ewa Elementary were both in Ewa Beach and less than 3 miles away from each other
INDOOR ENVIRONMENT	A	When calculating the PMV scores for thermal comfort, it was assumed that building occupants wore t-shirts and shorts and were sitting, for all classrooms.
	L/A	An unknown issue with the sensor caused the air speed readings at Kawaikini West to dramatically change in November 2014. As a consequence, this air speed data was not used as an input for calculating the PMV score. A constant value (industry average of 45 ft/min) was instead used as an input for the PMV function.
	L	The windows at Ilima were covered with newspapers for security reasons which prevented natural daylight to penetrate into the space. This was not done at either of the Kawaikini classrooms.
	L	The windows at D36 were inoperable and the louvers were always shut so there was no available daylight.
GENERAL	L	The designer of Ewa P6, Anderson Anderson Architecture, was contacted for the corresponding classroom operating procedures, but they did not respond.
	A	Planned School Hours were determined from the examining the school bell schedules for each of the three schools.
	L	The installation of the lighting system prevented the operation of several windows.
	L	With a limited sample size of 6 classrooms, broad generalizations regarding portable classrooms could not be concluded.

Glossary

Term	Study Definition
Asset Data	Any data related to physical classroom assets
Classroom	Term used to describe all six classrooms in the study
Coefficient of Determination (R^2)	The R^2 ($0<R^2<1$) value represents how well the data fits a regression line. This R^2 value is useful in understanding the predictability from one variable to another. Higher R^2 values indicate a better model fit.
Energy Use Intensity	Energy used per net square foot per year
Fan energy use	Ceiling fans excluding stand-alone plug-in fans, which are included in the plug load
FROG	Flexible Response to Ongoing Growth
FROG Test Platform	Term used to describe the group of classrooms (Kawaikini East, Kawaikini West and Ilima) designed by Project Frog
HIDOE	Hawaii Department of Education
Lights Off	When interior lighting power was below 0.02kW for any classroom
Lights On	When interior lighting power was above 0.02kW for any classroom
Microclimate	A smaller area within a climate zone that has a distinctly different climate from the surrounding area
Net Consumer Days (PV)	Days when more electricity was consumed by the classroom than generated by the PV system, which results in electricity used from the grid
Net Generator Days (PV)	Days when more electricity was generated by the PV system than consumed by the classroom, which results in electricity exported to the grid
Net Square Feet	Total square footage of usable space
Net Zero Energy	The total amount of energy consumption is equal to the total amount of energy generation
Non-School Days	Includes holidays and weekends according to the HIDOE calendar
Traditional Classroom	Term used to describe Ewa P1 and Ewa P6
Test Platform	Classrooms designed to be high performance: Kawaikini East, Kawaikini West, Ilima, and P6
Thermal Comfort[1]	The condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation
TMY3 dataset	A typical meteorological year (TMY) is an hourly weather dataset for a specific location created by the National Renewable Energy Laboratory from data collected across 30 years (1991 - 2005)

1: ANSI/ASHRAE Standard 55

Previous Reports

Listing of previous reports related to Subaward Number MA130005

Report Name	Completion Date
Task 1 Report: Planning and Specification	5/23/12
2: Kawaikini Extension Final Report & Final Quarterly Report	3/18/15
3a: Ilima Draft Report & Final Quarterly Report	9/24/15
3b: Ilima Final Report	12/2/15
4.4a-1: Ewa P1 Draft Report & Final Quarterly Report	10/5/15
4.4b-1: Ewa P1 Final Report	12/2/15
4.4a-2: Ewa P6 Draft Report & Final Quarterly Report	9/24/15
4.4b-2: Ewa P6 Final Report	12/2/15
4.4a-3: Ewa D36 Draft Report & Final Quarterly Report	10/14/15
4.4b-3: Ewa D36 Final Report	12/2/15
Comparable Sites Mid-Study Integrated Report (Revision)	12/9/15
5.1: Draft Report	12/9/15
5.2: Final Report for Review	12/28/15

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TEST PLATFORM PERFORMANCE ANALYSIS P2: APPENDIX

March 2016 | FINAL INTEGRATED REPORT | Researching the performance of 4 potentially Net-Zero Energy Test Platforms and 2 "traditional" Hawaiian classrooms

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HNEI SUBAWARD NO: MA130005

ONR Contract #N00014-12-1-0496

University of Hawaii's Asia-Pacific Research Initiative for Sustainable Energy Systems (APRISES)

Task 7 - Energy Efficiency

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DESCRIPTION

This section has 1 year energy and environmental charts supplemental to the main report. One chart compares monthly energy use intensity on non-school days for all six classrooms. The environmental data charts in this section show plots for each individual environmental sensor from each room. The environmental sensors measured air temperature, surface temperature, relative humidity and air speed. Also included are charts for plenum air temperatures in the three FROG Test Platforms (Kawaikini East & West, Ilima), which were used to gauge the performance of the air supply in those FROG test platforms. Finally, tables showing results from linear regression analyses are included in the end of this section.

WHY IMPORTANT

To answer the study questions:
CQ1: How do Test Platform performances compare to Traditional classrooms and to each other?
CQ3: Do all classrooms perform within established guidelines?
EQ3: How do local weather and differences in microclimates impact classroom operations and performance?

A1

1 Year Charts

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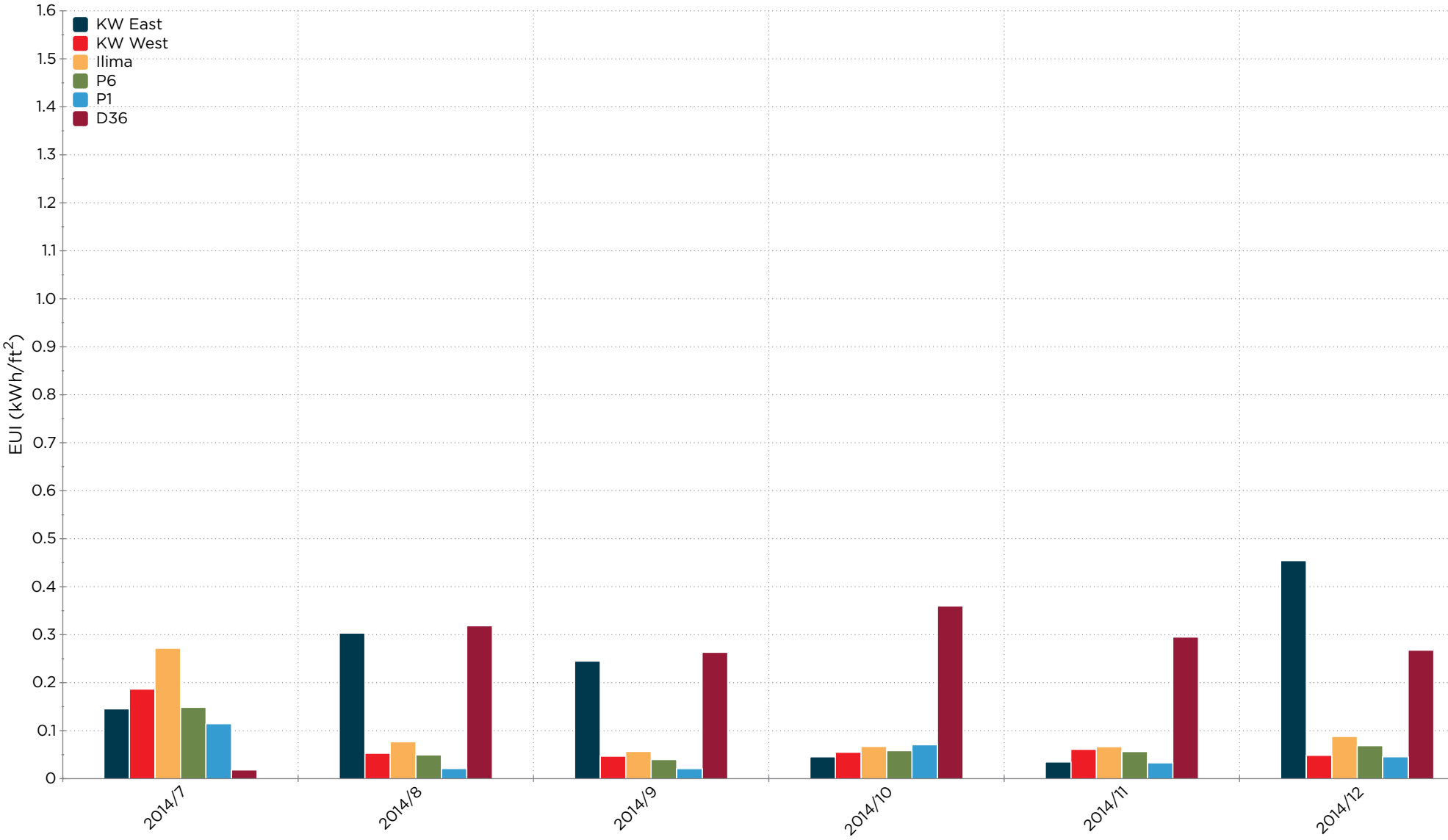
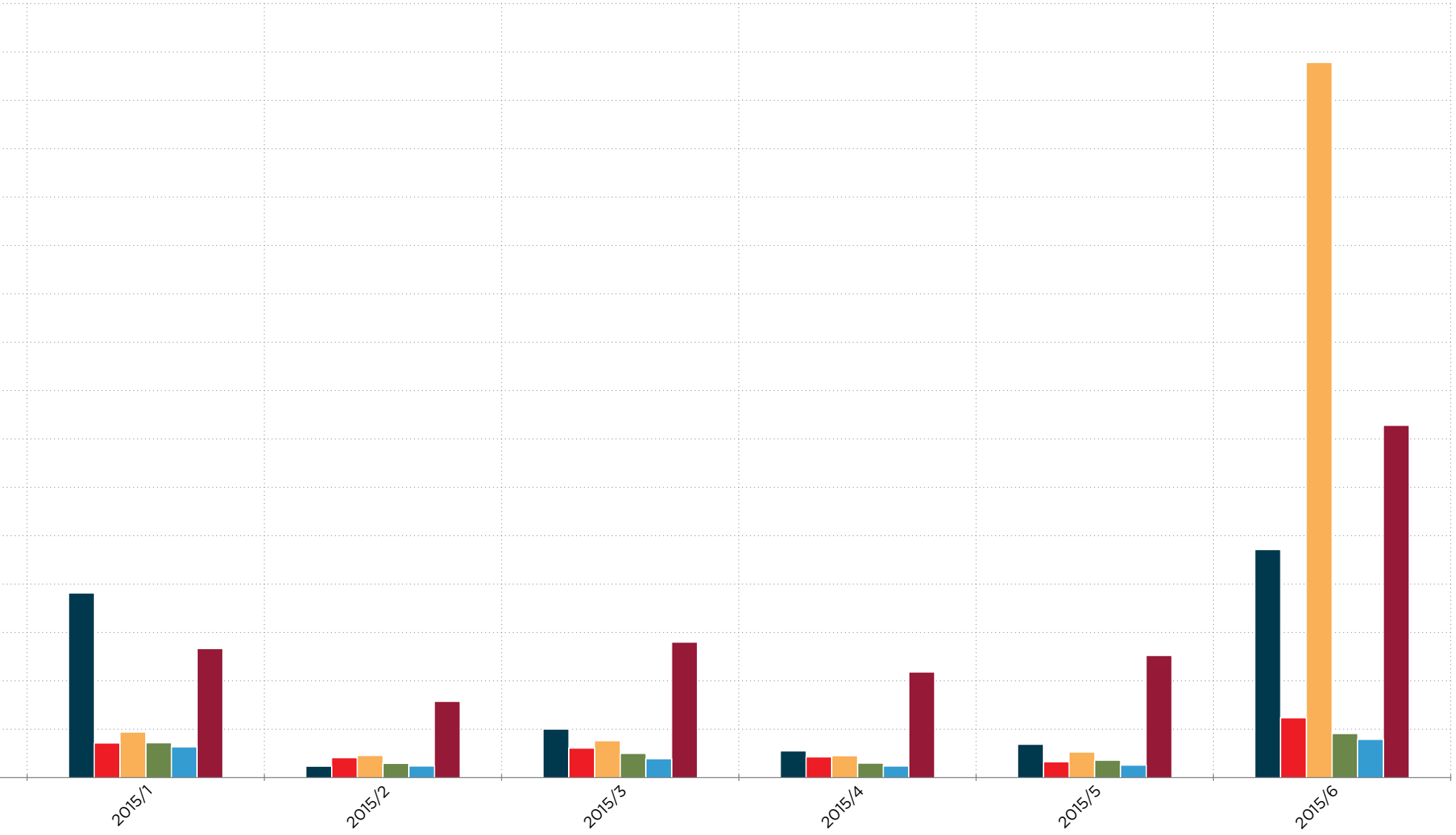
Monthly Energy Use Intensity for Non-School Days

Description: The chart describes the total energy use intensity of non-school day hours by month.



Findings: KW West, P6, and P1 never had a month when the EUI during non-school days exceeded 0.2 kWh/ft². D36 had 10 months (out of 12 total) when the EUI during non-school days exceeded 0.2 kWh/ft². Ilima's spike in June was due to the AC system left on continuously for 19 days.

Study Period: 07/01/2014 - 06/30/2015
Days: Non-School Days
Hours: All Hours

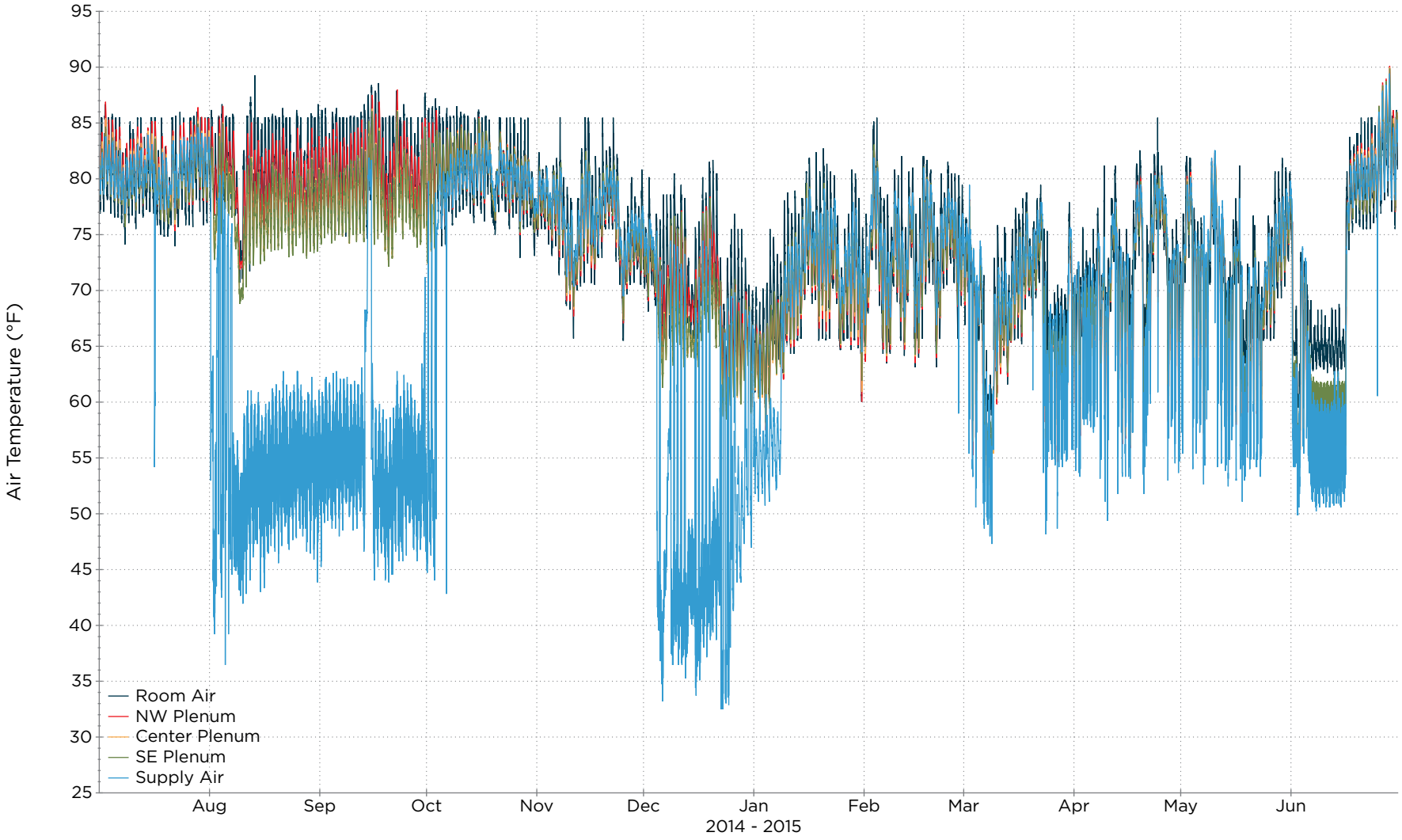


Kawaikini East: Air Supply Plenum Temperatures

Description: Air temperatures measured in 10 minute intervals from three floor plenums, the supply air temperature, and the ambient room air temperature at Kawaikini East. The fan coil unit in the split system AC was malfunctioning between 10/17/13 - 2/27/15.

Findings: Plenum air temperatures in Kawaikini East were within 10°F of supply air temperatures 75% of the time during school hours when the AC was on. During the time the fan coil unit was broken, the condenser unit still worked and was left on continuosly for weeks, causing the supply air temperatures to deviate from the room air temperatures. This occurred during August, September, and December.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

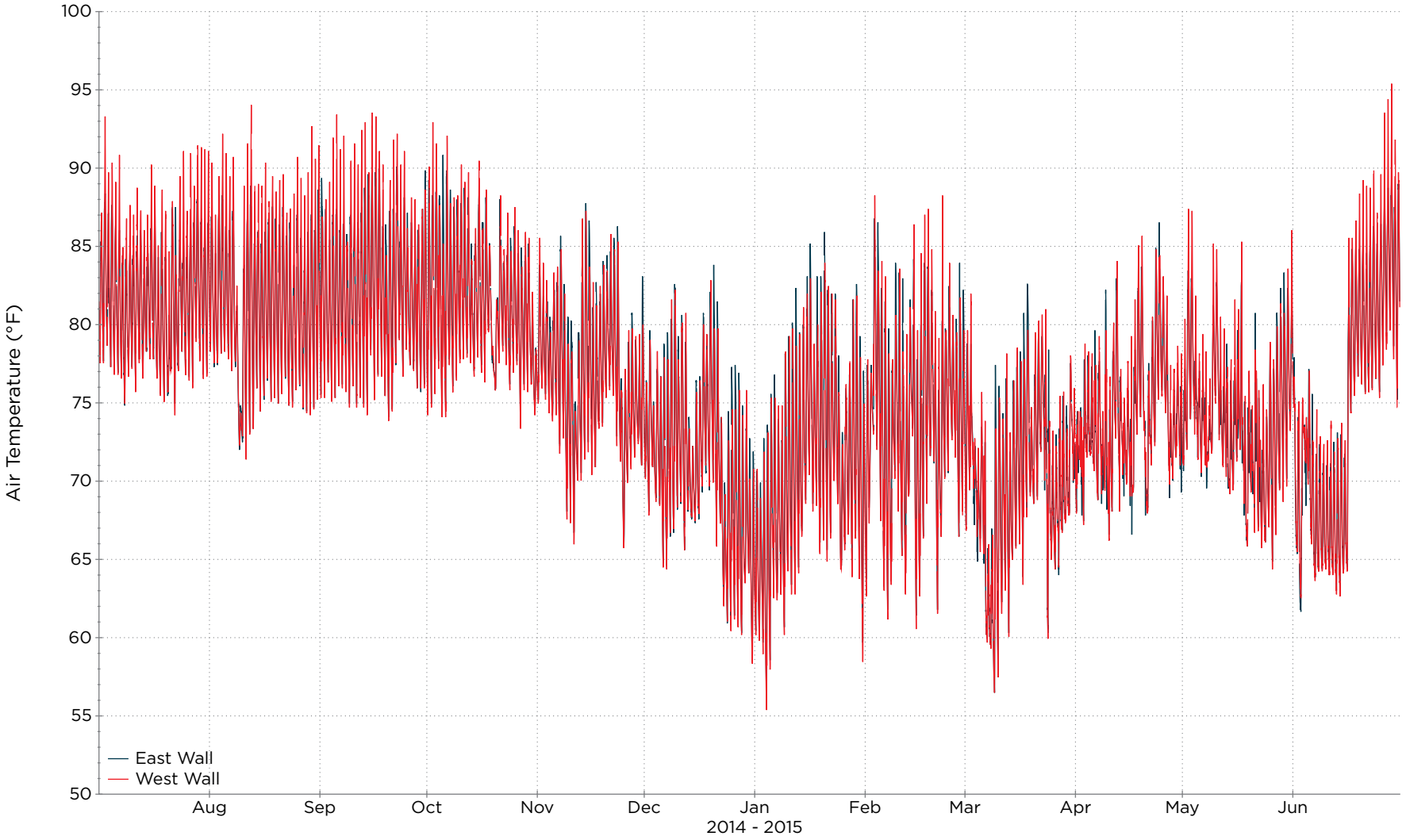


Kawaikini East: Indoor Air Temperatures

Description: Air temperature measured in 10 minute intervals at the east and west walls at Kawaikini East.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: Over the full study period, the average air temperature at the east wall was 76.2°F, and at the west wall was 75.9°F.



Kawaikini East: Indoor Surface Temperatures

Description: Surface temperature measured in 10 minute intervals at the east and west walls as well as at the northwest, center and southeast floor areas at Kawaikini East.

Findings: Over the full study period, the average surface temperature at the east wall was 76.3°F, at the west wall was 76.0°F, at the northwest area of the floor was 74.9°F, at the center area of the floor was 74.5°F, and at the southeast area of the floor was 74.9°F.

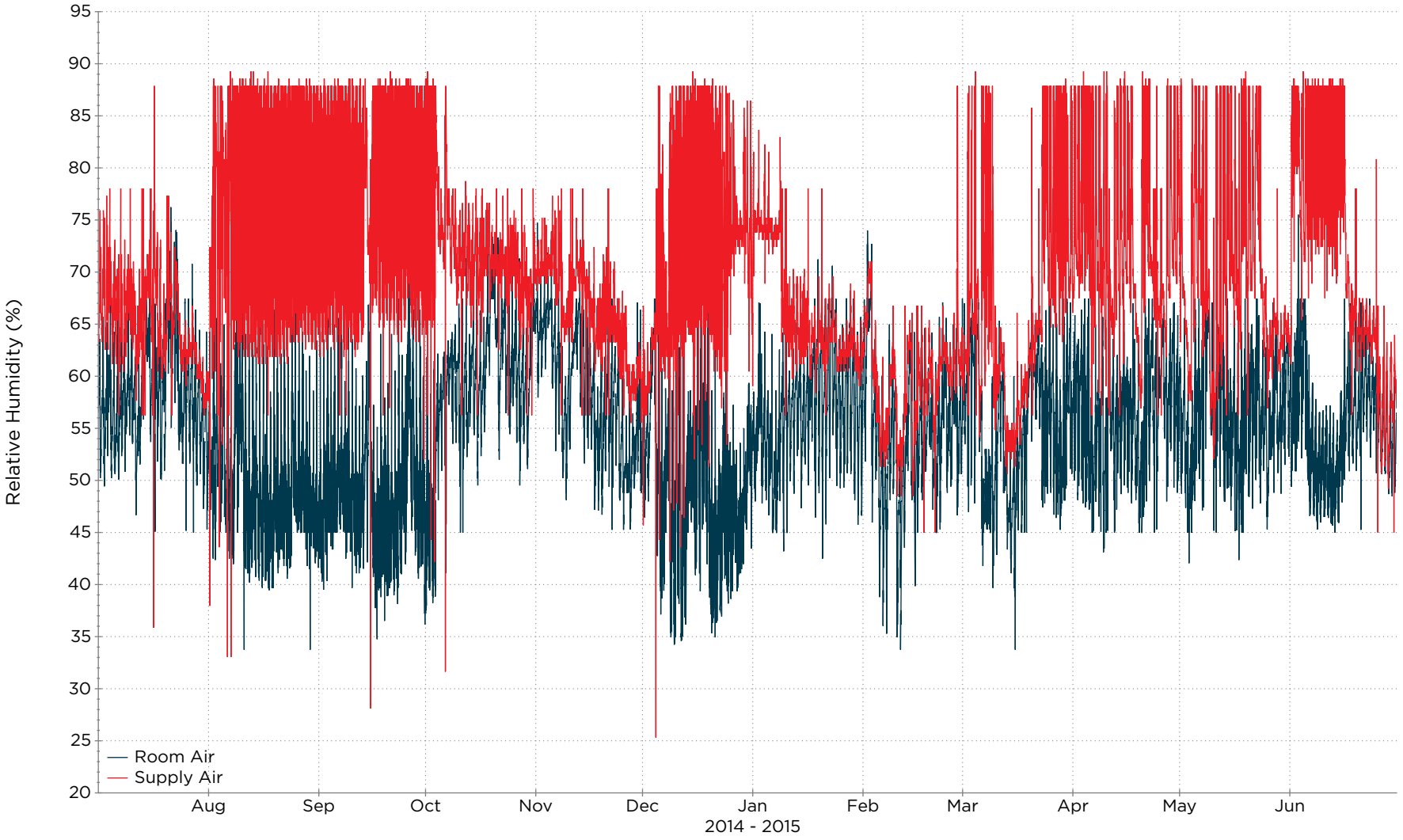
Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Kawaikini East: Indoor Relative Humidities

Description: Relative humidity measured in 10 minute intervals in the room and near the AC supply air at Kawaikini East.

Findings: Over the full study period, the average relative humidity in the room was 55.0% and near the supply air was 70.3%.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

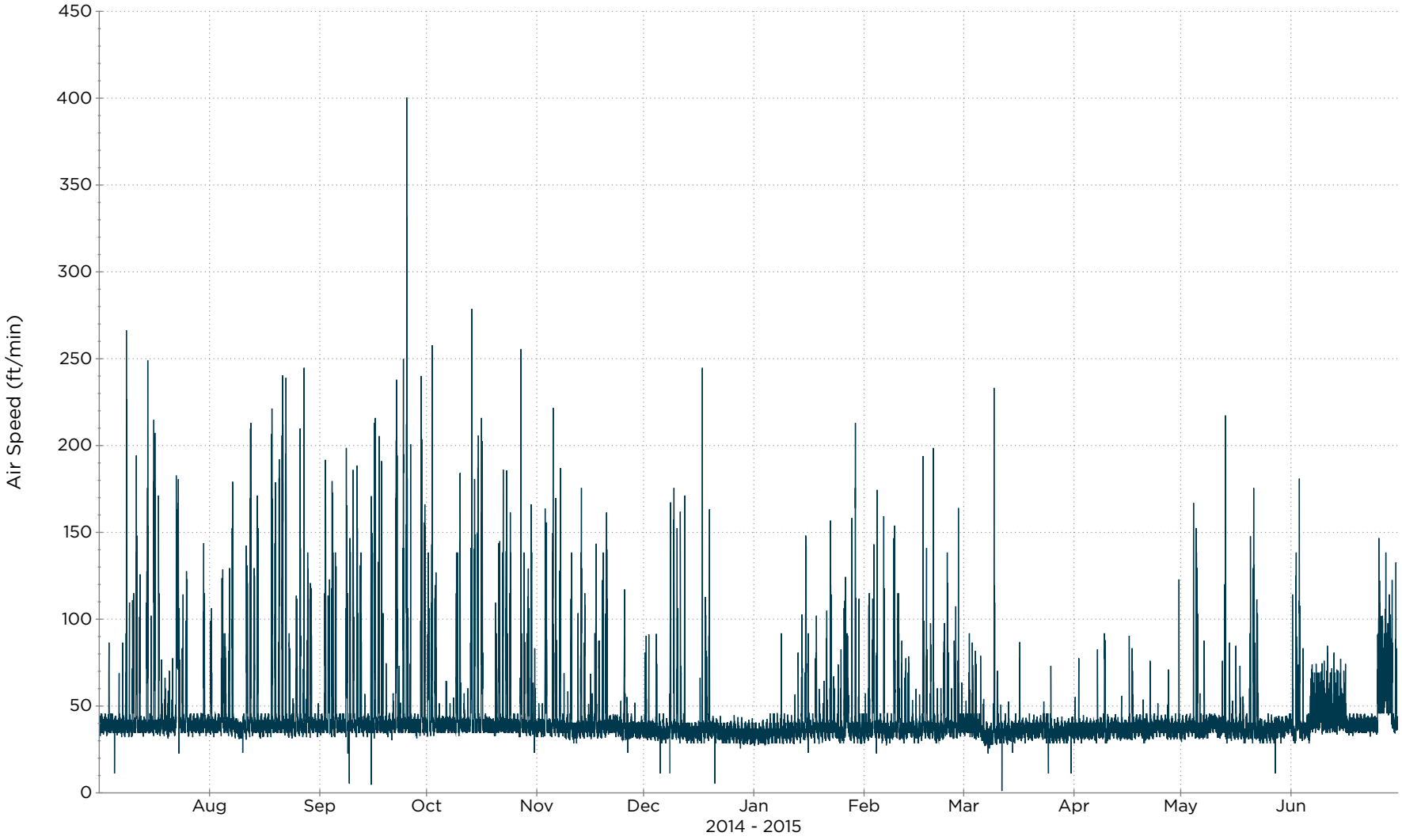


Kawaikini East: Indoor Air Speed

Description: Indoor air speed measured in 10 minute intervals at Kawaikini East.

Findings: Over the full study period, the average indoor air speed was 43.6 ft/min.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

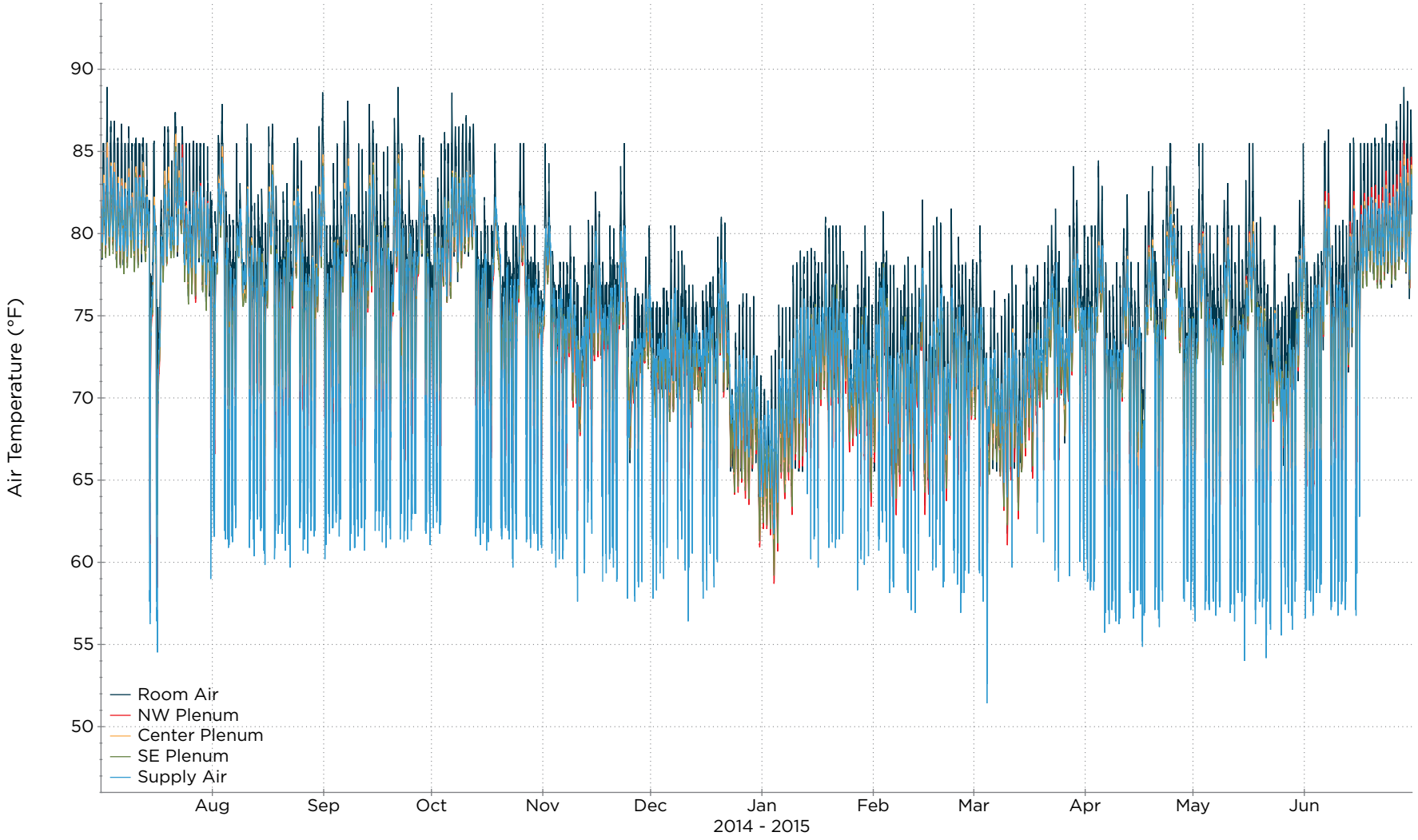


Kawaikini West: Air Supply Plenum Temperatures

Description: Air temperatures measured in 10 minute intervals from three floor plenums, the supply air temperature, and the ambient room air temperature at Kawaikini West.

Findings: Plenum air temperatures in Kawaikini West were within 10°F of supply air temperatures 93% of the time during school hours when the AC was on.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

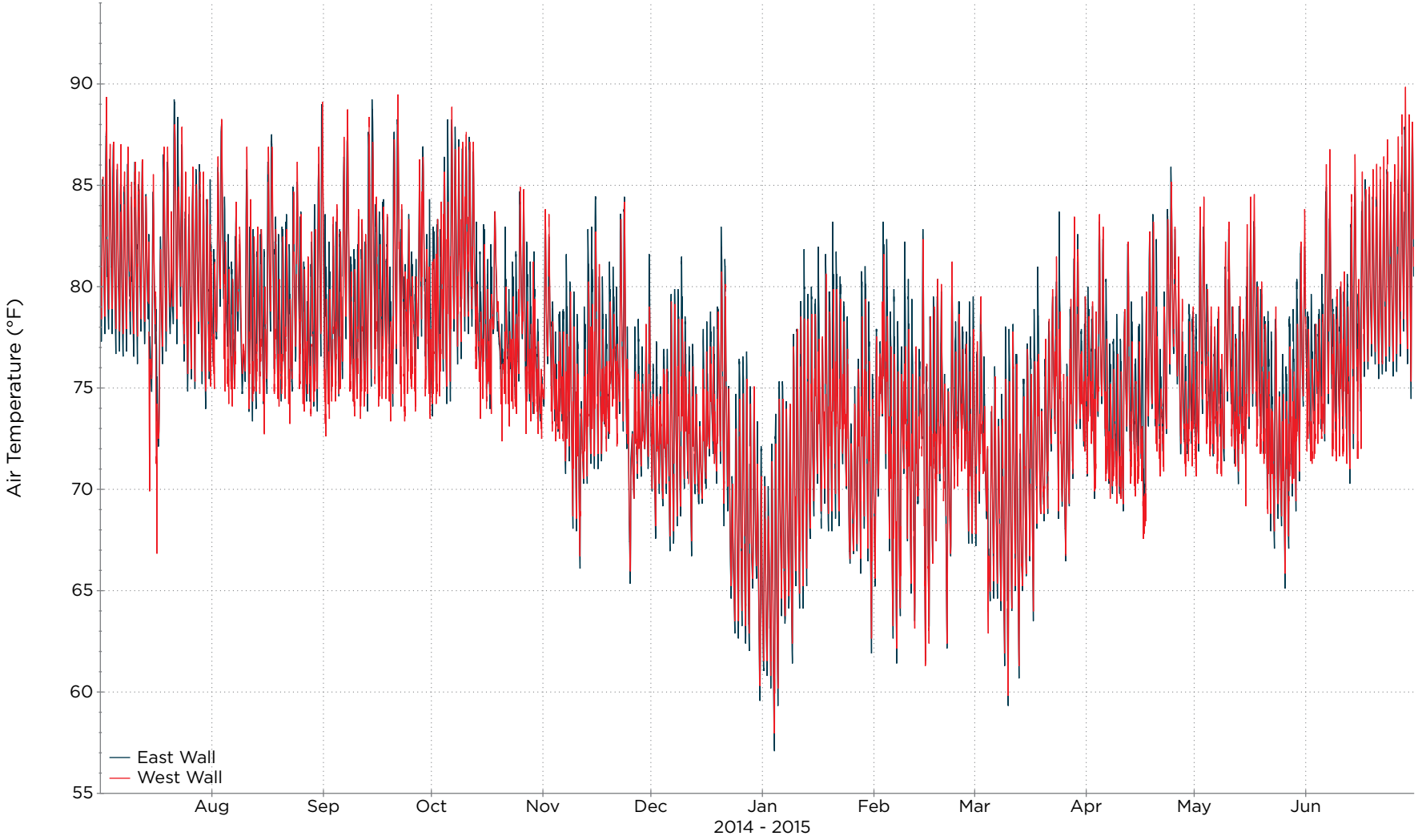


Kawaikini West: Indoor Air Temperatures

Description: Air temperature measured in 10 minute intervals at the east and west walls at Kawaikini West

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: Over the full study period, the average air temperature at the east wall was 76.3°F and at the west wall was 75.6°F.

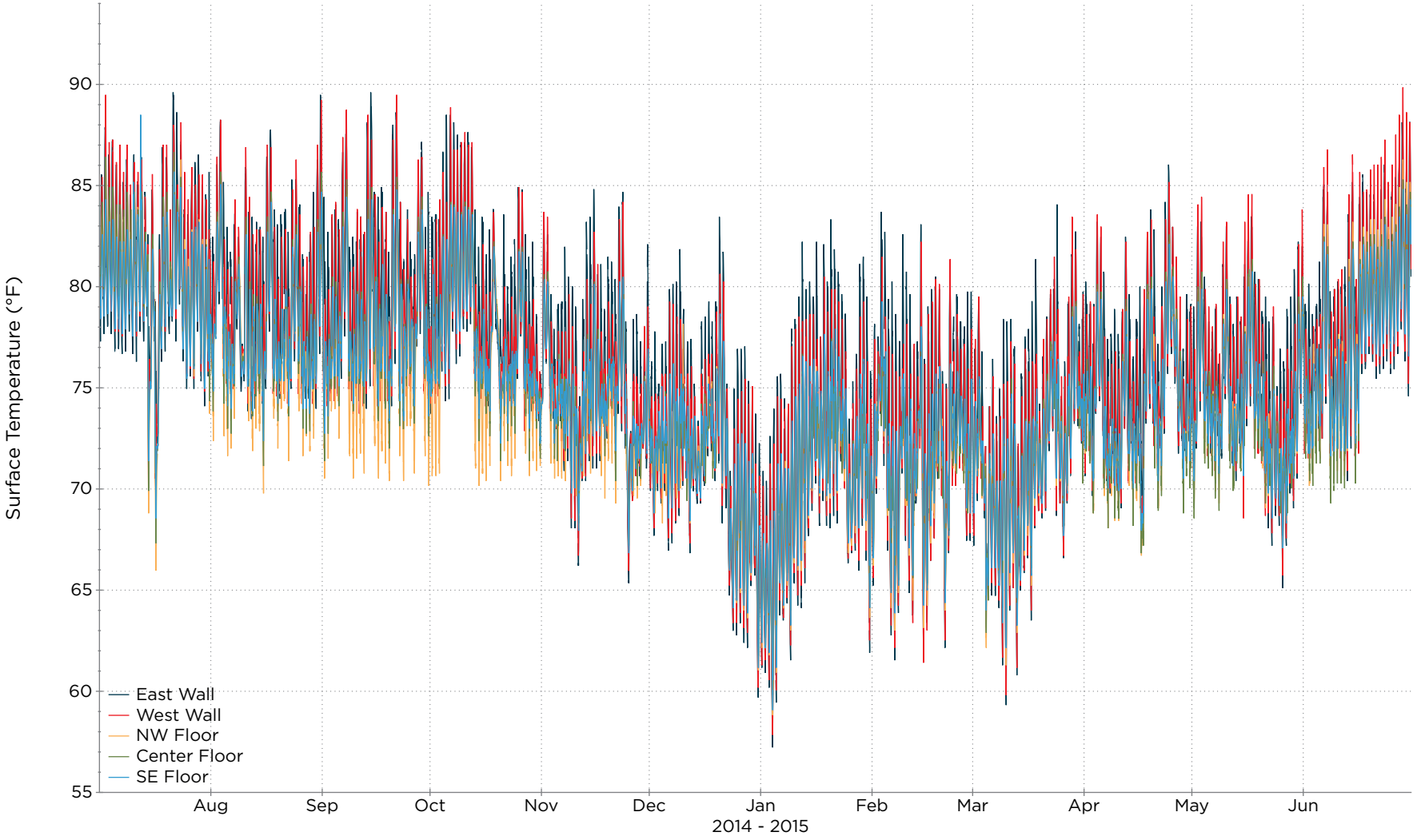


Kawaikini West: Indoor Surface Temperatures

Description: Surface temperature measured in 10 minute intervals at the east and west walls as well as at the northwest, center and southeast floor areas at Kawaikini West

Findings: Over the full study period, the average surface temperature at the east wall was 76.4°F, at the west wall was 75.5°F, at the northwest area of the floor was 74.6°F, at the center area of the floor was 75.0°F, and at the southeast area of the floor was 75.0°F.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

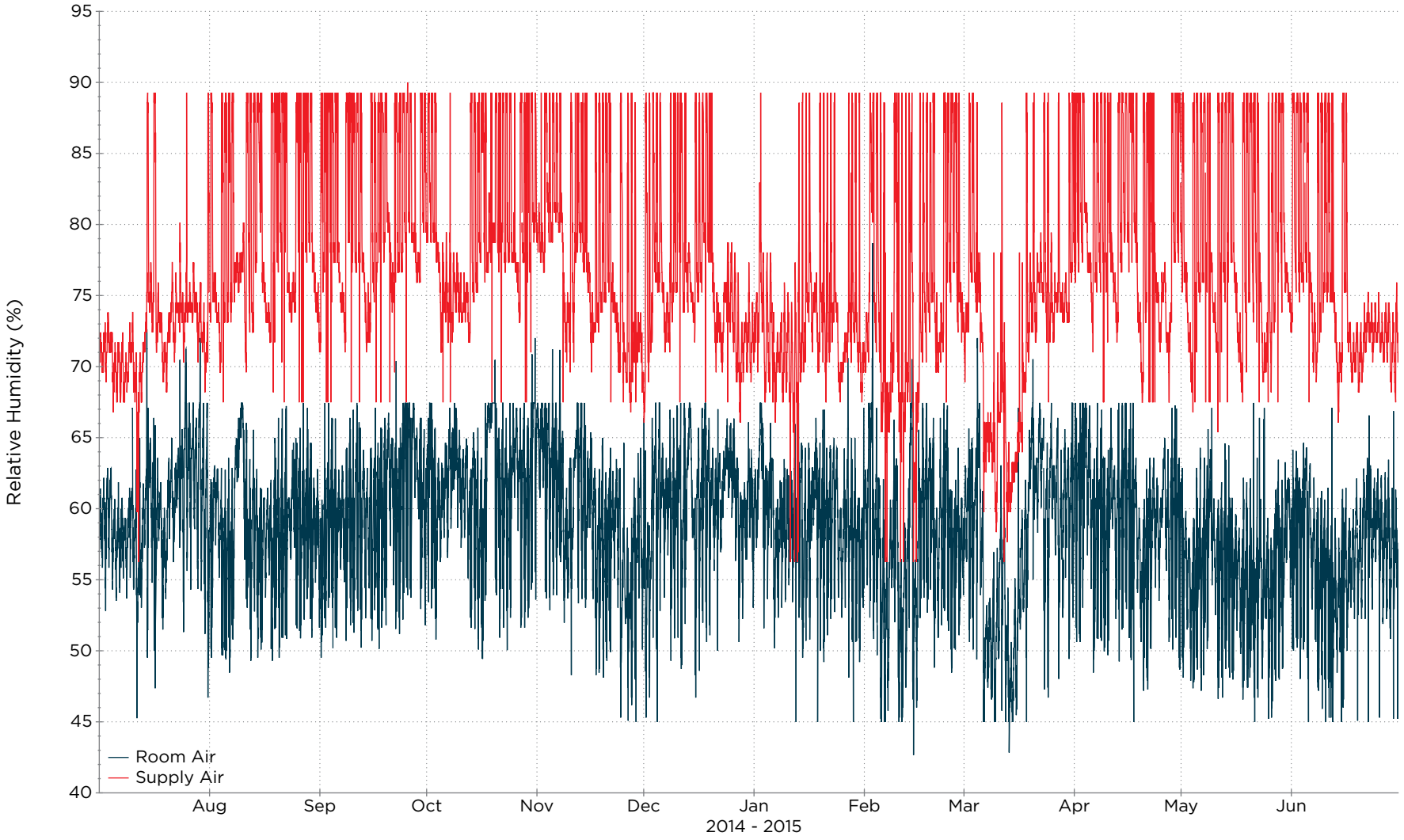


Kawaikini West: Indoor Relative Humidities

Description: Relative humidity measured in 10 minute intervals in the room and near the AC supply air at Kawaikini West.

Findings: Over the full study period, the average relative humidity in the room was 58.9% and near the supply air was 77.0%.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

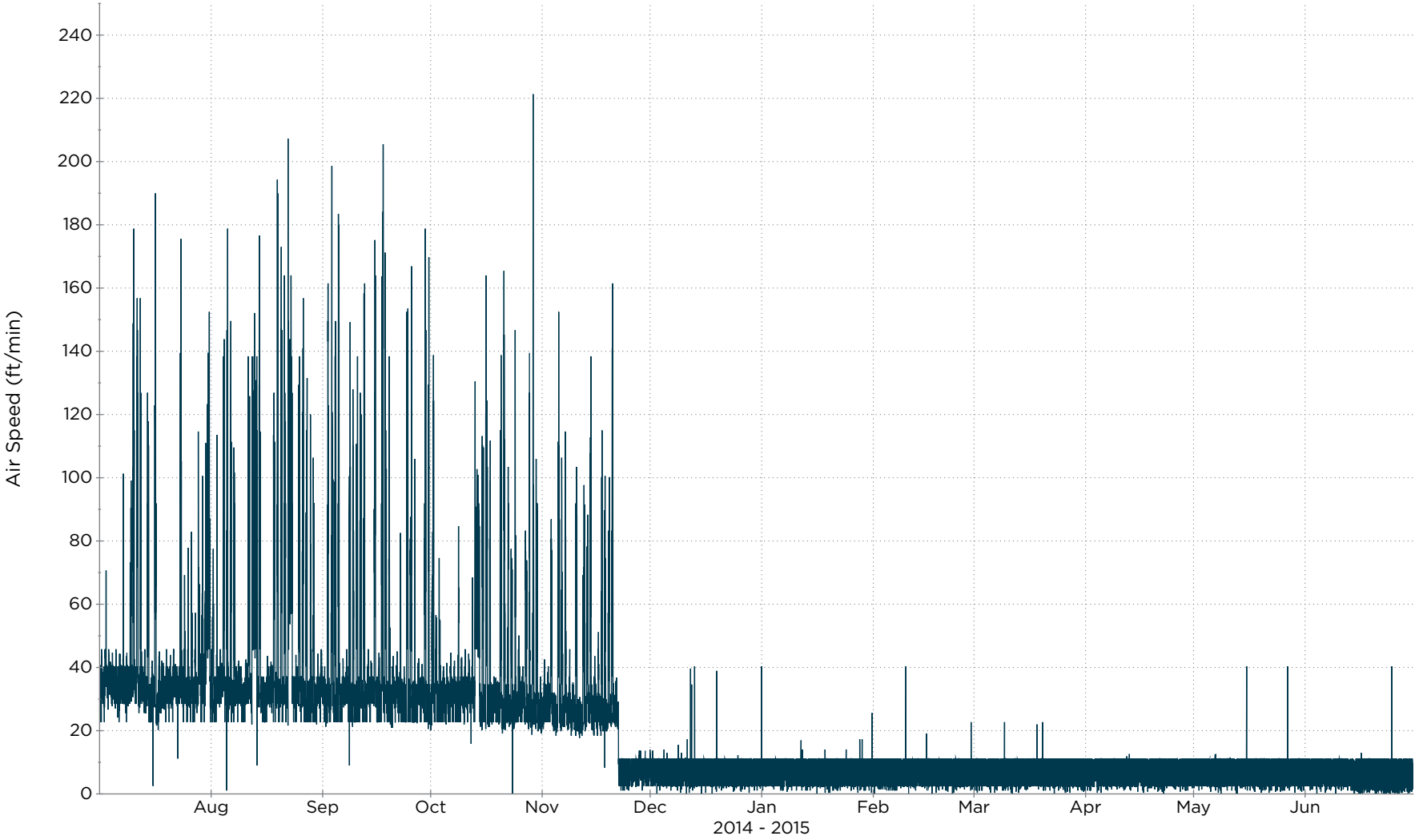


Kawaikini West: Indoor Air Speed

Description: Indoor air speed measured in 10 minute intervals at Kawaikini West.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: An unknown issue with the sensor caused the air speed readings to dramatically change in November 2014. As a consequence, this air speed data was not used as an input for calculating the PMV score. A constant value (industry average of 45 ft/min)[1] was instead used for the PMV function.



1: Reference from ASHRAE 55

Ilima: Air Supply Plenum Temperatures

Description: Air temperatures measured in 10 minute intervals from three floor plenums, the supply air temperature, and the ambient room air temperature at Ilima.

Findings: Plenum air temperatures in Ilima were within 10°F of supply air temperatures 91% of the time during school hours when the AC was on.

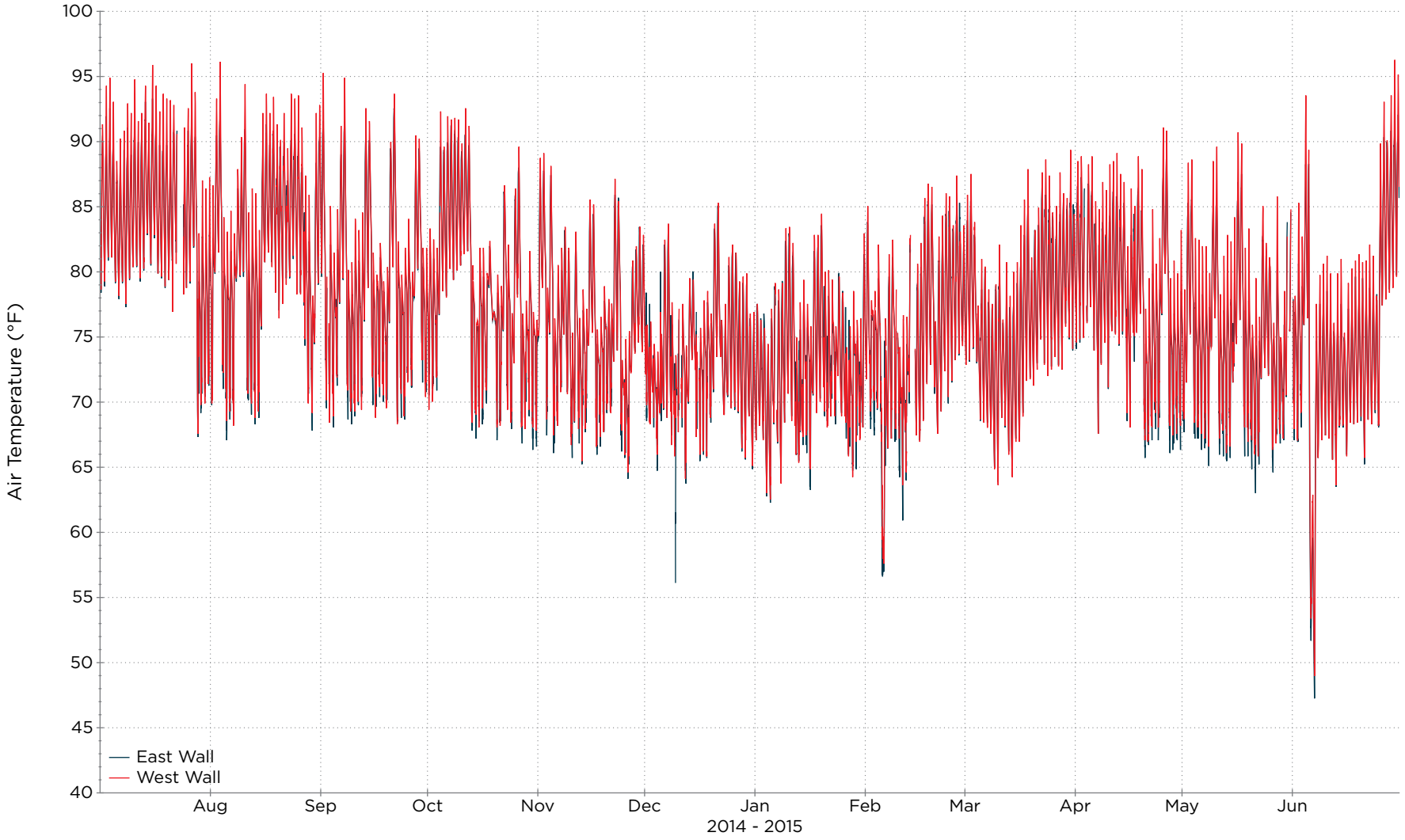
Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Ilima: Indoor Air Temperatures

Description: Air temperature measured in 10 minute intervals at the east and west walls at Ilima

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: Over the full study period, the average air temperature at the east wall was 77.2°F and at the west wall was 77.4°F.



Ilima: Indoor Surface Temperatures

Description: Surface temperature measured in 10 minute intervals at the east and west walls as well as at the northwest, center and southeast floor areas at Ilima

Findings: Over the full study period, the average surface temperature at the east wall was 77.1°F, at the west wall was 77.2°F, at the northwest area of the floor was 75.5°F, at the center area of the floor was 75.1°F, and at the southeast area of the floor was 76.1°F.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Ilima: Indoor Relative Humidities

Description: Relative humidity measured in 10 minute intervals in the room and near the AC supply air at Ilima

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

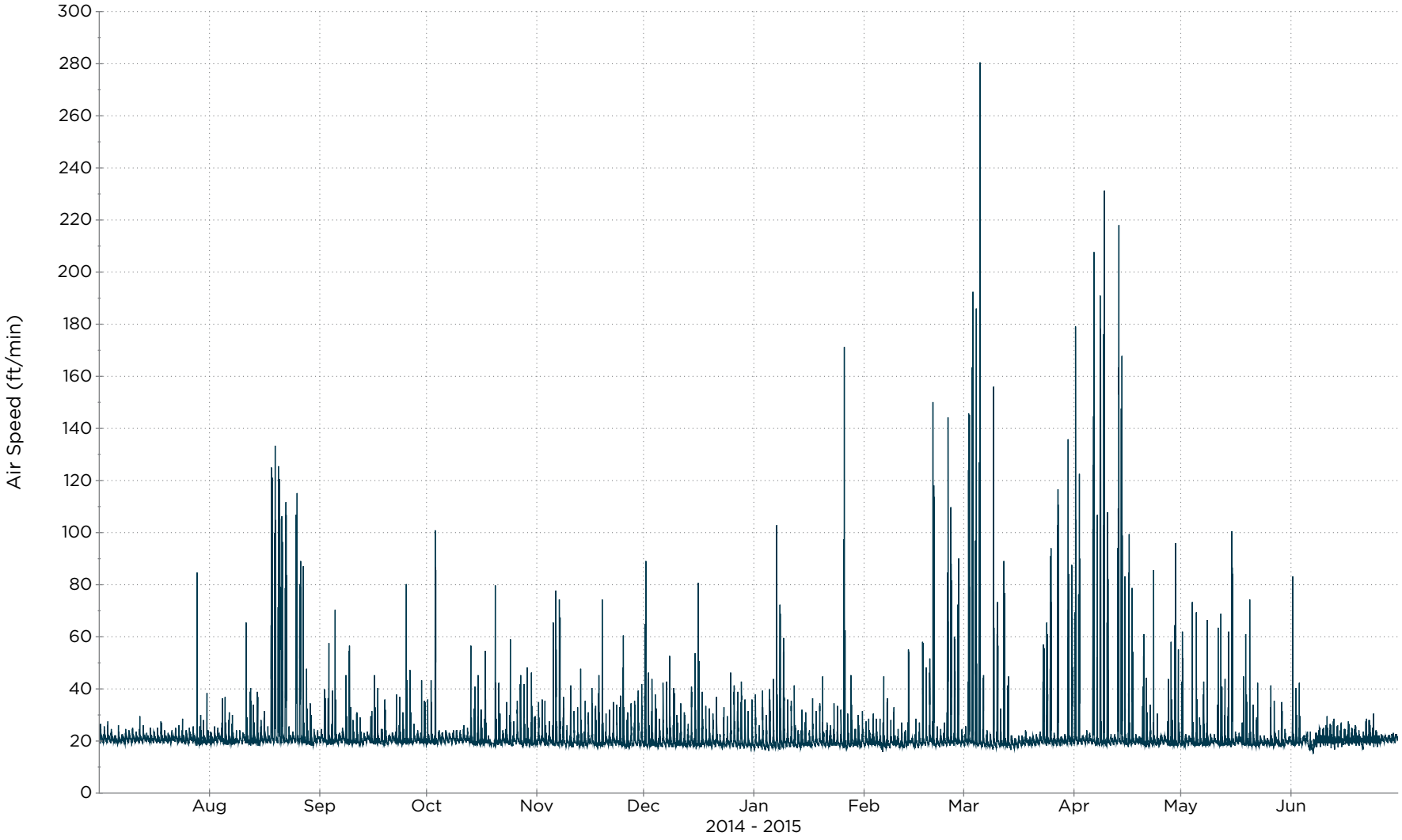
Findings: Over the full study period, the average relative humidity in the room was 58.2% and near the supply air was 71.7%.

Ilima: Indoor Air Speed

Description: Indoor air speed measured in 10 minute intervals at Ilima

Findings: Over the full study period, the average indoor air speed was 21.4 ft/min.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

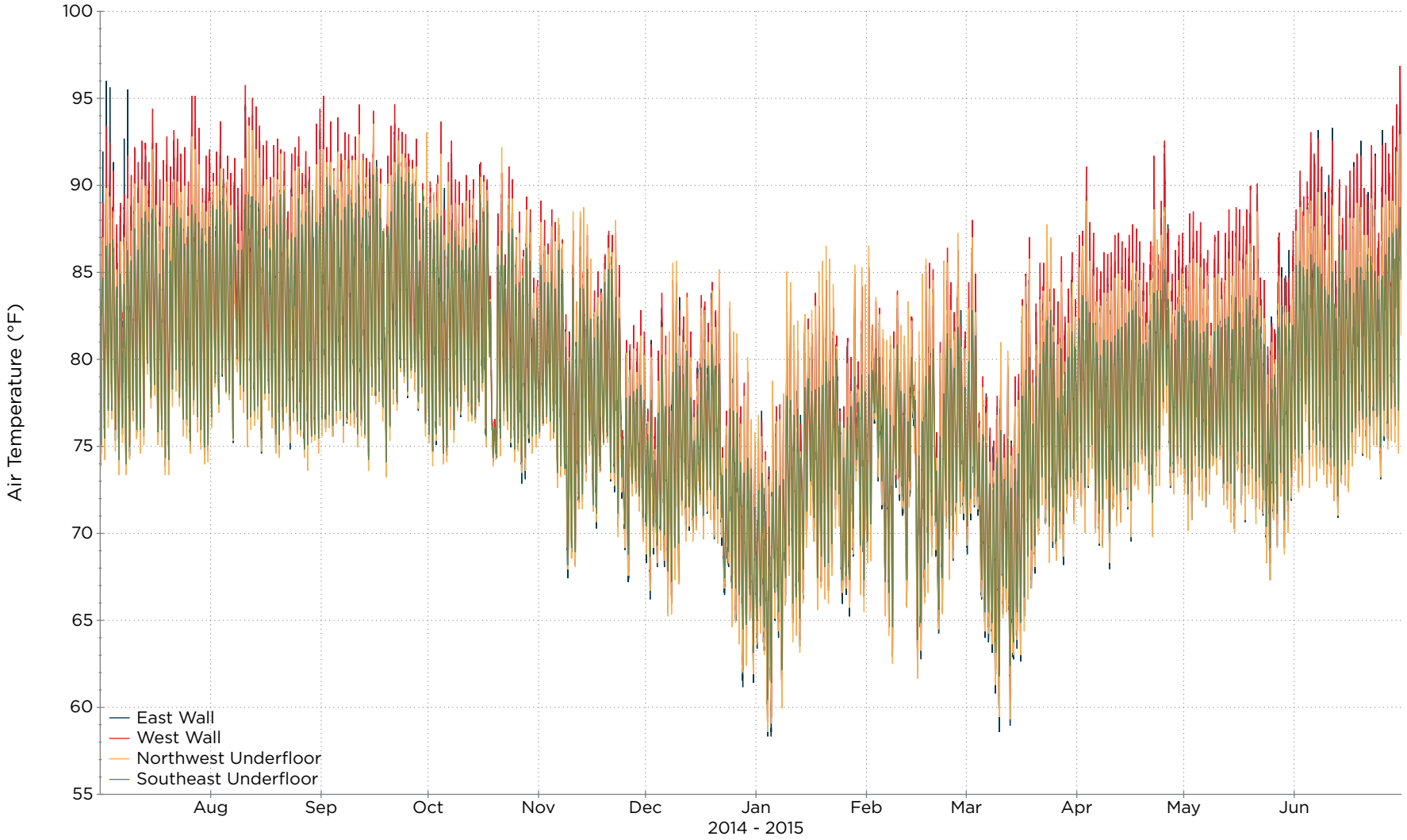


P6: Indoor Air Temperatures

Description: Air temperature measured in 10 minute intervals at the east and west walls and under the northwest and southeast areas of the floor at P6

Findings: Over the full study period, the average air temperature at the east wall was 78.8°F, at the west wall was 79.4°F, under the northwest area of the floor was 77.7°F, and under the southeast area of the floor was 78.4°F.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

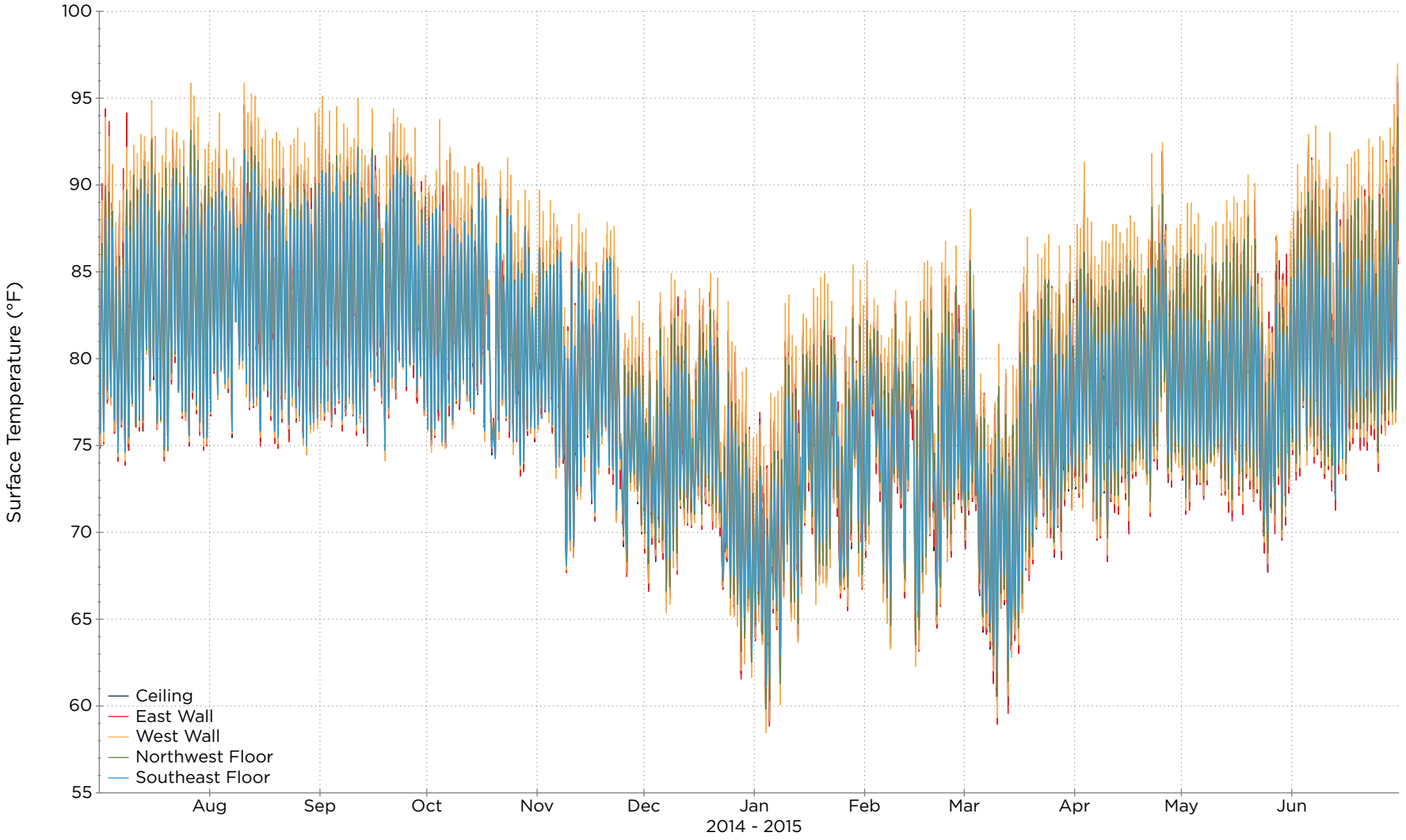


P6: Indoor Surface Temperatures

Description: Surface temperature measured in 10 minute intervals at the ceiling, at the east and west walls and at the northwest and southeast floor areas at P6.

Findings: Over the full study period, the average surface temperature at the ceiling was 79.1°F, at the east wall was 79.1°F, at the west wall was 79.3°F, at the northwest area of the floor was 78.7°F, and at the southeast area of the floor was 78.5°F.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

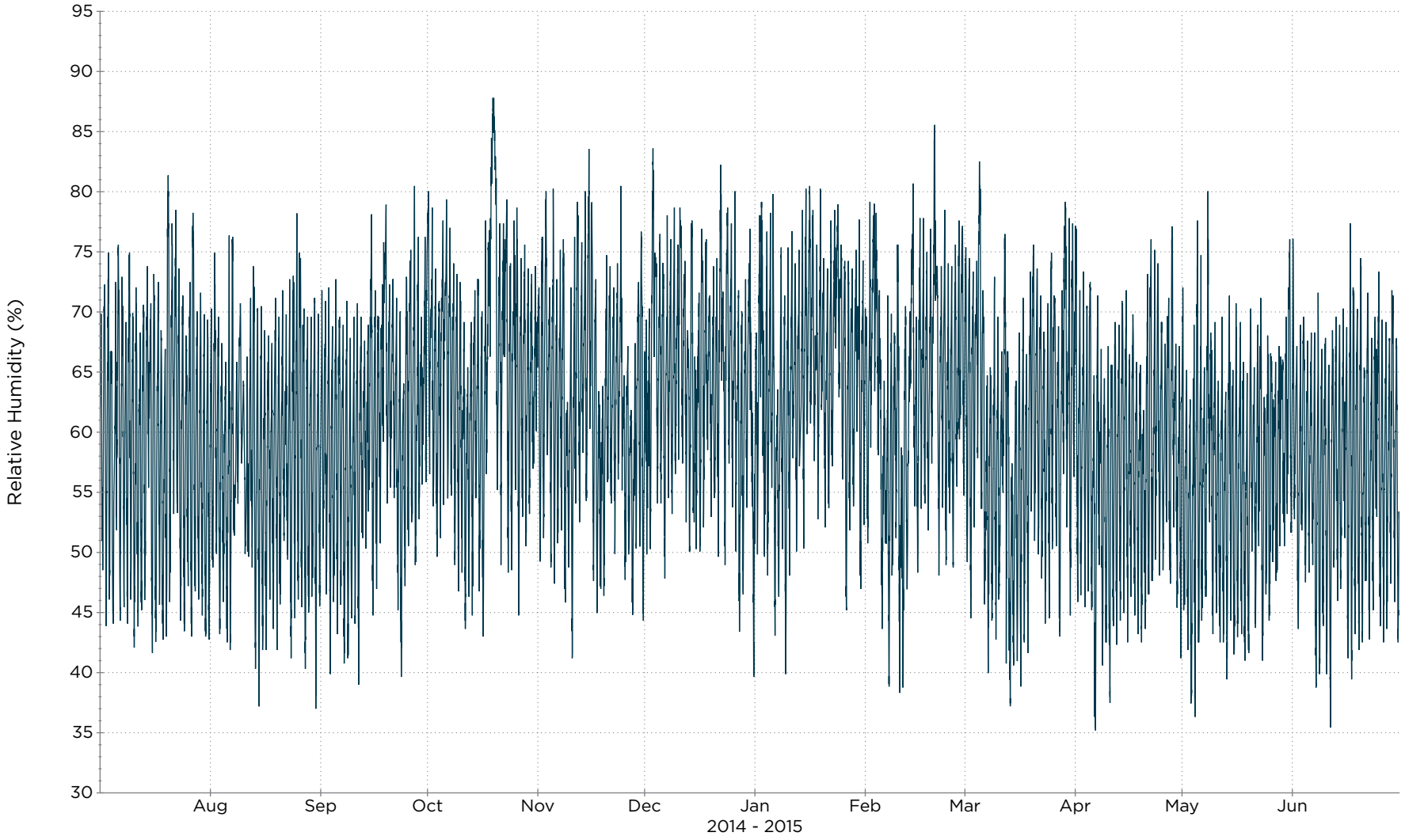


P6: Indoor Relative Humidity

Description: Relative humidity measured in 10 minute intervals at P6.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: Over the full study period, the average relative humidity in the room was 60.8%.

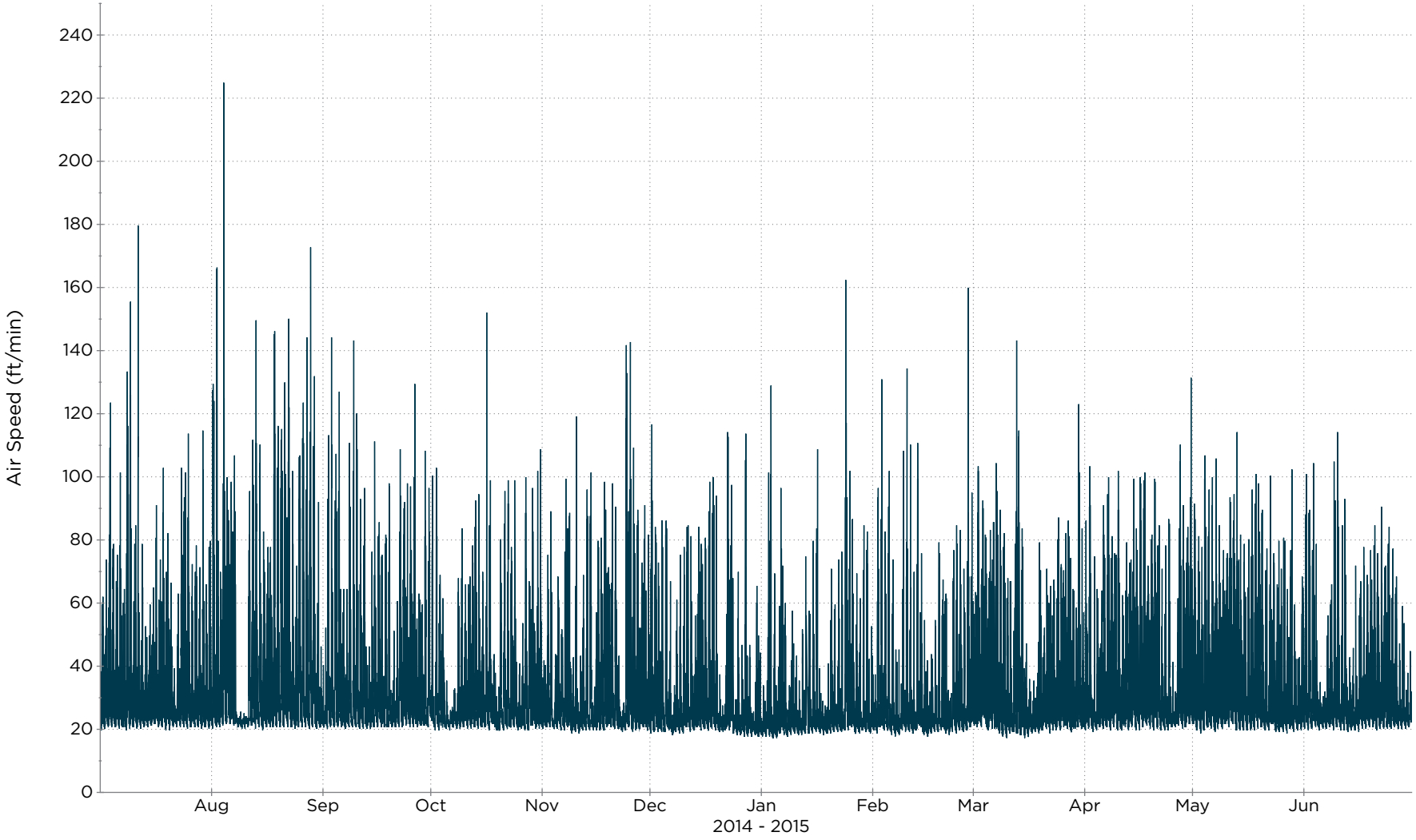


P6: Indoor Air Speed

Description: Indoor air speed measured in 10 minute intervals at P6.

Findings: Over the full study period, the average indoor air speed was 29.5 ft/min.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

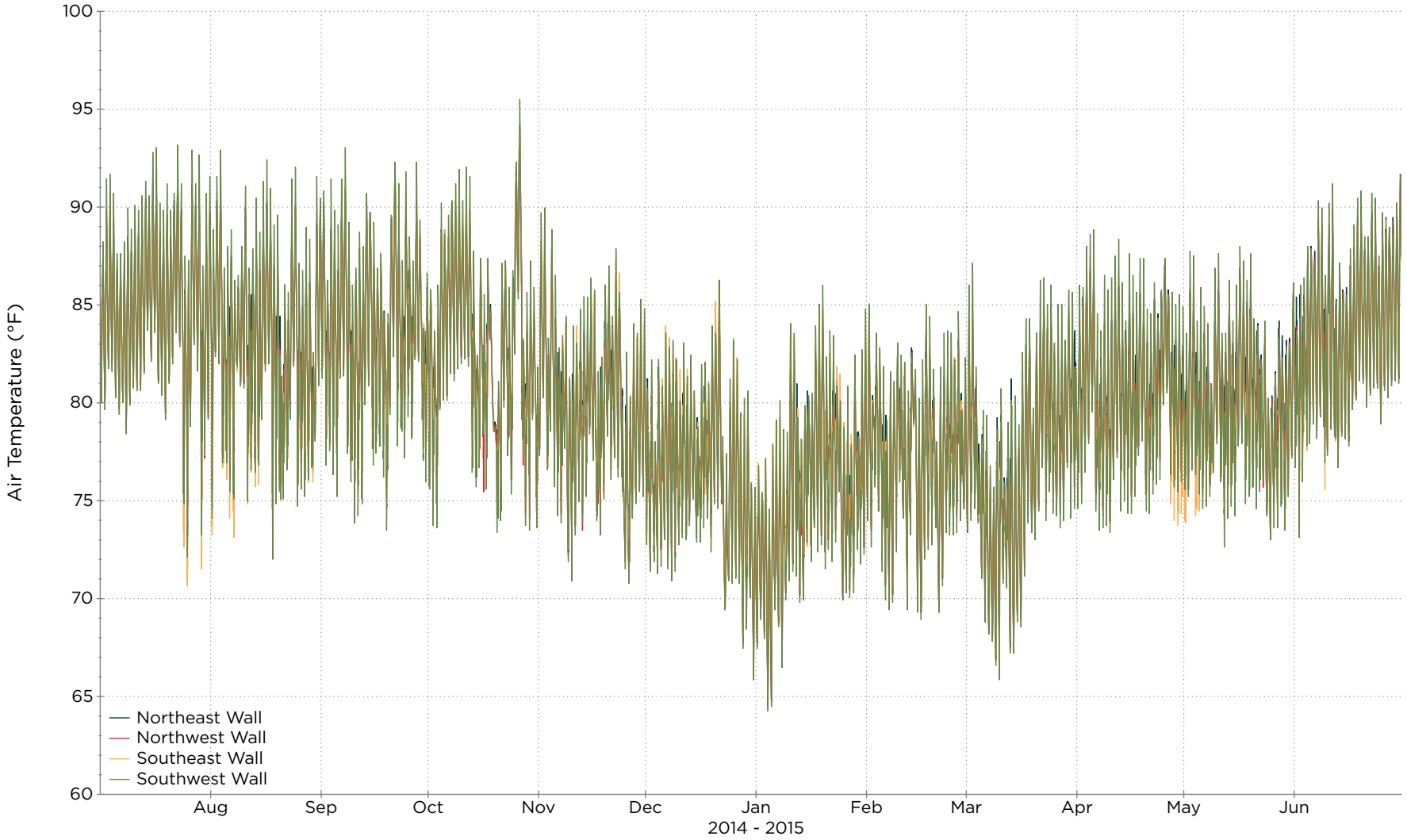


P1: Indoor Air Temperatures

Description: Air temperature measured in 10 minute intervals at the northeast, northwest, southeast and southwest walls at P1.

Findings: Over the full study period, the average air temperature at the northeast wall was 80.7°F, at the northwest wall was 80.4°F, at the southeast area of the floor was 80.5°F, and at the southwest area of the floor was 80.5°F.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

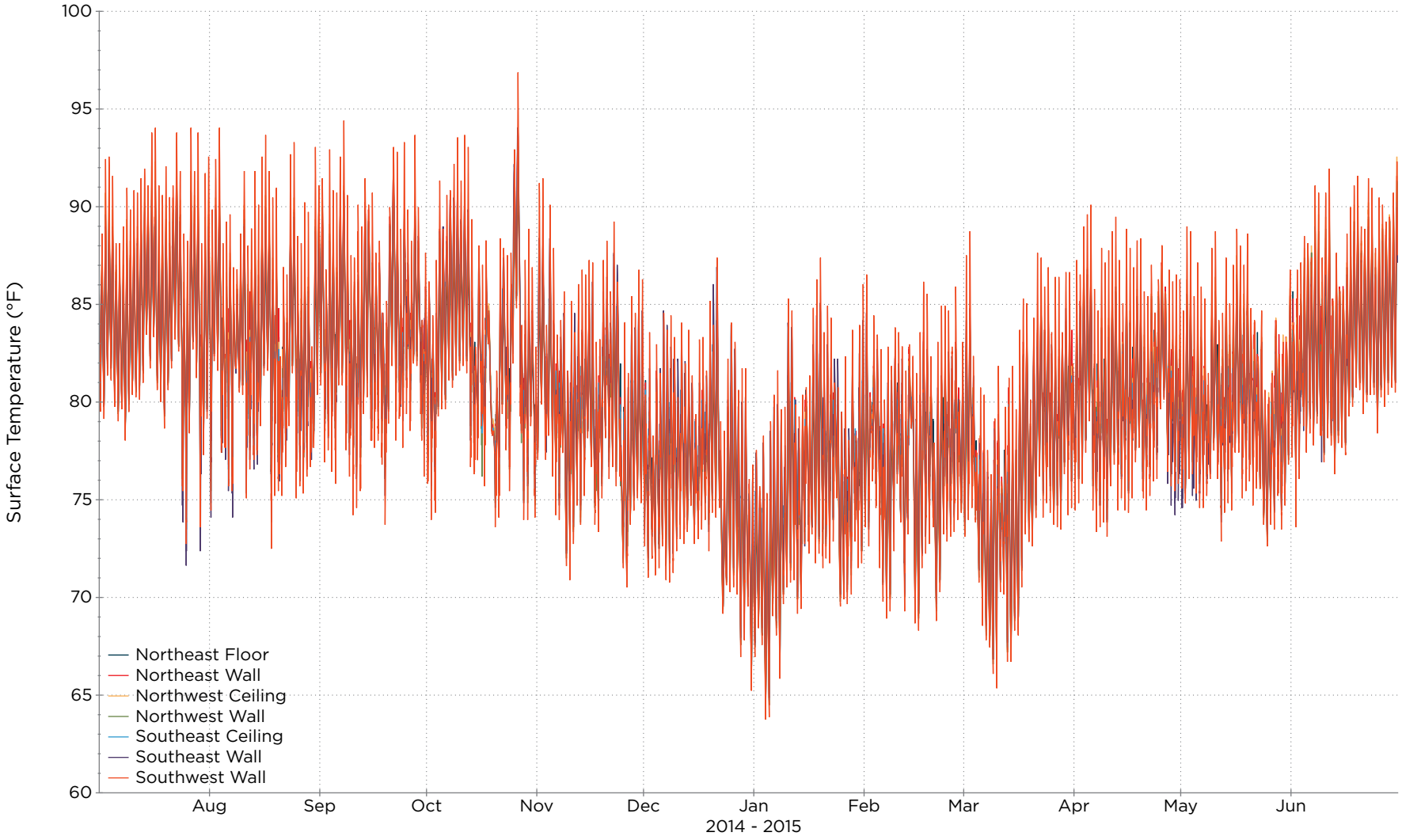


P1: Indoor Surface Temperatures

Description: Surface temperature measured in 10 minute intervals at the northwest and southeast areas of the ceiling, at the northeast, northwest, southeast and southwest walls and at the northeast floor area at P1

Findings: Over the full study period, the average surface temperature at the northeast area of the floor was 79.7°F, at the northeast wall was 80.6°F, at the northwest area of the ceiling was 80.5°F, at the northwest wall was 80.2°F, at the southeast area of the ceiling was 80.4°F, at the southeast wall was 80.5°F, and at the southwest wall was 80.5°F.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

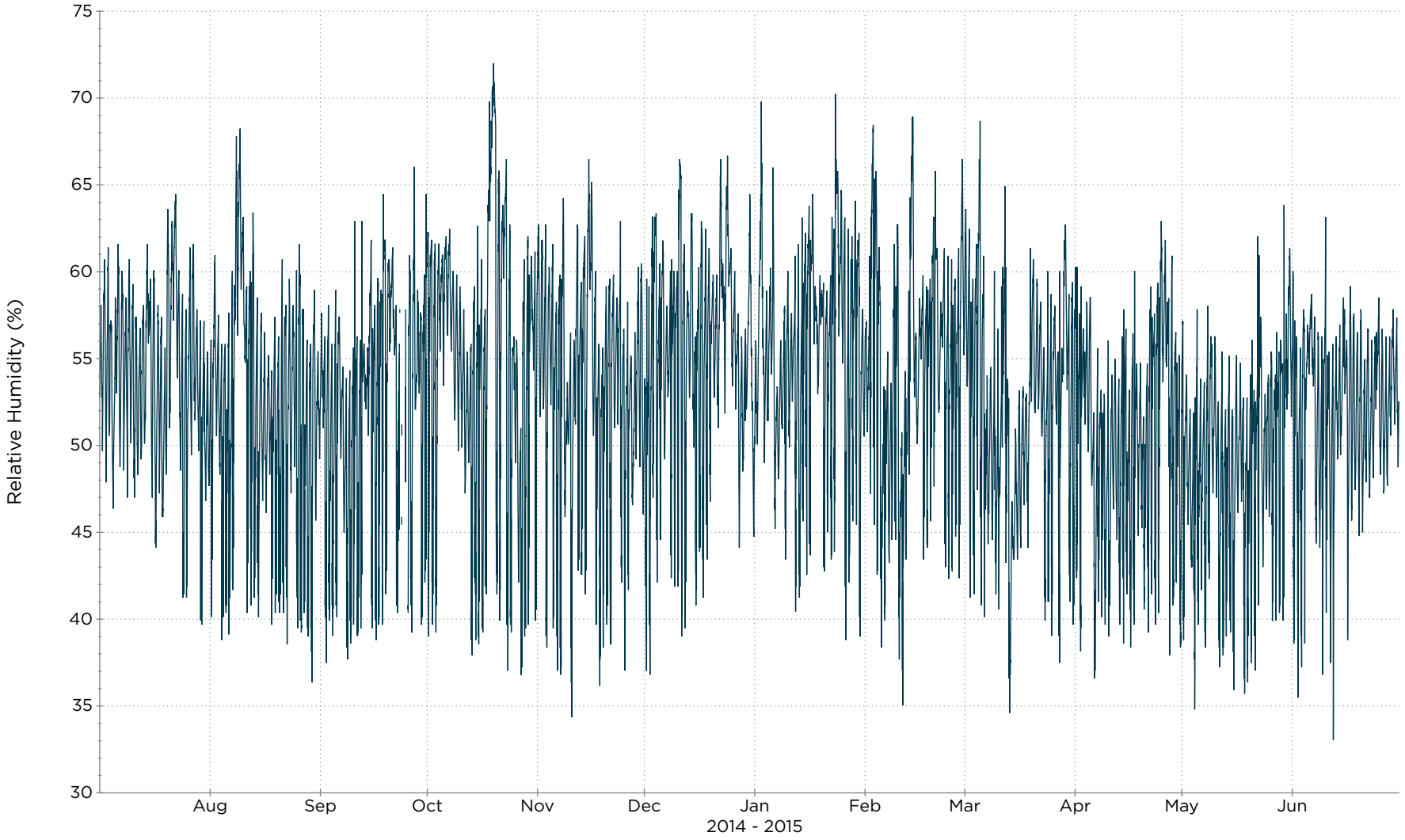


P1: Indoor Relative Humidity

Description: Relative humidity measured in 10 minute intervals at P1.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

Findings: Over the full study period, the average relative humidity in the room was 52.8%.

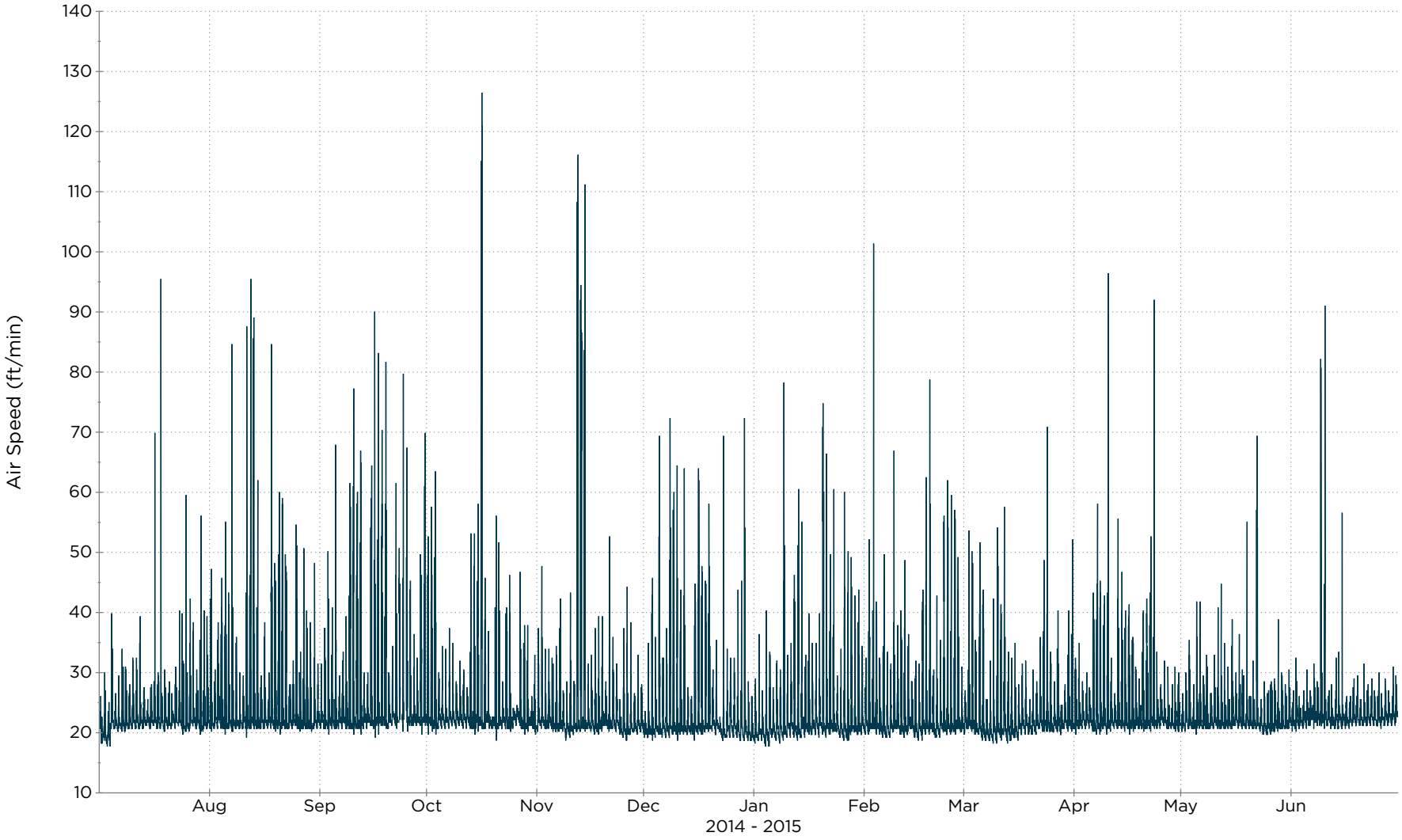


P1: Indoor Air Speed

Description: Indoor air speed measured in 10 minute intervals at P1.

Findings: Over the full study period, the average indoor air speed was 22.8 ft/min.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

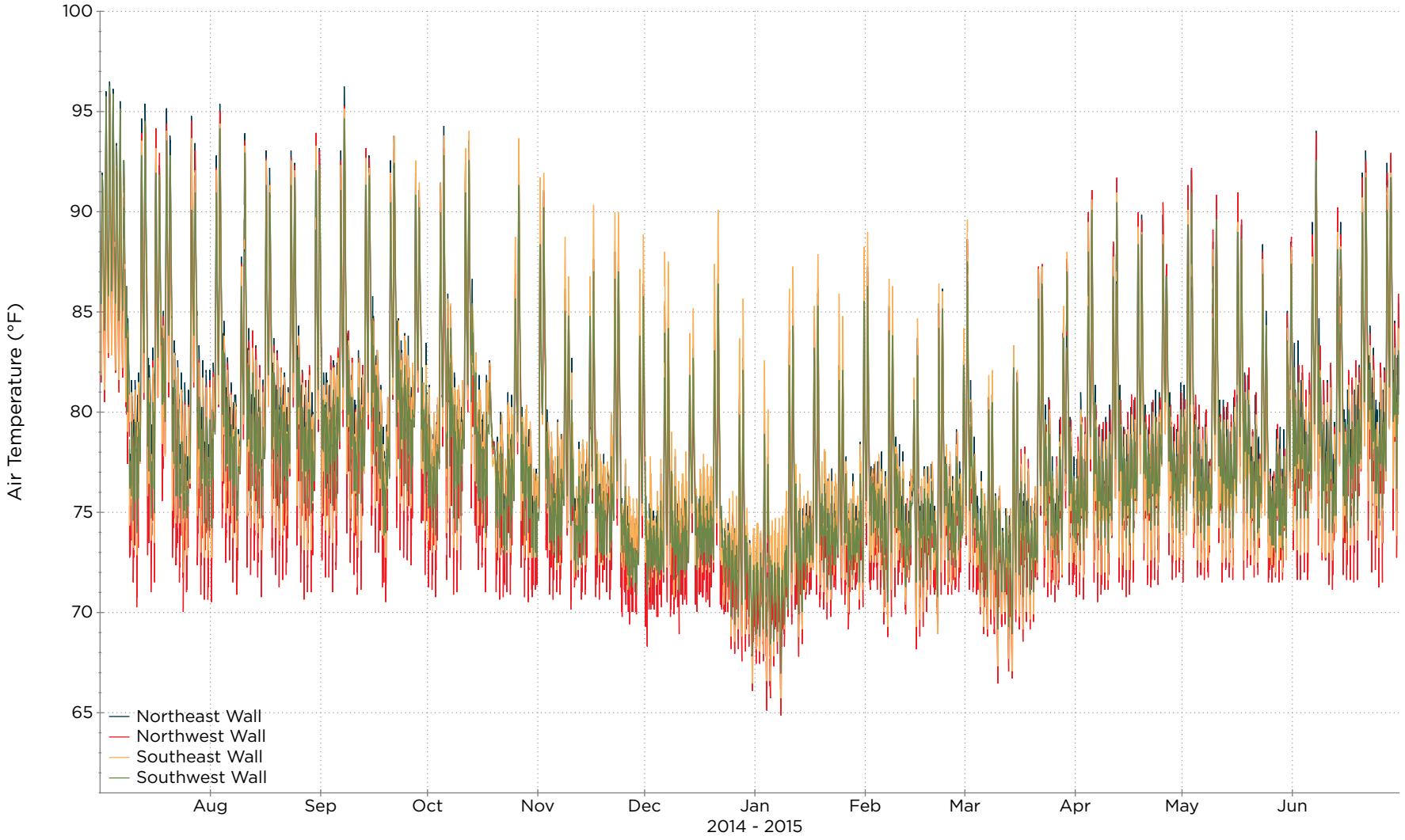


D36: Indoor Air Temperatures

Description: Air temperature measured in 10 minute intervals at the northeast, northwest, southeast and southwest walls at D36.

Findings: Over the full study period, the average air temperature at the northeast wall was 78.6°F, at the northwest wall was 77.4°F, at the southeast area of the floor was 78.2°F, and at the southwest area of the floor was 78.1°F.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

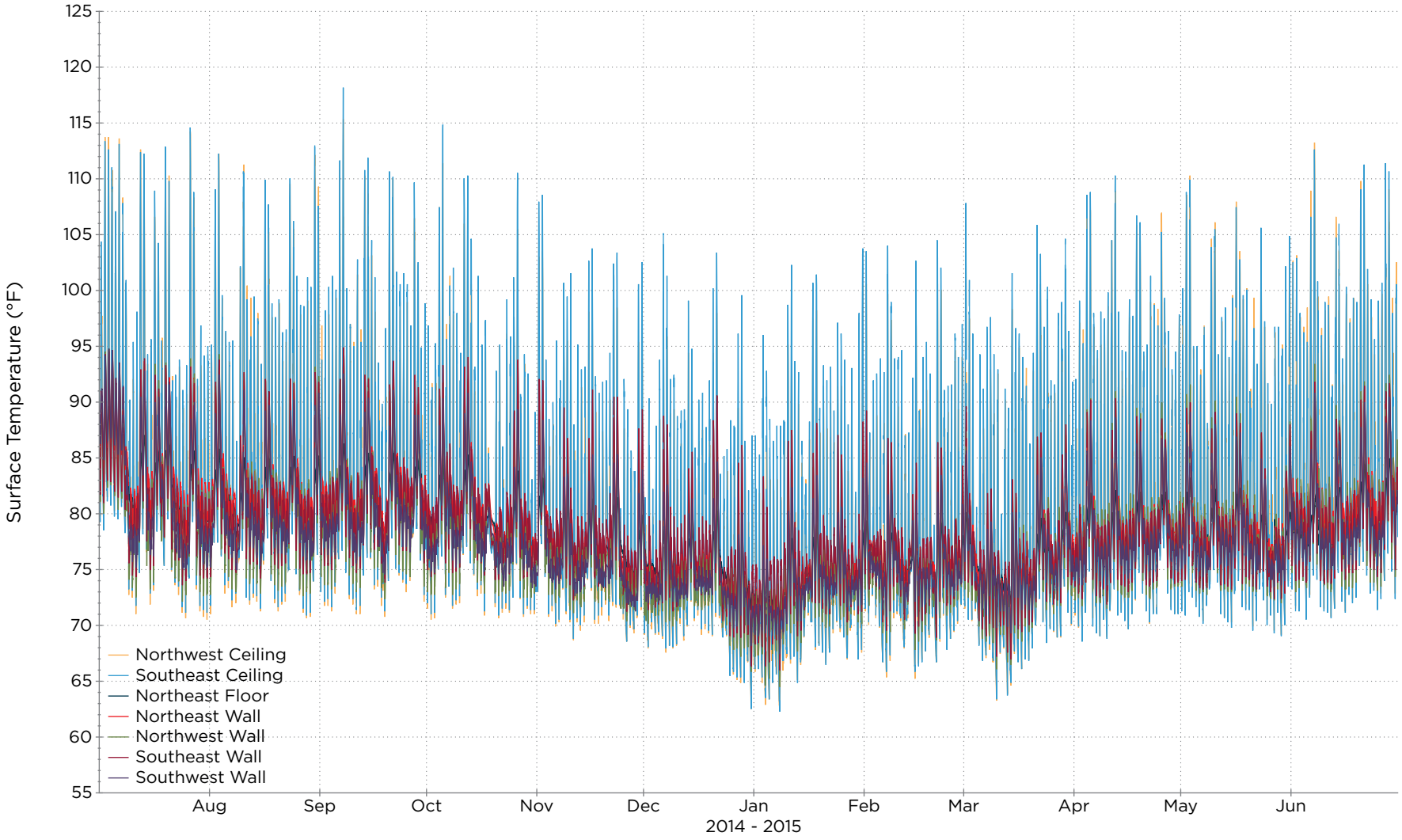


D36: Indoor Surface Temperatures

Description: Surface temperature measured in 10 minute intervals at the northwest and southeast areas of the ceiling, at the northeast, northwest, southeast and southwest walls and at the northeast floor area at D36.

Findings: Over the full study period, the average surface temperature at the northwest area of the ceiling was 80.6°F, at the southeast area of the ceiling was 81.2°F, at the northeast area of the floor was 78.3°F, at the northeast wall was 79.5°F, at the northwest wall was 77.9°F, at the southeast wall was 78.8°F, and at the southwest wall was 78.0°F.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

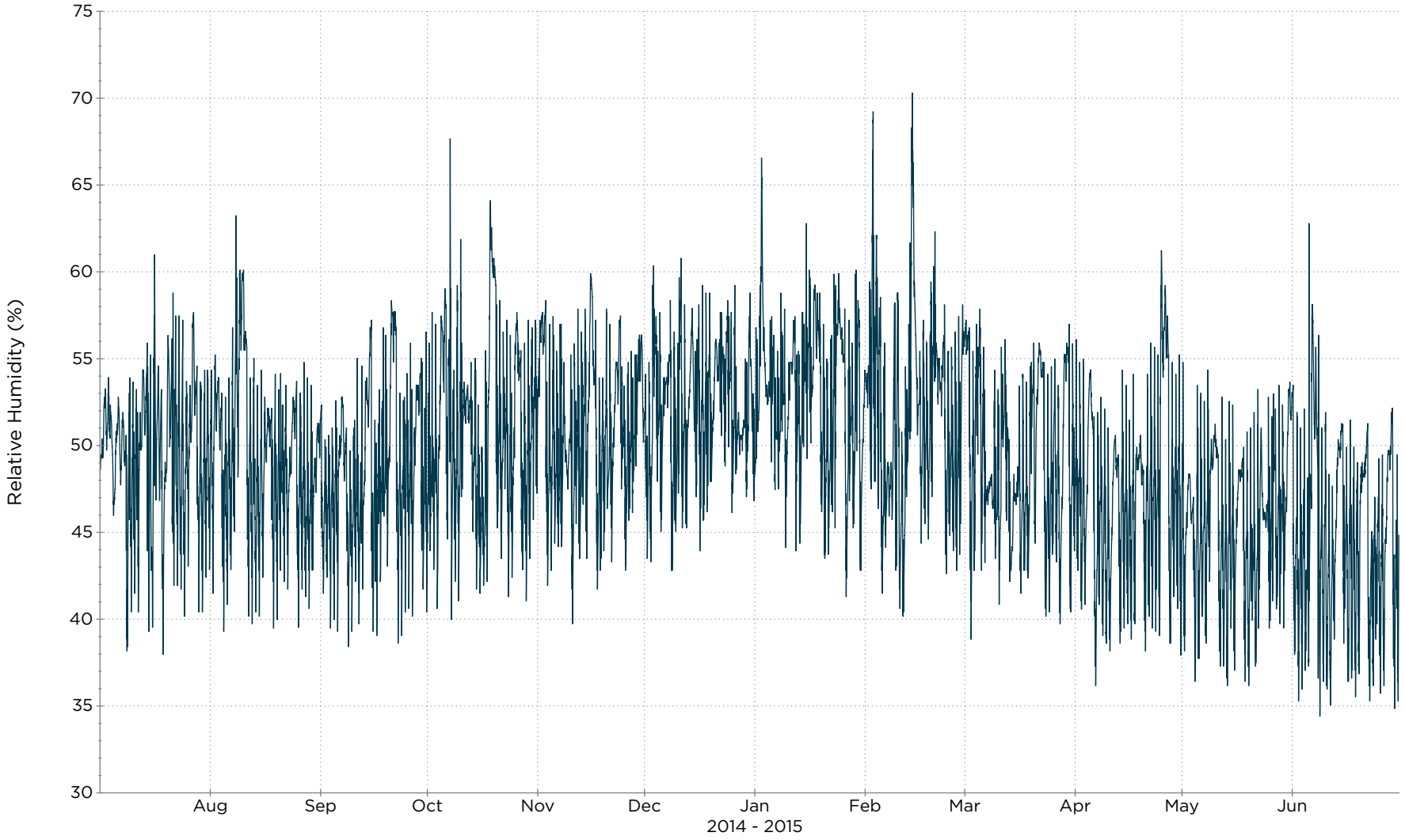


D36: Indoor Relative Humidity

Description: Relative humidity measured in 10 minute intervals at D36.

Findings: Over the full study period, the average relative humidity in the room was 49.2%.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours

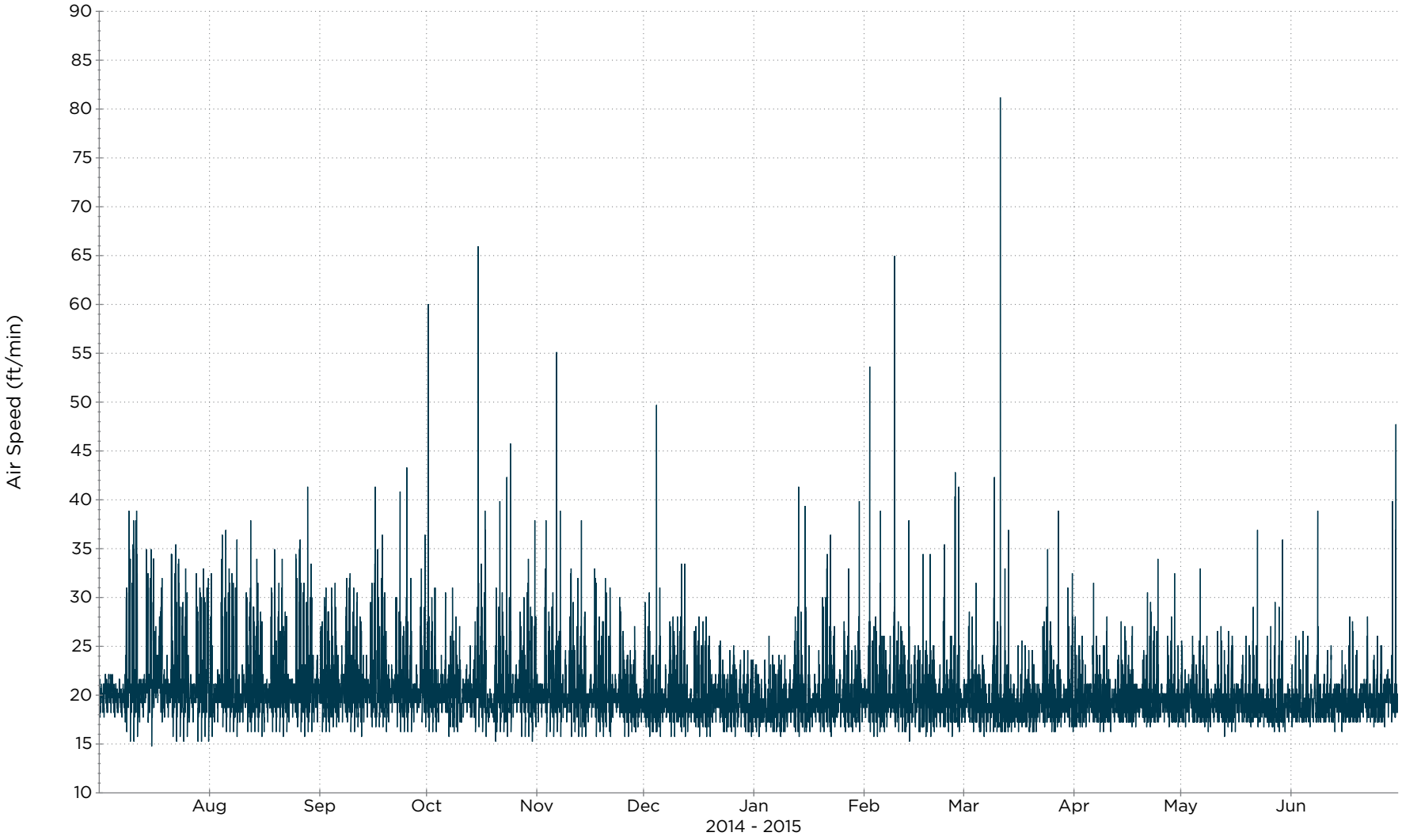


D36: Indoor Air Speed

Description: Indoor air speed measured in 10 minute intervals at D36

Findings: Over the full study period, the average indoor air speed was 19.9 ft/min.

Study Period: 07/01/2014 - 06/30/2015
Days: All Days
Hours: All Hours



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Lihu'e Weather vs. Kawaikini East Energy/Thermal Comfort

Description: These tables show the outputs of linear regression analyses performed for the following pairs of variables: Average Lihu'e Weather vs. Kawaikini East AC Energy, Max Lihu'e Weather vs. Kawaikini East AC Energy, Average Lihu'e Weather vs. Kawaikini East Lighting Energy, Average Lihu'e Weather vs. Kawaikini East PMV

Average Lihu'e Weather vs. Kawaikini East AC Energy						
OVERALL FIT						
Multiple R	0.709					
R Square	0.502					
Adjusted R Square	0.474					
Standard Error	12.887					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	11721.205	2930.301	17.644	0.000	yes
Residual	70	11625.754	166.082			
Total	74	23346.959				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-192.024	61.439	-3.125	0.003	-314.560	-69.489
Temp	0.446	0.910	0.490	0.626	-1.369	2.262
%RH	1.443	0.442	3.265	0.002	0.561	2.324
Wind Speed	2.897	2.128	1.361	0.178	-1.348	7.142
Solar Rad	0.210	0.033	6.318	0.000	0.144	0.276

Max Lihu'e Weather vs. Kawaikini East AC Energy						
OVERALL FIT						
Multiple R	0.547					
R Square	0.299					
Adjusted R Square	0.259					
Standard Error	15.288					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	6986.865	1746.716	7.474	0.000	yes
Residual	70	16360.094	233.716			
Total	74	23346.959				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-189.799	72.374	-2.622	0.011	-334.145	-45.454
Max Temp	1.299	0.928	1.400	0.166	-0.551	3.149
Max RH	0.499	0.596	0.837	0.405	-0.690	1.688
Max Wind Speed	0.741	0.977	0.758	0.451	-1.207	2.689
Max Solar Rad	0.039	0.014	2.777	0.007	0.011	0.066

Findings: Among these four pairs, the strongest correlation occurred between average Lihu'e weather and Kawaikini East PMV (r^2=0.885).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Average Lihu'e Weather vs. Kawaikini East Lighting Energy						
OVERALL FIT						
Multiple R	0.460					
R Square	0.212					
Adjusted R Square	0.167					
Standard Error	1.385					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	36.070	9.017	4.704	0.002	yes
Residual	70	134.189	1.917			
Total	74	170.259				
	coeff	std err	t stat	p-value	lower	upper
Intercept	18.467	6.601	2.798	0.007	5.302	31.632
Temp	-0.196	0.098	-2.001	0.049	-0.391	-0.001
%RH	-0.020	0.047	-0.413	0.681	-0.114	0.075
Wind Speed	0.205	0.229	0.895	0.374	-0.251	0.661
Solar Rad	-0.007	0.004	-1.876	0.065	-0.014	0.000

Average Lihu'e Weather vs. Kawaikini East PMV						
OVERALL FIT						
Multiple R	0.941					
R Square	0.885					
Adjusted R Square	0.879					
Standard Error	0.131					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	9.342	2.335	135.216	0.0	yes
Residual	70	1.209	0.017			
Total	74	10.551				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-10.453	0.627	-16.683	0.0	-11.702	-9.203
Temp	0.137	0.009	14.739	0.0	0.118	0.155
%RH	0.008	0.005	1.875	0.065	-0.001	0.017
Wind Speed	-0.040	0.022	-1.852	0.068	-0.083	0.003
Solar Rad	0.002	0.000	4.900	0.000	0.001	0.002

Lihu'e Weather vs. Kawaikini West Energy/Thermal Comfort

Description: These tables show the outputs of linear regression analyses performed for the following pairs of variables: Average Lihu'e Weather vs. Kawaikini West AC Energy, Max Lihu'e Weather vs. Kawaikini West AC Energy, Average Lihu'e Weather vs. Kawaikini West Lighting Energy, Average Lihu'e Weather vs. Kawaikini West PMV

Average Lihu'e Weather vs. Kawaikini West AC Energy						
OVERALL FIT						
Multiple R	0.829					
R Square	0.687					
Adjusted R Square	0.669					
Standard Error	2.305					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	817.581	204.395	38.461	0.0	yes
Residual	70	372.005	5.314			
Total	74	1189.586				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-74.988	10.990	-6.823	0.000	-96.907	-53.069
Temp	1.142	0.163	7.013	0.000	0.817	1.467
%RH	0.004	0.079	0.046	0.964	-0.154	0.161
Wind Speed	-1.184	0.381	-3.111	0.003	-1.943	-0.425
Solar Rad	0.023	0.006	3.954	0.000	0.012	0.035

Max Lihu'e Weather vs. Kawaikini West AC Energy						
OVERALL FIT						
Multiple R	0.806					
R Square	0.650					
Adjusted R Square	0.630					
Standard Error	2.438					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	773.685	193.421	32.555	0.0	yes
Residual	70	415.901	5.941			
Total	74	1189.586				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-60.677	11.539	-5.258	0.000	-83.692	-37.663
Max Temp	0.717	0.148	4.845	0.000	0.422	1.012
Max RH	-0.007	0.095	-0.075	0.941	-0.197	0.182
Max Wind Speed	0.512	0.156	3.288	0.002	0.201	0.823
Max Solar Rad	0.009	0.002	3.958	0.000	0.004	0.013

Findings: Among these four pairs, the strongest correlation occurred between average Lihu'e weather and Kawaikini West PMV (r^2=0.805).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Average Lihu'e Weather vs. Kawaikini West Lighting Energy						
OVERALL FIT						
Multiple R	0.240					
R Square	0.058					
Adjusted R Square	0.004					
Standard Error	1.683					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	12.143	3.036	1.072	0.377	no
Residual	70	198.288	2.833			
Total	74	210.431				
	coeff	std err	t stat	p-value	lower	upper
Intercept	4.932	8.024	0.615	0.541	-11.071	20.935
Temp	0.072	0.119	0.608	0.545	-0.165	0.309
%RH	-0.055	0.058	-0.960	0.340	-0.170	0.060
Wind Speed	-0.452	0.278	-1.625	0.109	-1.006	0.103
Solar Rad	-0.006	0.004	-1.435	0.156	-0.015	0.002

Average Lihu'e Weather vs. Kawaikini West PMV						
OVERALL FIT						
Multiple R	0.897					
R Square	0.805					
Adjusted R Square	0.794					
Standard Error	0.120					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	4.144	1.036	72.310	0.0	yes
Residual	70	1.003	0.014			
Total	74	5.146				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-6.483	0.571	-11.361	0.0	-7.621	-5.345
Temp	0.062	0.008	7.338	0.000	0.045	0.079
%RH	0.019	0.004	4.680	0.000	0.011	0.027
Wind Speed	0.048	0.020	2.453	0.017	0.009	0.088
Solar Rad	0.002	0.000	6.754	0.000	0.001	0.003

Honolulu Weather vs. Ilima Energy/Thermal Comfort

Description: These tables show the outputs of linear regression analyses performed for the following pairs of variables: Average Honolulu Weather vs. Ilima AC Energy, Max Honolulu Weather vs. Ilima AC Energy, Average Honolulu Weather vs. Ilima Lighting Energy, Average Honolulu Weather vs. Ilima PMV

Average Honolulu Weather vs. Ilima AC Energy						
OVERALL FIT						
Multiple R	0.294					
R Square	0.087					
Adjusted R Square	0.034					
Standard Error	13.406					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	1191.663	297.916	1.658	0.170	no
Residual	70	12579.995	179.714			
Total	74	13771.658				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-13.426	87.862	-0.153	0.879	-188.662	161.810
Temp	1.262	0.917	1.376	0.173	-0.567	3.090
%RH	-0.459	0.438	-1.047	0.299	-1.333	0.415
Wind Speed	-5.004	2.737	-1.829	0.072	-10.463	0.454
Solar Rad	-0.021	0.028	-0.748	0.457	-0.076	0.035

Max Honolulu Weather vs. Ilima AC Energy						
OVERALL FIT						
Multiple R	0.251					
R Square	0.063					
Adjusted R Square	0.009					
Standard Error	13.578					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	865.667	216.417	1.174	0.330	no
Residual	70	12905.991	184.371			
Total	74	13771.658				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-20.914	72.025	-0.290	0.772	-164.563	122.734
Max Temp	1.102	0.691	1.596	0.115	-0.276	2.480
Max RH	0.044	0.311	0.141	0.888	-0.577	0.664
Max Wind Speed	-1.412	1.281	-1.103	0.274	-3.967	1.142
Max Solar Rad	-0.030	0.045	-0.670	0.505	-0.121	0.060

Findings: Among these four pairs, the strongest correlation occurred between average Honolulu weather and Ilima PMV (r^2=0.271).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Average Honolulu Weather vs. Ilima Lighting Energy						
OVERALL FIT						
Multiple R	0.143					
R Square	0.021					
Adjusted R Square	-0.035					
Standard Error	1.495					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	3.288	0.822	0.368	0.831	no
Residual	70	156.453	2.235			
Total	74	159.740				
	coeff	std err	t stat	p-value	lower	upper
Intercept	11.916	9.798	1.216	0.228	-7.627	31.458
Temp	-0.105	0.102	-1.025	0.309	-0.309	0.099
%RH	-0.001	0.049	-0.020	0.984	-0.098	0.097
Wind Speed	-0.164	0.305	-0.538	0.592	-0.773	0.444
Solar Rad	0.003	0.003	0.852	0.397	-0.004	0.009

Average Honolulu Weather vs. Ilima PMV						
OVERALL FIT						
Multiple R	0.520					
R Square	0.271					
Adjusted R Square	0.229					
Standard Error	0.448					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	5.205	1.301	6.491	0.000	yes
Residual	70	14.033	0.200			
Total	74	19.239				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-11.118	2.935	-3.789	0.000	-16.971	-5.265
Temp	0.092	0.031	3.013	0.004	0.031	0.153
%RH	0.039	0.015	2.656	0.010	0.010	0.068
Wind Speed	0.161	0.091	1.761	0.083	-0.021	0.343
Solar Rad	0.002	0.001	2.560	0.013	0.001	0.004

Lihu'e Weather Difference vs. Kawaikini West Energy/Thermal Comfort Difference

Description: These tables show the outputs of linear regression analyses performed for the following pairs of variables: Average Lihu'e Weather Difference vs. Kawaikini West AC Energy Difference, Max Lihu'e Weather Difference vs. Kawaikini West AC Energy Difference, Average Lihu'e Weather Difference vs. Kawaikini West Lighting Energy Difference, Average Lihu'e Weather Difference vs. Kawaikini West PMV Difference

Average Lihu'e Weather Difference vs. Kawaikini West AC Energy Difference						
OVERALL FIT						
Multiple R	0.142					
R Square	0.020					
Adjusted R Square	-0.036					
Standard Error	13.464					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	259.461	64.865	0.358	0.838	no
Residual	70	12689.429	181.278			
Total	74	12948.891				
	coeff	std err	t stat	p-value	lower	upper
Intercept	22.633	6.551	3.455	0.001	9.569	35.698
Temp	1.422	2.264	0.628	0.532	-3.092	5.937
%RH	0.527	0.556	0.948	0.346	-0.582	1.637
Wind Speed	-1.672	2.888	-0.579	0.565	-7.432	4.089
Solar Rad	-0.007	0.032	-0.230	0.819	-0.070	0.056

Max Lihu'e Weather Difference vs. Kawaikini West AC Energy Difference						
OVERALL FIT						
Multiple R	0.185					
R Square	0.034					
Adjusted R Square	-0.021					
Standard Error	13.366					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	443.933	110.983	0.621	0.649	no
Residual	70	12504.958	178.642			
Total	74	12948.891				
	coeff	std err	t stat	p-value	lower	upper
Intercept	20.721	5.525	3.750	0.000	9.701	31.741
Temp	-0.568	0.821	-0.693	0.491	-2.206	1.069
%RH	0.236	0.407	0.579	0.564	-0.577	1.049
Wind Speed	-0.751	0.747	-1.006	0.318	-2.241	0.738
Solar Rad	0.008	0.010	0.758	0.451	-0.013	0.028

Findings: Among these four pairs, the strongest correlation occurred between the average Lihu'e weather difference and the Kawaikini West PMV difference (r^2=0.056).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Average Lihu'e Weather Difference vs. Kawaikini West Lighting Energy Difference						
OVERALL FIT						
Multiple R	0.184					
R Square	0.034					
Adjusted R Square	-0.021					
Standard Error	2.240					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	12.341	3.085	0.615	0.653	no
Residual	70	351.082	5.015			
Total	74	363.423				
	coeff	std err	t stat	p-value	lower	upper
Intercept	1.568	0.926	1.693	0.095	-0.279	3.414
Temp	-0.208	0.138	-1.515	0.134	-0.483	0.066
%RH	-0.010	0.068	-0.152	0.879	-0.147	0.126
Wind Speed	-0.009	0.125	-0.070	0.945	-0.258	0.241
Solar Rad	0.001	0.002	0.527	0.600	-0.003	0.004

Average Lihu'e Weather Difference vs. Kawaikini West PMV Difference						
OVERALL FIT						
Multiple R	0.237					
R Square	0.056					
Adjusted R Square	0.002					
Standard Error	0.436					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	0.790	0.198	1.038	0.394	no
Residual	70	13.320	0.190			
Total	74	14.110				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-0.349	0.180	-1.935	0.057	-0.709	0.011
Temp	0.044	0.027	1.629	0.108	-0.010	0.097
%RH	-0.004	0.013	-0.322	0.748	-0.031	0.022
Wind Speed	0.032	0.024	1.313	0.193	-0.017	0.081
Solar Rad	-0.000	0.000	-0.232	0.817	-0.001	0.001

Honolulu Weather vs. Ewa P6 Energy/Thermal Comfort

Description: These tables show the outputs of linear regression analyses performed for the following pairs of variables: Average Honolulu Weather vs. Ewa P6 Fan Energy, Max Honolulu Weather vs. Ewa P6 Fan Energy, Average Honolulu Weather vs. Ewa P6 Lighting Energy, Average Honolulu Weather vs. Ewa P6 PMV

Average Honolulu Weather vs. Ewa P6 Fan Energy						
OVERALL FIT						
Multiple R	0.494					
R Square	0.244					
Adjusted R Square	0.200					
Standard Error	0.342					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	2.637	0.659	5.637	0.001	yes
Residual	70	8.185	0.117			
Total	74	10.822				
	coeff	std err	t stat	p-value	lower	upper
Intercept	1.154	2.241	0.515	0.608	-3.315	5.624
Temp	-0.009	0.023	-0.396	0.693	-0.056	0.037
%RH	0.011	0.011	0.979	0.331	-0.011	0.033
Wind Speed	-0.034	0.070	-0.494	0.623	-0.174	0.105
Solar Rad	0.003	0.001	4.319	0.000	0.002	0.004

Max Honolulu Weather vs. Ewa P6 Fan Energy						
OVERALL FIT						
Multiple R	0.358					
R Square	0.128					
Adjusted R Square	0.078					
Standard Error	0.367					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	1.384	0.346	2.565	0.046	yes
Residual	70	9.438	0.135			
Total	74	10.822				
	coeff	std err	t stat	p-value	lower	upper
Intercept	1.366	1.948	0.701	0.486	-2.519	5.250
Max Temp	0.050	0.019	2.666	0.010	0.013	0.087
Max RH	-0.014	0.008	-1.690	0.096	-0.031	0.003
Max Wind Speed	-0.005	0.035	-0.132	0.895	-0.074	0.064
Max Solar Rad	-0.002	0.001	-1.520	0.133	-0.004	0.001

Findings: Among these four pairs, the strongest correlation occurred between average Honolulu weather and Ewa P6 PMV (r^2=0.914).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Average Honolulu Weather vs. Ewa P6 Lighting Energy						
OVERALL FIT						
Multiple R	0.390					
R Square	0.152					
Adjusted R Square	0.103					
Standard Error	2.541					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	80.996	20.249	3.136	0.020	yes
Residual	70	452.036	6.458			
Total	74	533.032				
	coeff	std err	t stat	p-value	lower	upper
Intercept	37.769	16.655	2.268	0.026	4.552	70.987
Temp	-0.391	0.174	-2.252	0.027	-0.738	-0.045
%RH	0.004	0.083	0.045	0.964	-0.162	0.169
Wind Speed	-0.470	0.519	-0.906	0.368	-1.505	0.565
Solar Rad	-0.003	0.005	-0.641	0.524	-0.014	0.007

Average Honolulu Weather vs. Ewa P6 PMV						
OVERALL FIT						
Multiple R	0.956					
R Square	0.914					
Adjusted R Square	0.909					
Standard Error	0.110					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	8.972	2.243	186.073	0.0	yes
Residual	70	0.844	0.012			
Total	74	9.816				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-11.848	0.720	-16.465	0.0	-13.283	-10.413
Temp	0.159	0.008	21.205	0.0	0.144	0.174
%RH	0.009	0.004	2.420	0.018	0.002	0.016
Wind Speed	-0.081	0.022	-3.610	0.001	-0.126	-0.036
Solar Rad	0.001	0.000	4.378	0.000	0.001	0.001

Honolulu Weather vs. Ewa P1 Energy/Thermal Comfort

Description: These tables show the outputs of linear regression analyses performed for the following pairs of variables: Average Honolulu Weather vs. Ewa P1 Fan-Lighting Energy, Max Honolulu Weather vs. Ewa P1 Fan-Lighting Energy, Average Honolulu Weather vs. Ewa P1 Lighting Energy, Average Honolulu Weather vs. Ewa P1 PMV

Average Honolulu Weather vs. Ewa P1 Fan-Lighting Energy						
OVERALL FIT						
Multiple R	0.259					
R Square	0.067					
Adjusted R Square	0.013					
Standard Error	1.607					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	12.947	3.237	1.253	0.297	no
Residual	70	180.802	2.583			
Total	74	193.749				
	coeff	std err	t stat	p-value	lower	upper
Intercept	13.869	10.533	1.317	0.192	-7.139	34.877
Temp	-0.111	0.110	-1.007	0.318	-0.330	0.109
%RH	-0.020	0.053	-0.372	0.711	-0.124	0.085
Wind Speed	-0.369	0.328	-1.125	0.264	-1.023	0.285
Solar Rad	0.006	0.003	1.828	0.072	-0.001	0.013

Max Honolulu Weather vs. Ewa P1 Fan-Lighting Energy						
OVERALL FIT						
Multiple R	0.197					
R Square	0.039					
Adjusted R Square	-0.016					
Standard Error	1.631					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	7.523	1.881	0.707	0.590	no
Residual	70	186.226	2.660			
Total	74	193.749				
	coeff	std err	t stat	p-value	lower	upper
Intercept	9.557	8.652	1.105	0.273	-7.698	26.813
Max Temp	0.068	0.083	0.825	0.412	-0.097	0.234
Max RH	-0.042	0.037	-1.124	0.265	-0.117	0.033
Max Wind Speed	-0.152	0.154	-0.991	0.325	-0.459	0.154
Max Solar Rad	-0.005	0.005	-0.899	0.372	-0.016	0.006

Findings: Among these four pairs, the strongest correlation occurred between average Honolulu weather and Ewa P1 PMV (r^2=0.144).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Average Honolulu Weather vs. Ewa P1 Lighting Energy						
OVERALL FIT						
Multiple R	0.369					
R Square	0.136					
Adjusted R Square	0.087					
Standard Error	1.212					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	16.173	4.043	2.754	0.035	yes
Residual	70	102.784	1.468			
Total	74	118.957				
	coeff	std err	t stat	p-value	lower	upper
Intercept	15.539	7.942	1.957	0.054	-0.301	31.378
Temp	-0.115	0.083	-1.391	0.169	-0.281	0.050
%RH	-0.040	0.040	-1.007	0.317	-0.119	0.039
Wind Speed	-0.341	0.247	-1.379	0.172	-0.834	0.152
Solar Rad	0.006	0.003	2.470	0.016	0.001	0.011

Average Honolulu Weather vs. Ewa P1 PMV						
OVERALL FIT						
Multiple R	0.380					
R Square	0.144					
Adjusted R Square	0.096					
Standard Error	0.257					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	0.779	0.195	2.955	0.026	yes
Residual	70	4.616	0.066			
Total	74	5.395				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-2.099	1.683	-1.247	0.217	-5.455	1.258
Temp	0.039	0.018	2.229	0.029	0.004	0.074
%RH	0.003	0.008	0.345	0.731	-0.014	0.020
Wind Speed	-0.042	0.052	-0.806	0.423	-0.147	0.062
Solar Rad	-0.001	0.001	-2.220	0.030	-0.002	-0.000

Honolulu Weather vs. Ewa D36 Energy/Thermal Comfort

Description: These tables show the outputs of linear regression analyses performed for the following pairs of variables: Average Honolulu Weather vs. Ewa D36 Lighting Energy, Average Honolulu Weather vs. Ewa D36 PMV

No linear regression was performed for the AC energy usage in D36 because it was modeled data.

Findings: Between these two pairs, the strongest correlation occurred between average Honolulu weather and Ewa D36 PMV (r^2=0.529).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Average Honolulu Weather vs. Ewa D36 Lighting Energy						
OVERALL FIT						
Multiple R	0.374					
R Square	0.140					
Adjusted R Square	0.090					
Standard Error	0.469					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	2.497	0.624	2.837	0.031	yes
Residual	70	15.405	0.220			
Total	74	17.902				
	coeff	std err	t stat	p-value	lower	upper
Intercept	4.299	3.075	1.398	0.166	-1.833	10.431
Temp	-0.036	0.032	-1.133	0.261	-0.100	0.028
%RH	-0.007	0.015	-0.442	0.660	-0.037	0.024
Wind Speed	-0.071	0.096	-0.741	0.461	-0.262	0.120
Solar Rad	0.003	0.001	2.797	0.007	0.001	0.005

Average Honolulu Weather vs. Ewa D36 PMV						
OVERALL FIT						
Multiple R	0.727					
R Square	0.529					
Adjusted R Square	0.502					
Standard Error	0.178					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	4	2.501	0.625	19.638	0.000	yes
Residual	70	2.229	0.032			
Total	74	4.729				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-3.911	1.169	-3.344	0.001	-6.243	-1.578
Temp	0.059	0.012	4.835	0.000	0.035	0.083
%RH	-0.006	0.006	-1.047	0.299	-0.018	0.006
Wind Speed	-0.059	0.036	-1.621	0.110	-0.132	0.014
Solar Rad	0.001	0.000	2.820	0.006	0.000	0.002

Kawaikini West Energy/Thermal Comfort vs Kawaikini East Energy/Thermal Comfort

Description: These tables show the outputs of linear regression analyses performed for the following pairs of variables: Kawaikini West AC Energy vs. Kawaikini East AC Energy, Kawaikini West Lighting Energy vs. Kawaikini East Lighting Energy, Kawaikini West PMV vs. Kawaikini East PMV

Kawaikini West AC Energy vs. Kawaikini East AC Energy						
OVERALL FIT						
Multiple R	0.466					
R Square	0.217					
Adjusted R Square	0.206					
Standard Error	15.828					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	1	5059.734	5059.734	20.198	0.000	yes
Residual	73	18287.225	250.510			
Total	74	23346.959				
	coeff	std err	t stat	p-value	lower	upper
Intercept	-8.440	6.660	-1.267	0.209	-21.714	4.834
KwW AC Energy	2.062	0.459	4.494	0.000	1.148	2.977

Kawaikini West Lighting Energy vs. Kawaikini East Lighting Energy						
OVERALL FIT						
Multiple R	0.331					
R Square	0.109					
Adjusted R Square	0.097					
Standard Error	1.441					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	1	18.628	18.628	8.968	0.004	yes
Residual	73	151.631	2.077			
Total	74	170.259				
	coeff	std err	t stat	p-value	lower	upper
Intercept	0.111	0.343	0.325	0.746	-0.572	0.795
Lighting Energy	0.298	0.099	2.995	0.004	0.100	0.496

Findings: Among these three pairs, the strongest correlation occurred between Kawaikini West PMV and Kawaikini East PMV (r^2=0.660).

Study Period: 07/01/2014 - 06/30/2015
Days: School Days
Hours: All Hours

Kawaikini West PMV vs. Kawaikini East PMV						
OVERALL FIT						
Multiple R	0.813					
R Square	0.660					
Adjusted R Square	0.656					
Standard Error	0.222					
Observations	75					
ANOVA				Alpha	0.05	
	df	SS	MS	F	p-value	sig
Regression	1	6.967	6.967	141.893	0.0	yes
Residual	73	3.584	0.049			
Total	74	10.551				
	coeff	std err	t stat	p-value	lower	upper
Intercept	0.369	0.055	6.652	0.000	0.258	0.479
Tc PMV	1.163	0.098	11.912	0.0	0.969	1.358

DESCRIPTION
This section analyzes classroom performance across the study criteria, looking at performance annually, monthly, and daily where appropriate. Performance is also analyzed with respect to asset characteristics, weather characteristics, and group behavior characteristics to uncover what factors influenced performance.

WHY IMPORTANT
To answer the study questions:
CQ1: How do Test Platform performances compare to Traditional classrooms and to each other?
CQ3: Do all classrooms perform within established guidelines?
EQ1: How well did Test Platforms achieve “energy-neutrality”?

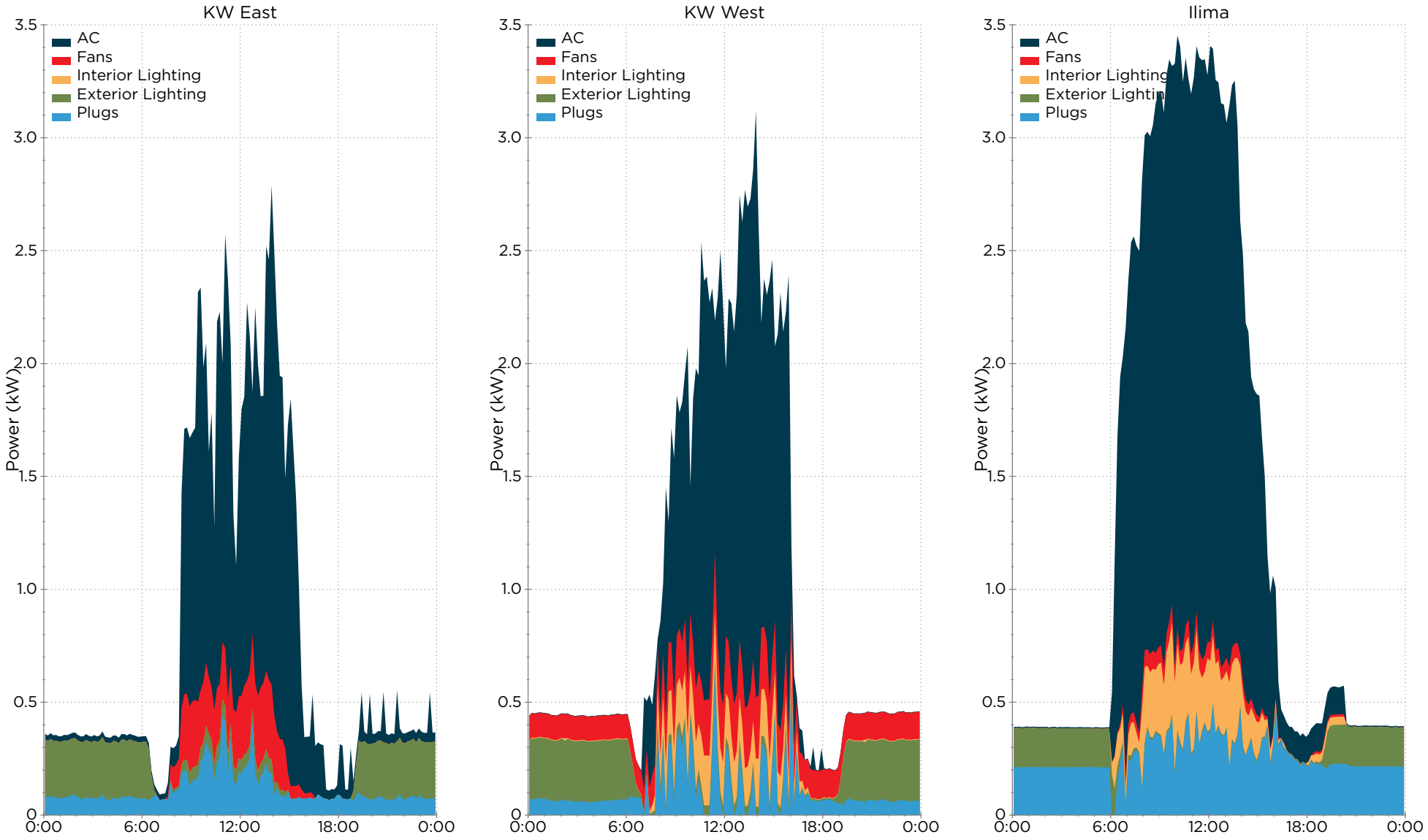
A2

2 Year Charts

A2.1	Total Energy Consumption	54
A2.2	Indoor Environmental Quality (IEQ)	72
A2.3	Net Zero Energy (NZE)	84
A2.4	TMY3 Weather Comparison	92

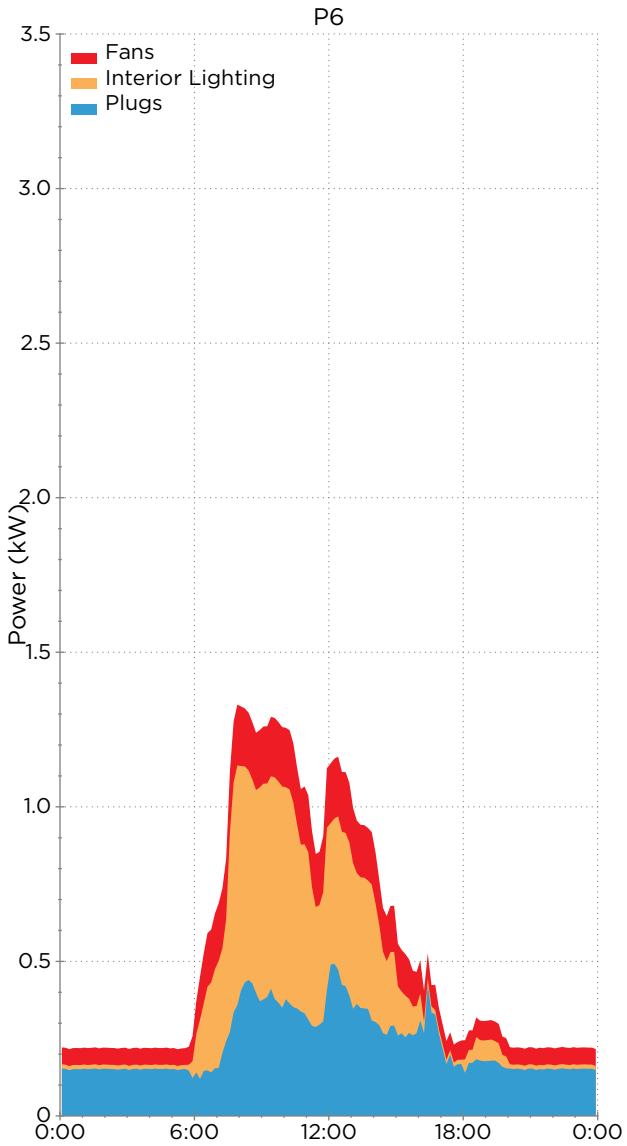
Hourly Average August Load Profiles by End Use

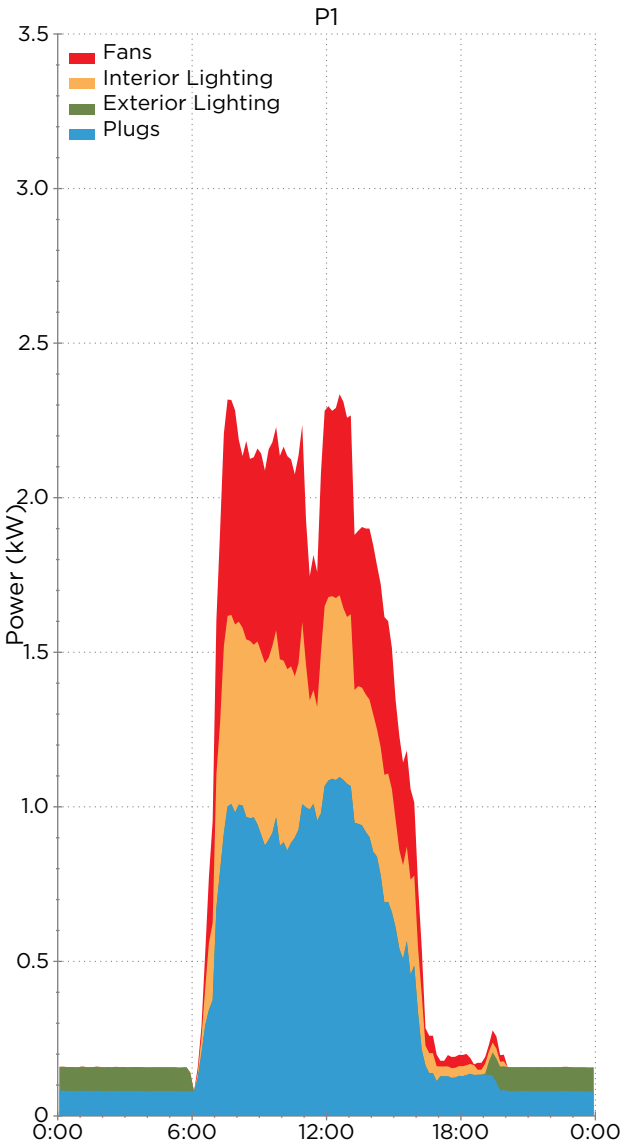
Description: The charts show power consumption (kW) from different end uses across a typical day (0:00 to 24:00) in August. August was selected to highlight how different building systems are used under extreme conditions (i.e. hot weather) across classrooms.

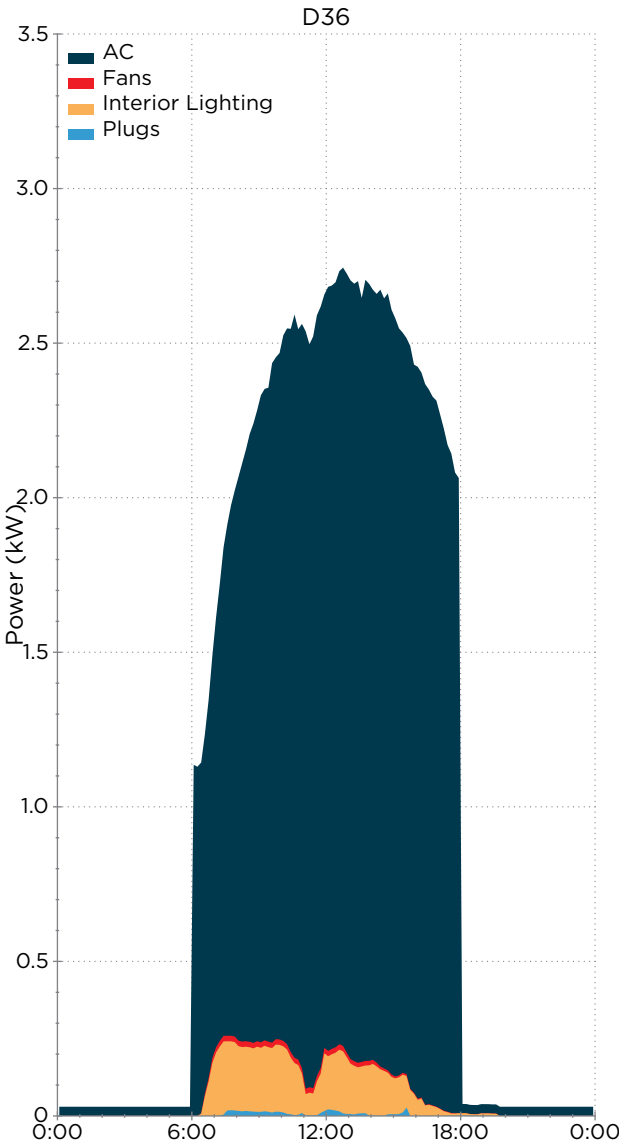


Findings: The three FROG Test Platforms (KW East, KW West and Ilima) have close to double the power consumption than the remaining classrooms at 10pm. Exterior lighting was primarily responsible for the variation during the night.

Study Period: 08/01/2013 - 08/31/2013, 08/01/2014 - 08/31/2014
Days: School Days
Hours: All Hours

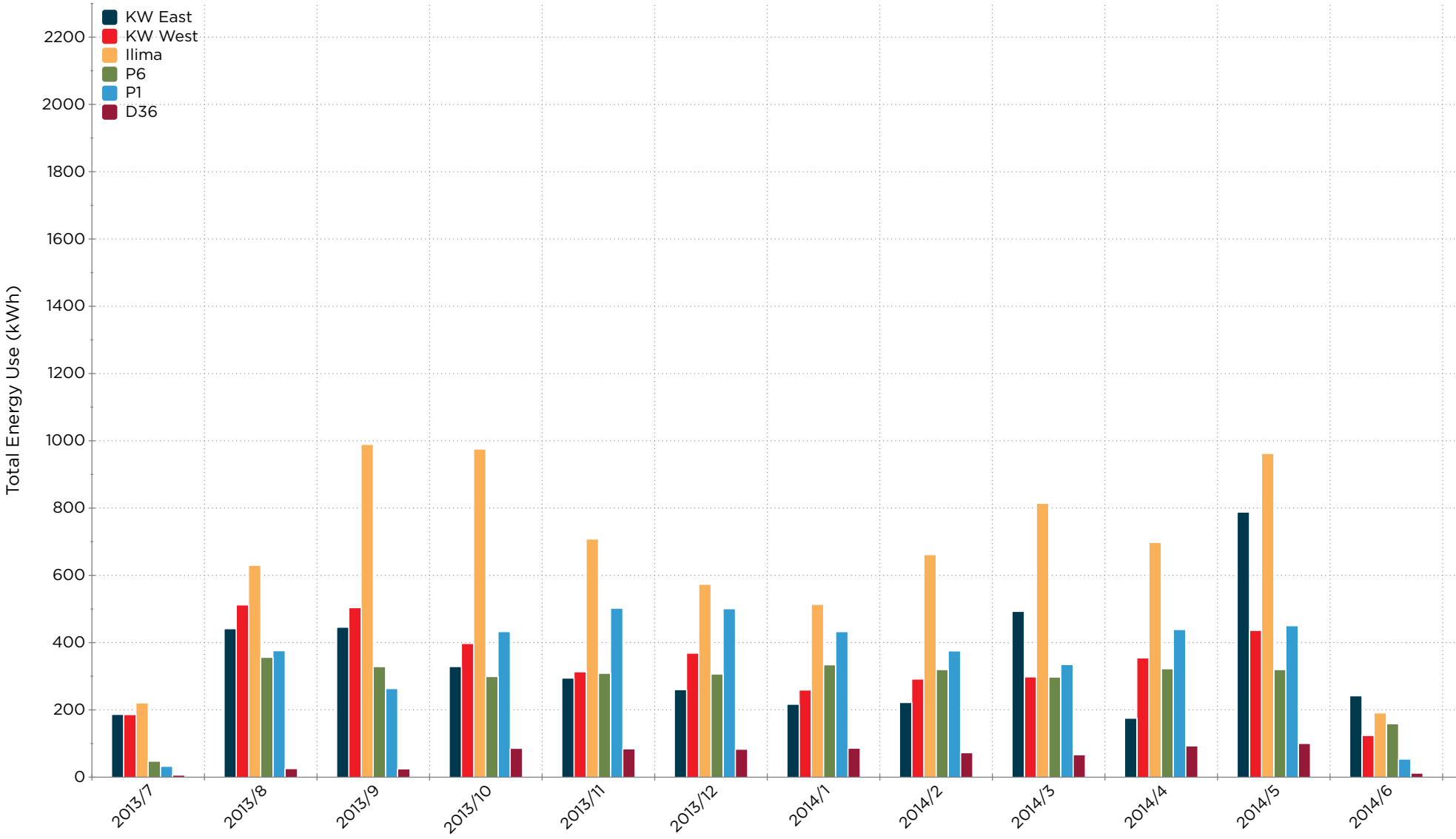






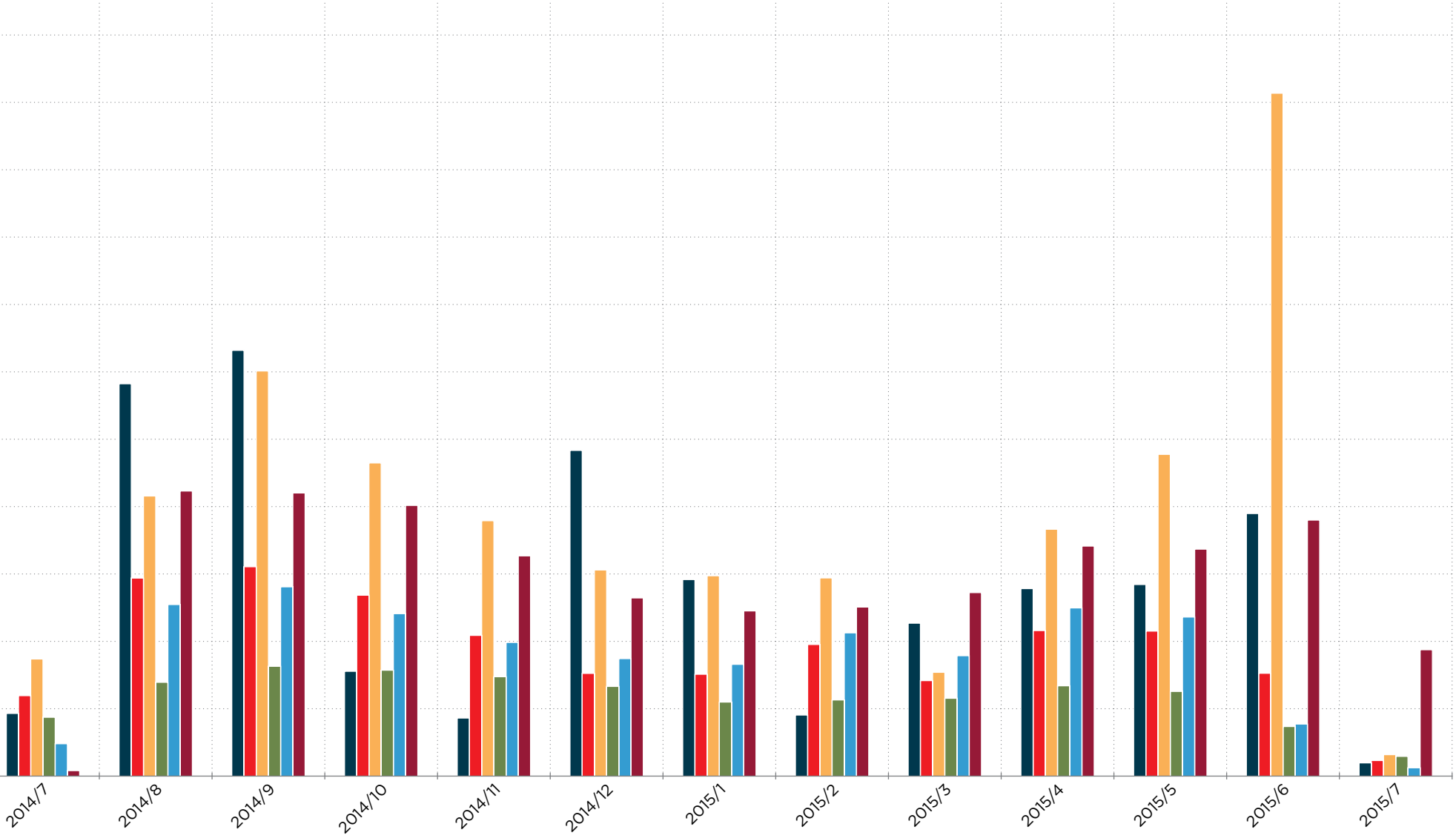
Monthly Total Energy Use

Description: Total energy use for each classroom grouped by month



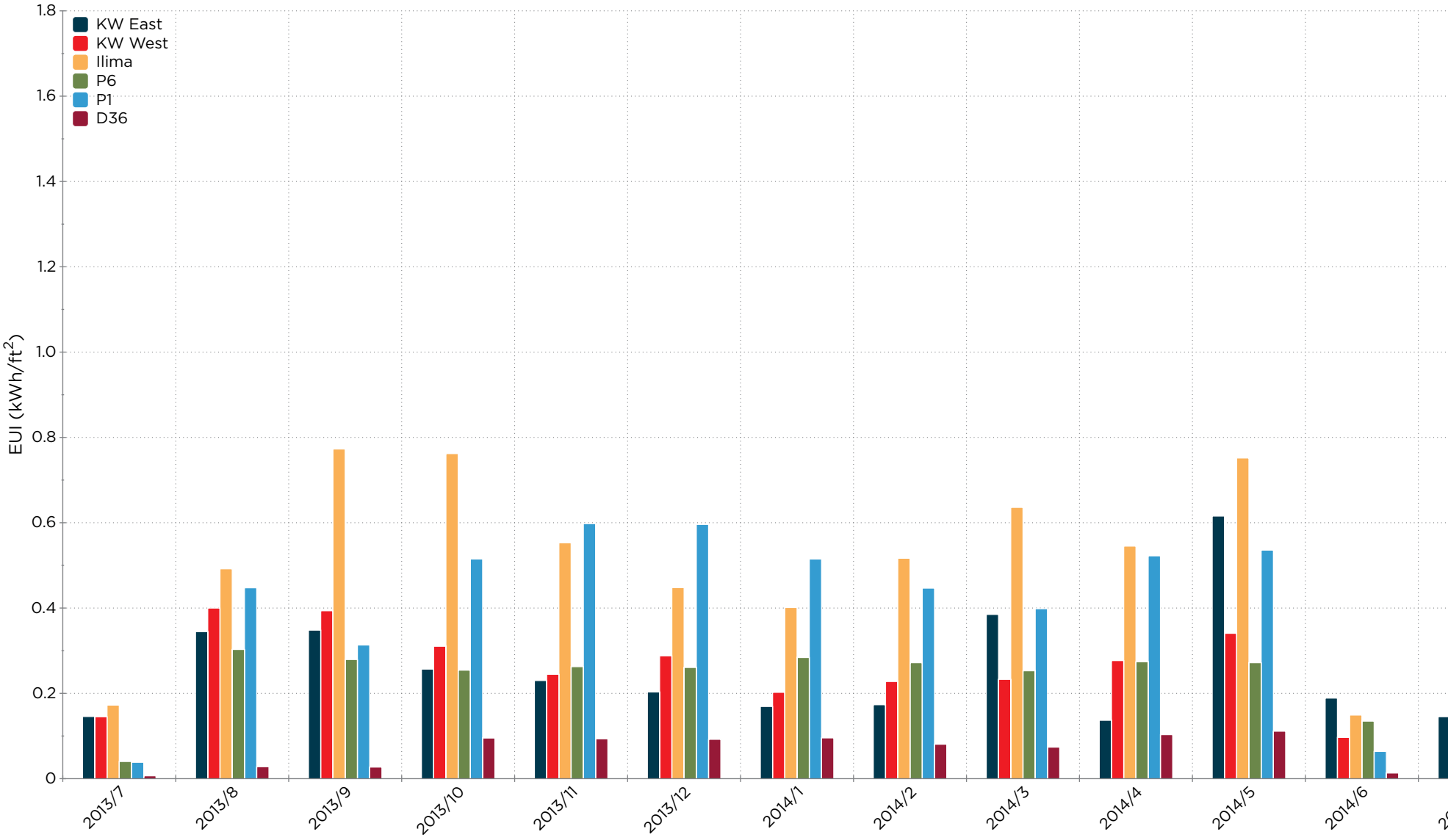
Findings: Ilima had the greatest amount of total energy use for 19 out of 25 months. KW East had the greatest total energy for 4 months and D36 for 2 months.

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours



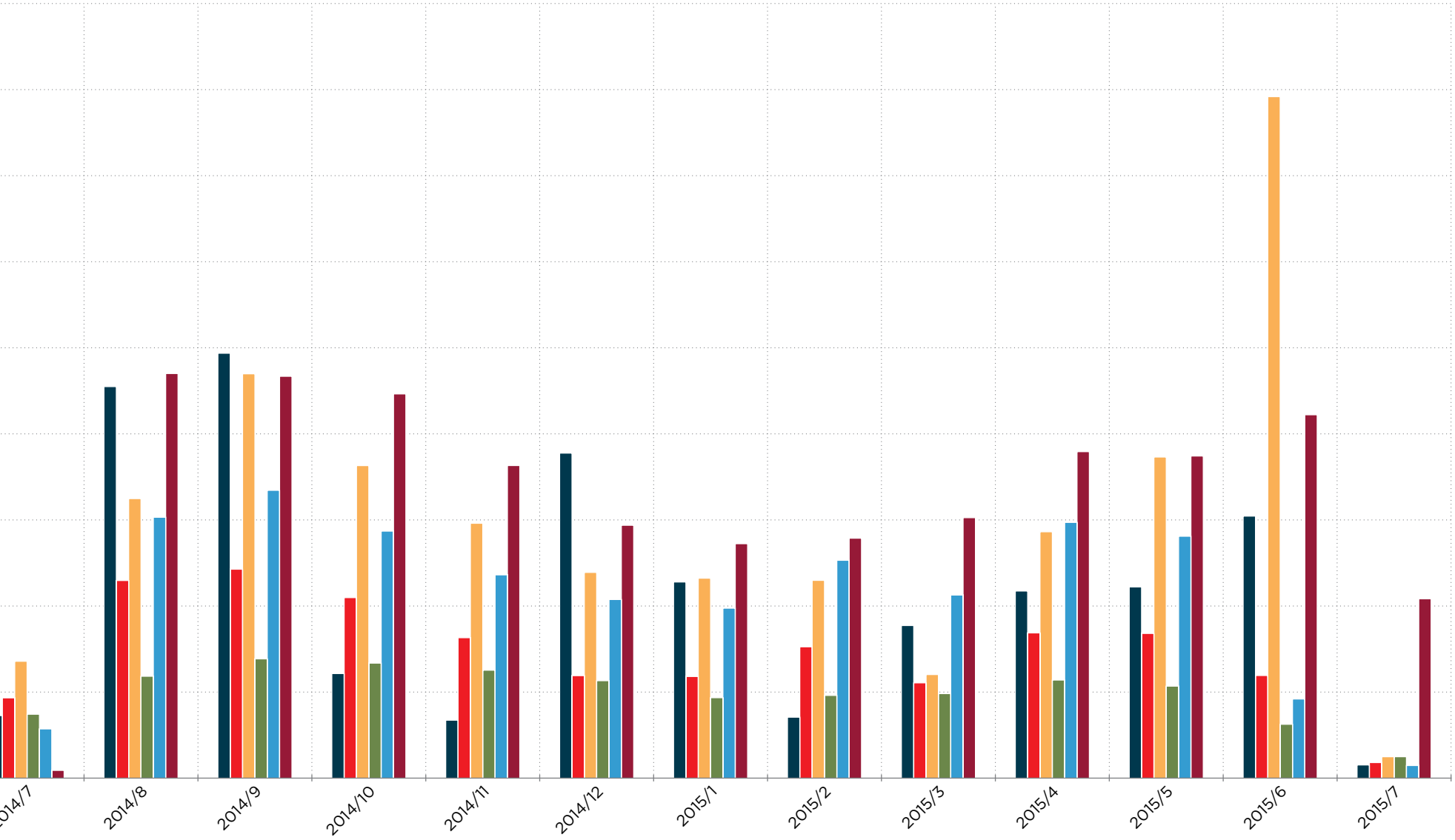
Monthly Energy Use Intensity

Description: Energy use intensity for each classroom grouped by month



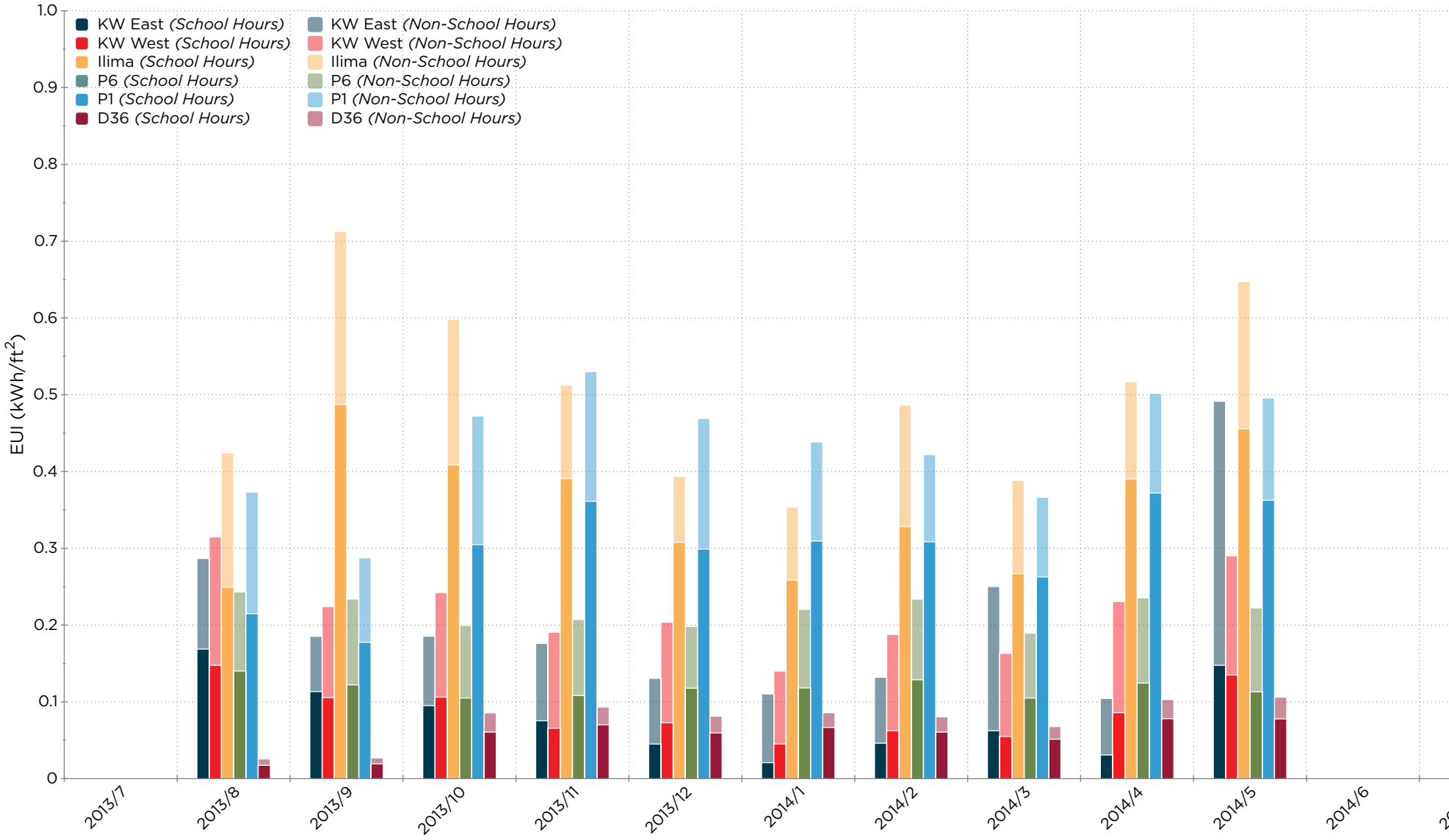
Findings: Ilima had the greatest energy use intensity for 10 out of 25 months. D36 had the greatest energy use intensity for 9 months, and KW East and P1 both for 3 months.

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours



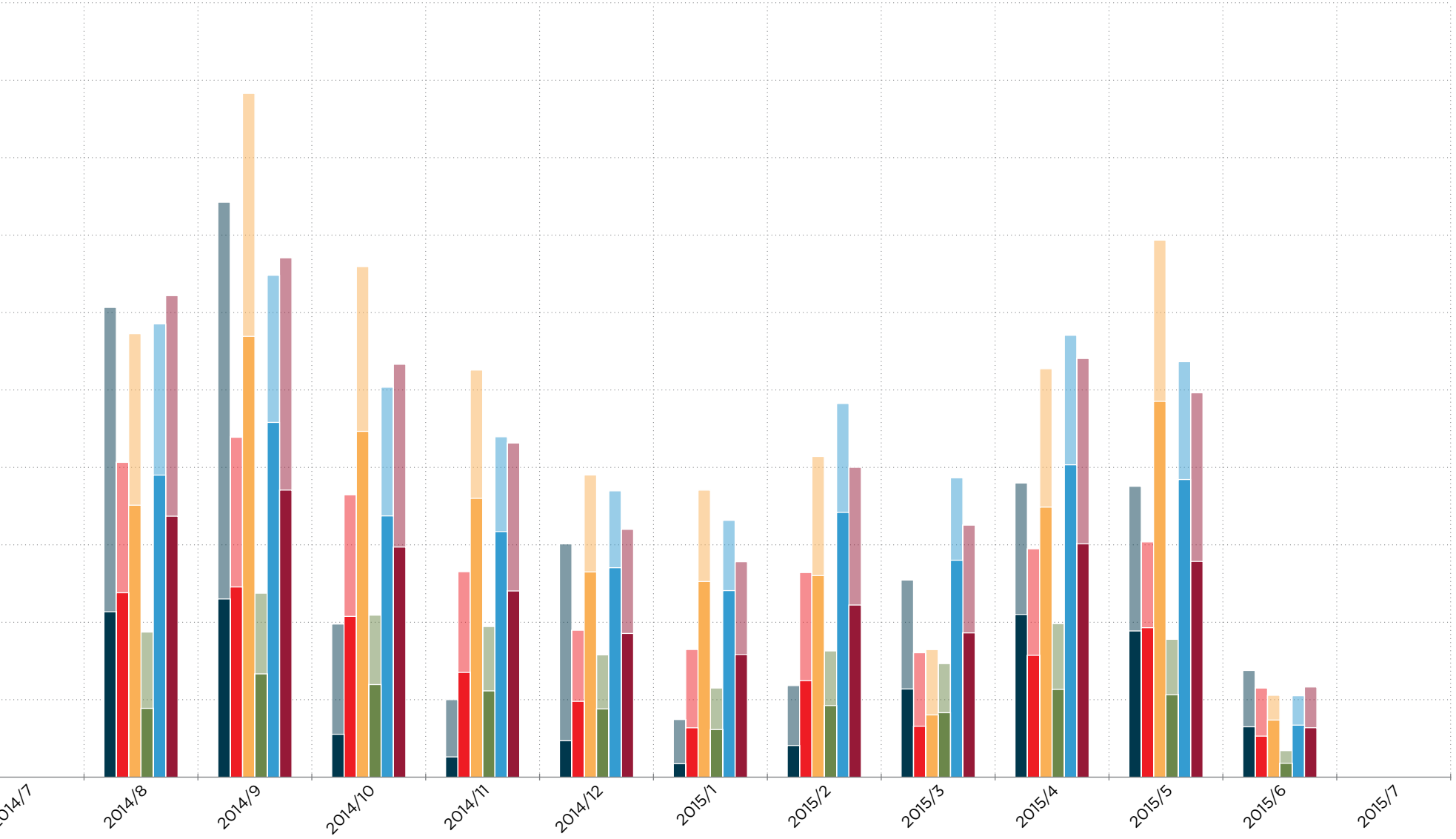
Monthly Energy Use Intensity for School Days

Description: Energy use intensity on school days, separated between school hours and non-school hours for each month, for each classroom. There were no school days in July.



Findings: Ilima had the largest variability across the year in average monthly school day energy use intensity (0.11 to 0.88 kWh/ft²). P6 was the most consistent in monthly energy use intensity with the smallest variability (0.03 to 0.24 kWh/ft²).

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: All Hours

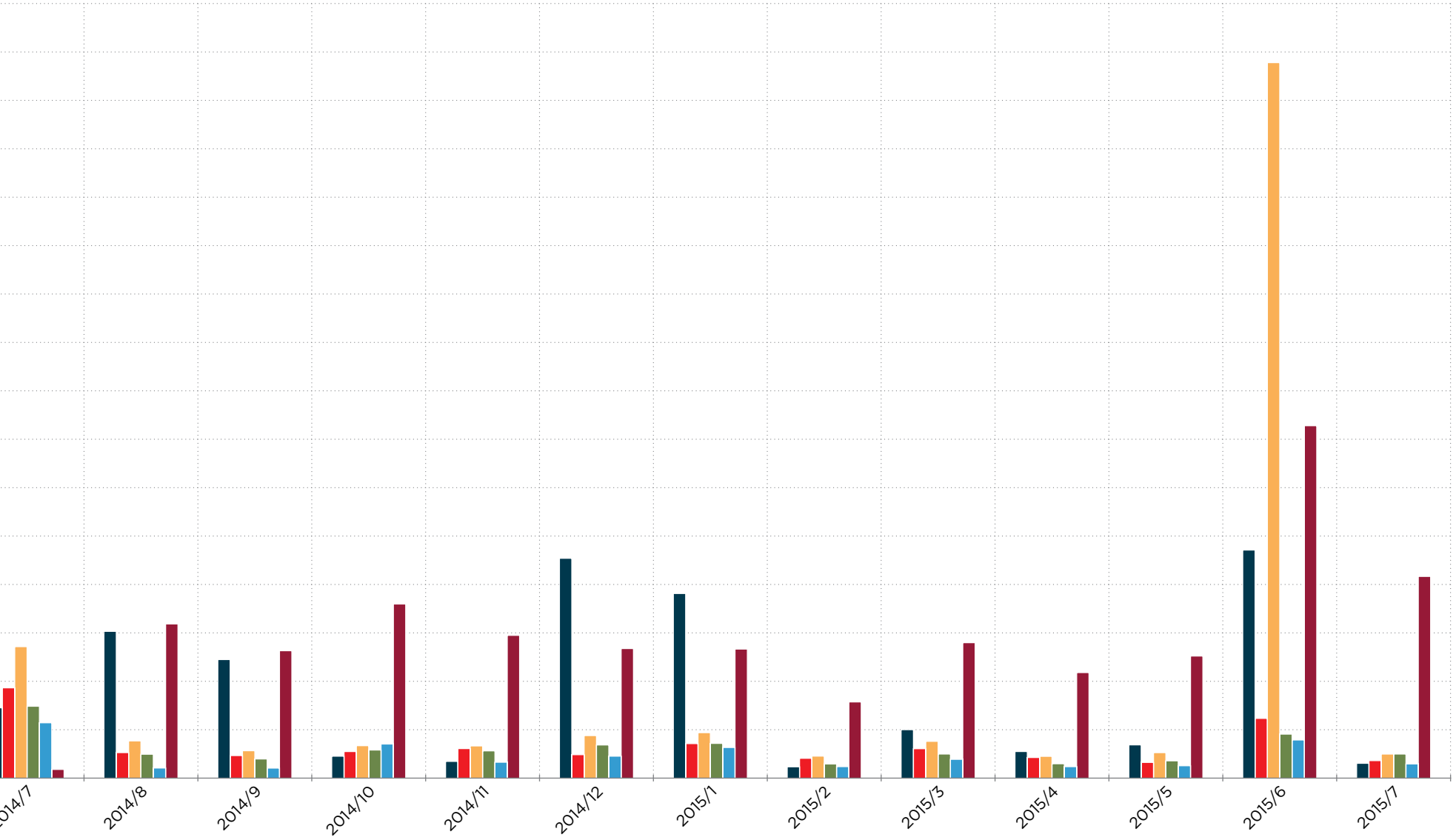


Monthly Energy Use Intensity for Non-School Days

Description: Energy use intensity on non-school days, for each month for each classroom

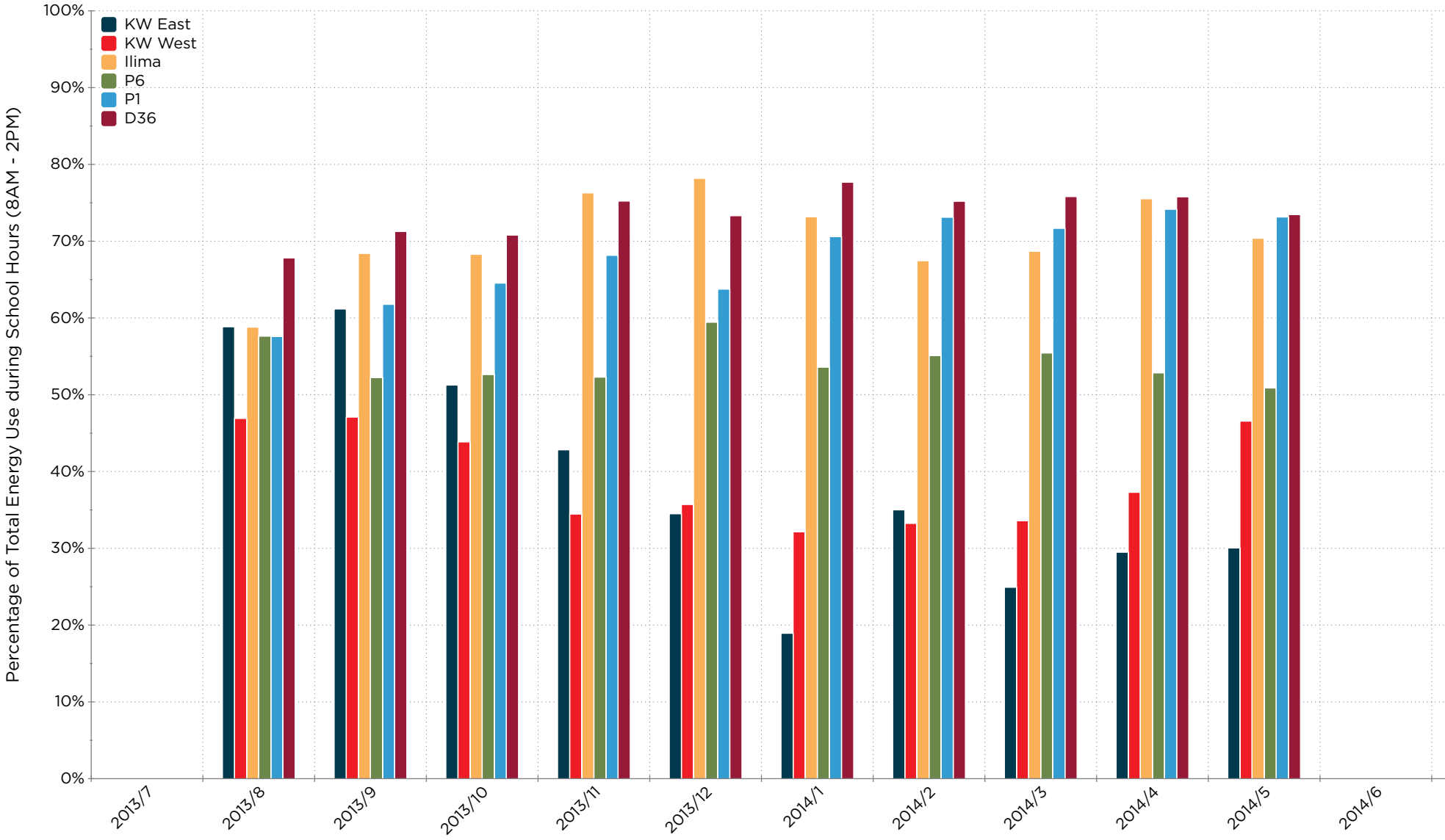
Findings: KW West, P6, and P1 never had a month when the EUI during non-school days exceeded 0.2 kWh/ft². During the entire '13-'14 school year, the only instance when a classroom exceeded 0.2 kWh/ft² in a month was Ilima during March. Ilima's spike in June was due to the AC system left on continuously.

Study Period: 07/16/2013 - 07/16/2015
Days: Non-School Days
Hours: All Hours



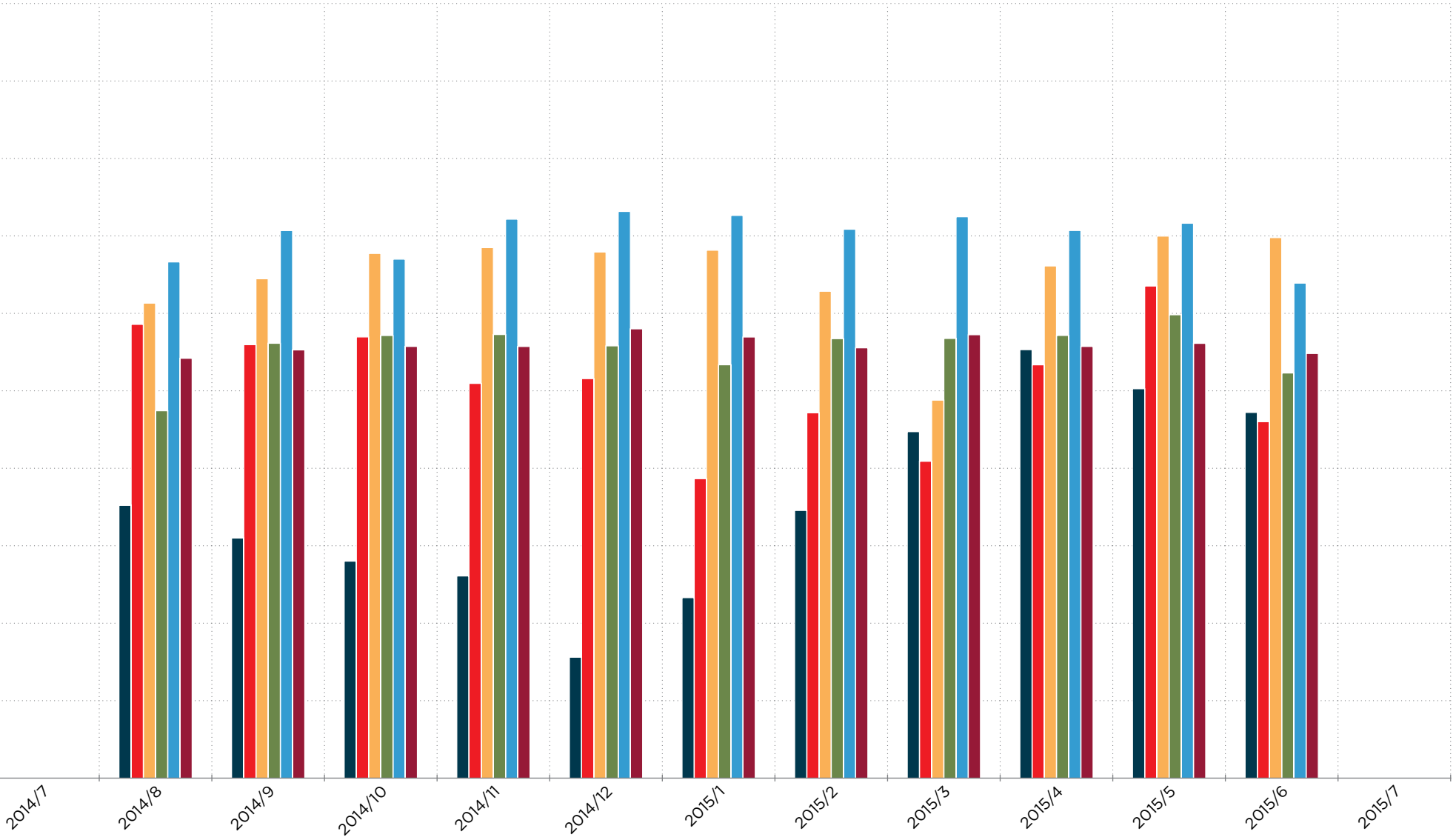
Monthly Total Energy Use during School Hours by Percent

Description: The percentages of total energy use on school days which occurred during school hours, for each month for each classroom. There were no school days in July 2013, June 2014, July 2014 and July 2015.



Findings: At KW East, there were only 5 months out of 21 where more than half the total energy use occurred during school hours. At KW West, there were only 7 months where more than half the total energy use occurred during school hours.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

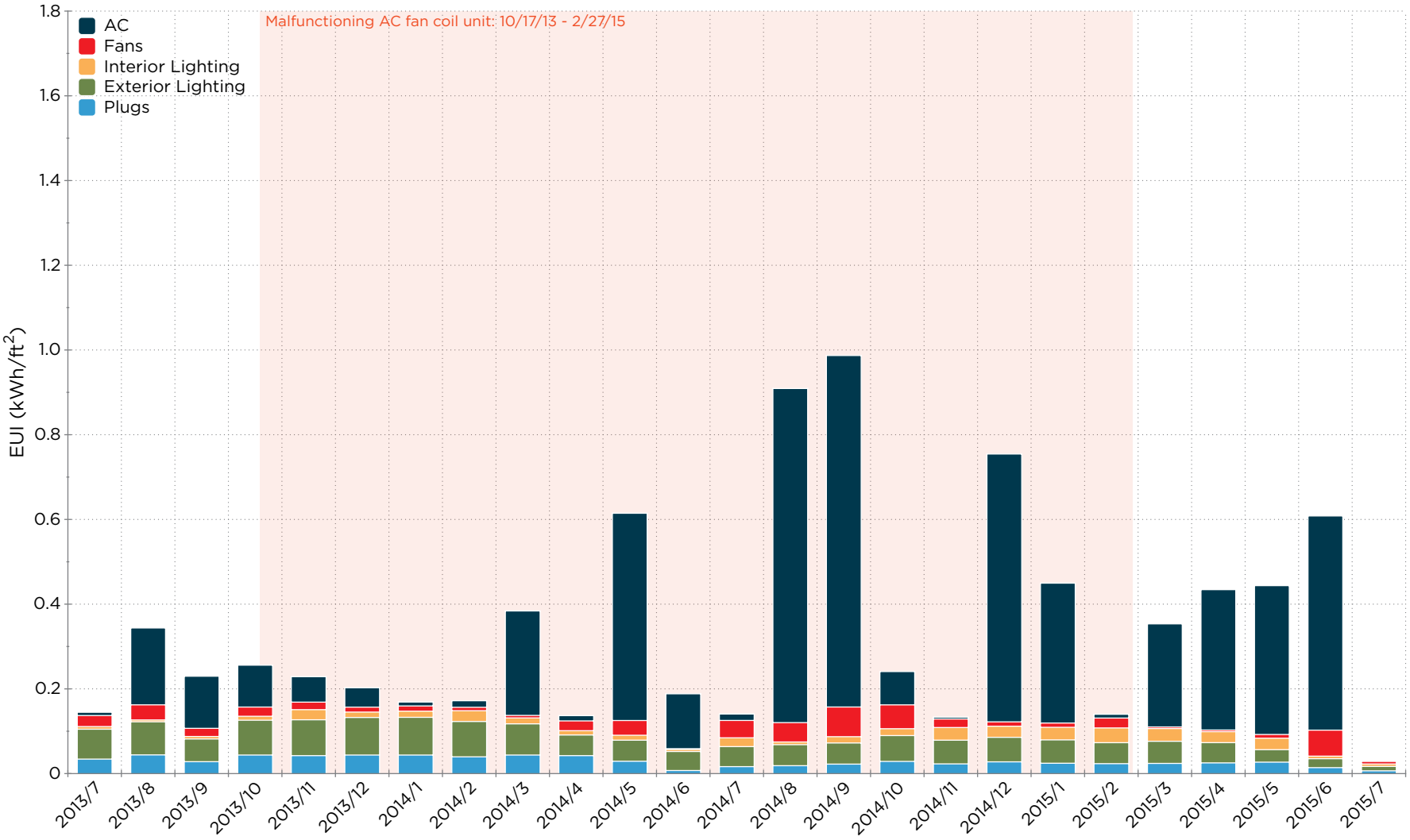


Monthly Energy Use Intensity by End Use: Kawaikini East

Description: Energy use intensity divided by end use for each month for Kawaikini East. The fan coil unit in the split system AC was malfunctioning between 10/17/13 - 2/27/15.

Findings: From March 2015 to June 2015, AC consumed 77% of the energy use intensity on average.

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours

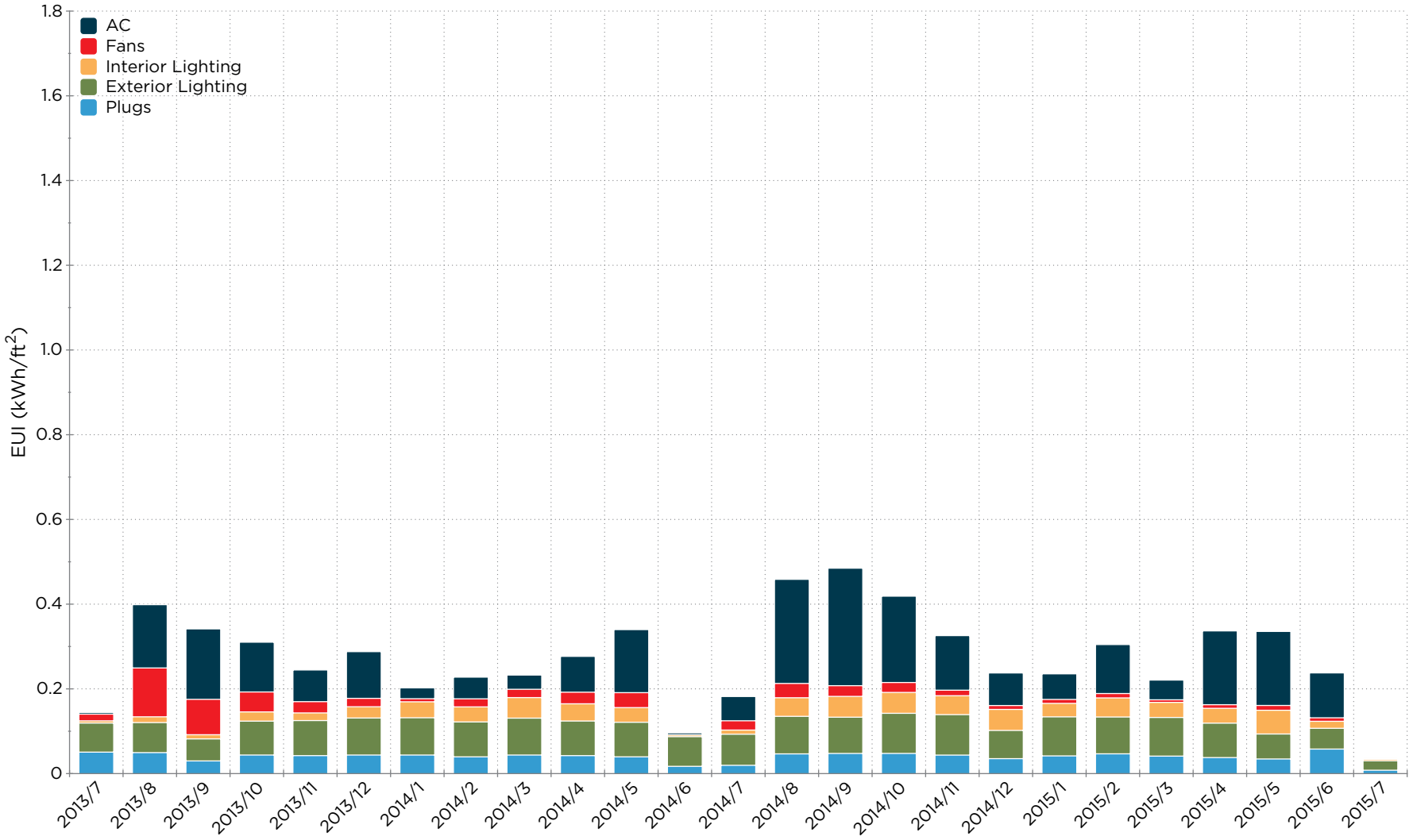


Monthly Energy Use Intensity by End Use: Kawaikini West

Description: Energy use intensity divided by end use for each month for Kawaikini West

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours

Findings: Fan usage was greatest during August 2013, when it accounted for 29% of the total EUI. AC usage accounted for 37% of the total EUI in August 2013. However, in August 2014, fan usage accounted for only 7% of the total EUI, while AC usage accounted for 53% of the total EUI.

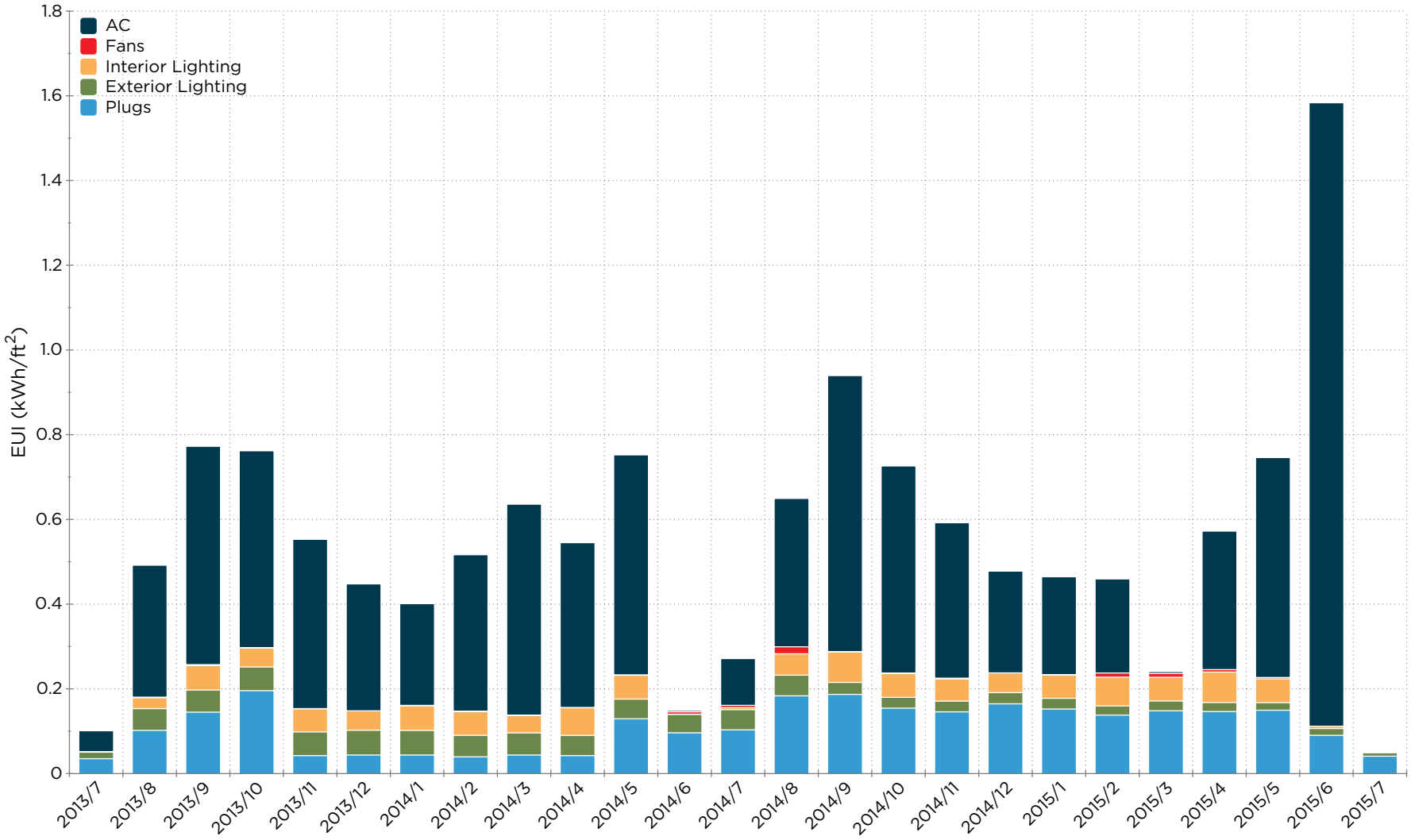


Monthly Energy Use Intensity by End Use: Ilima

Description: Energy use intensity divided by end use for each month for Ilima. The AC was left continuously for 19 days on during June 2015 after the end of the school year.

Findings: AC usage accounted for over half of the total EUI for 17 out of 25 months.

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours

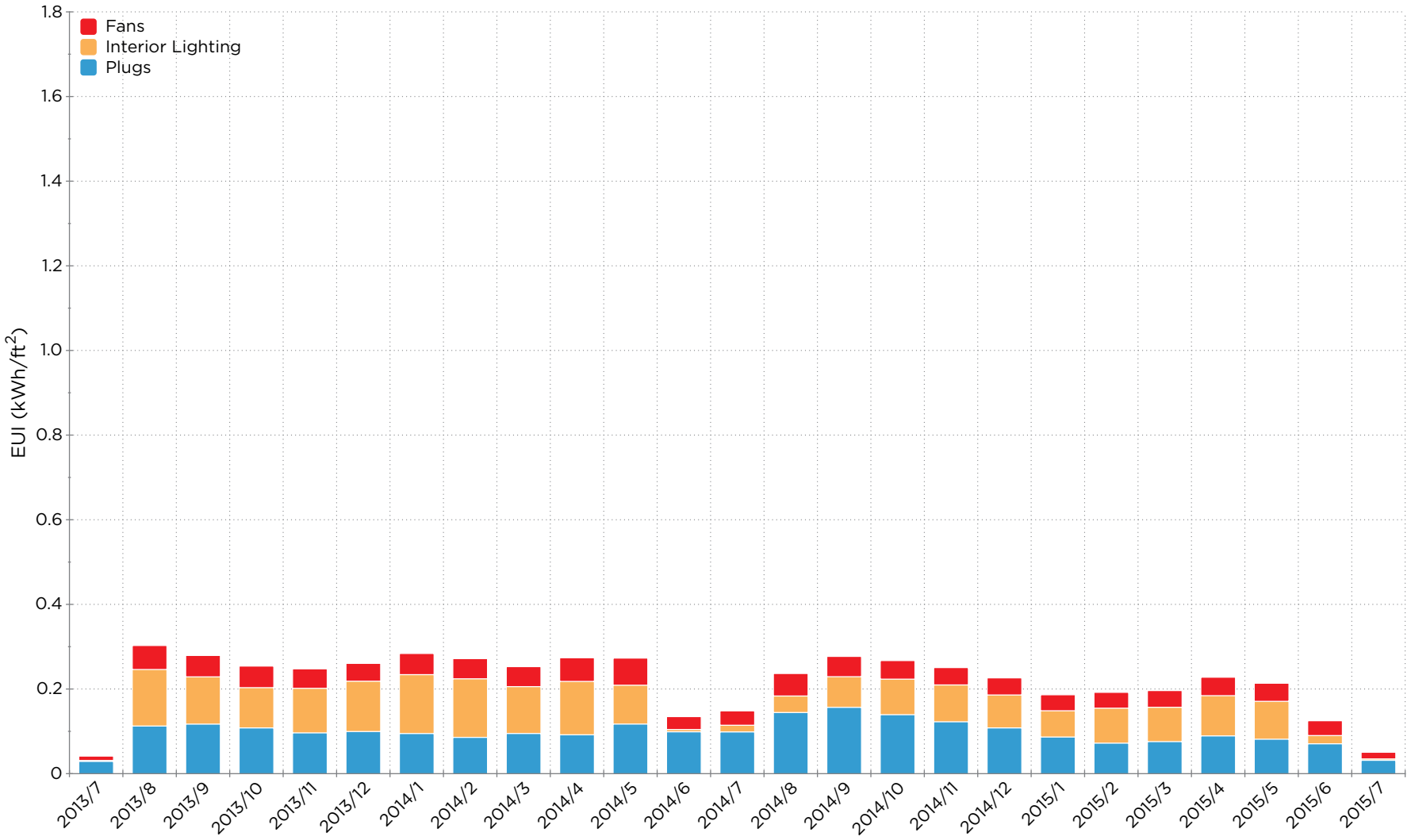


Monthly Energy Use Intensity by End Use: Ewa P6

Description: Energy use intensity divided by end use for each month for P6

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours

Findings: During the '13-'14 school year (Aug 2013 - May 2014), interior lighting was the end use with the greatest EUI for 7 out of 10 months. During the '13-'14 school year (Aug 2014 - June 2015), plugs were the end use with the greatest EUI for 7 out of 11 months.

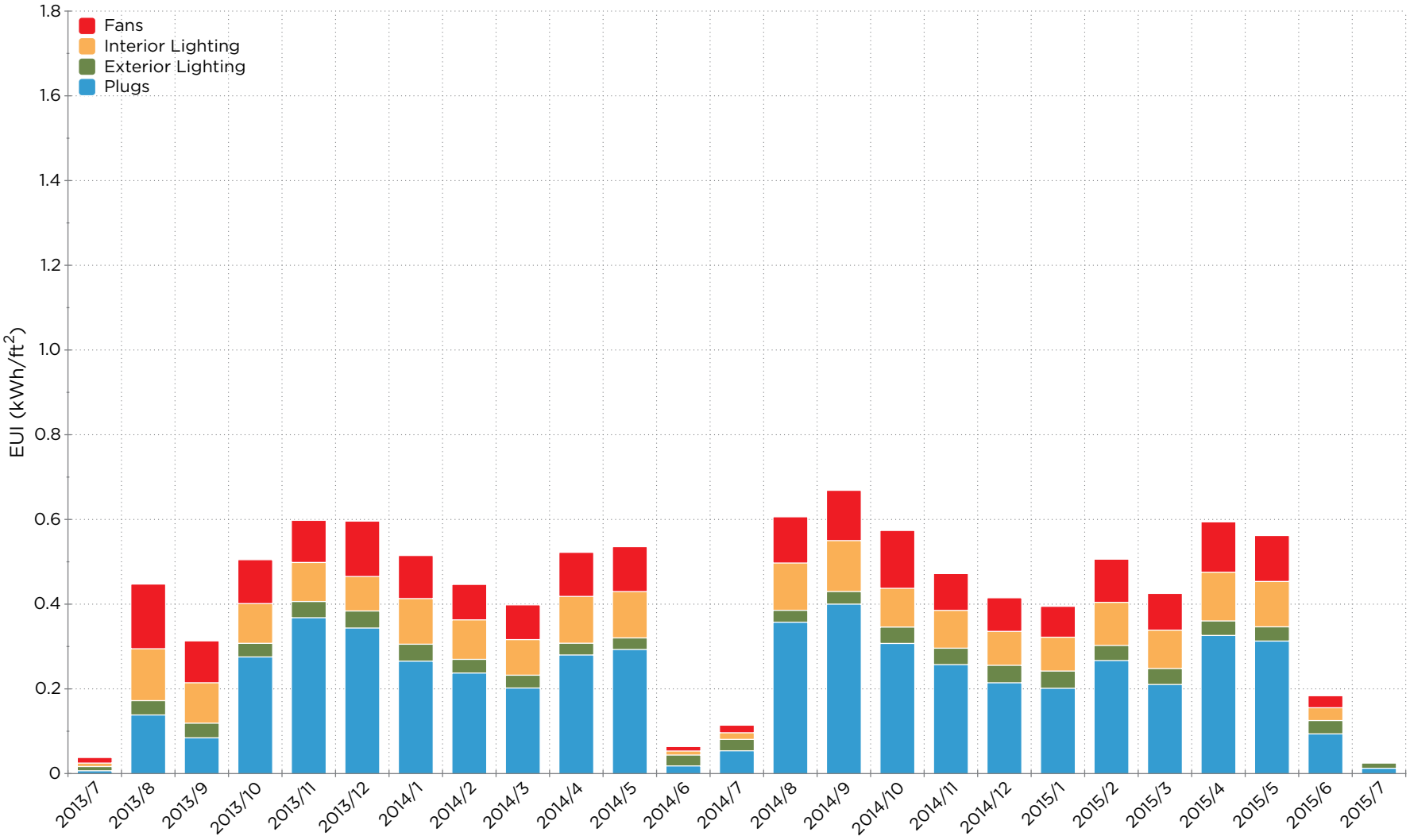


Monthly Energy Use Intensity by End Use: Ewa P1

Description: Energy use intensity divided by end use for each month for P1. P1 has two window air conditioning units that are not metered as a separate end use. Therefore, the plug load category contains the energy use for the two window air conditioning units.

Findings: Plugs accounted for over half the total EUI for 19 out of 25 months.

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours

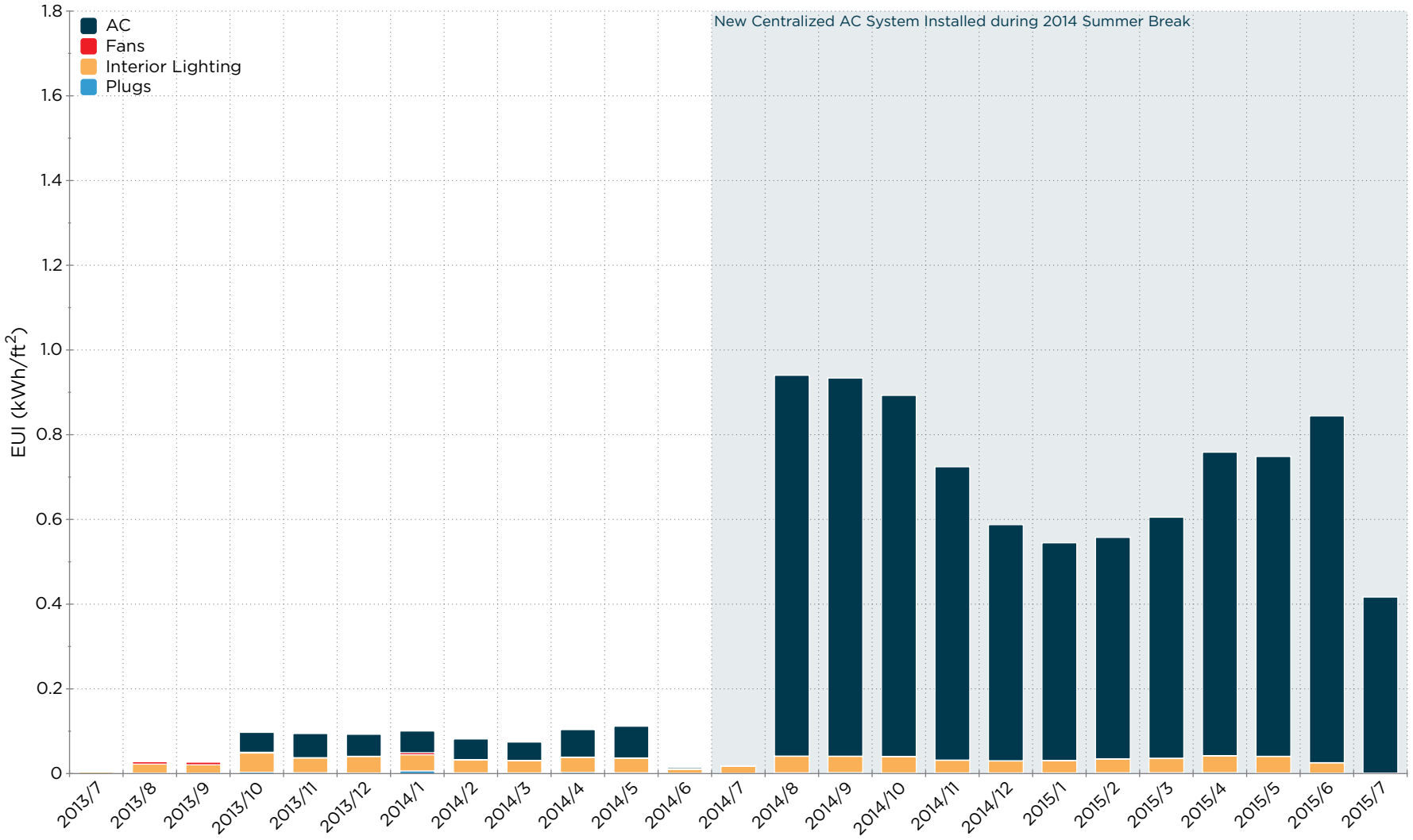


Monthly Energy Use Intensity by End Use: Ewa D36

Description: Energy use intensity divided by end use for each month, for Ewa D36. The air conditioning in Ewa D36 is a central system shared with 3 other classrooms. The AC energy was extrapolated[1] for 7/1/14-6/30/15 based on measured data from 11/12/15-11/20/15. The AC is programmed to run from 6am to 6pm on weekdays.

Findings: Interior lighting energy use was greatest in October 2013, when it accounted for 46% of the total EUI.

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours



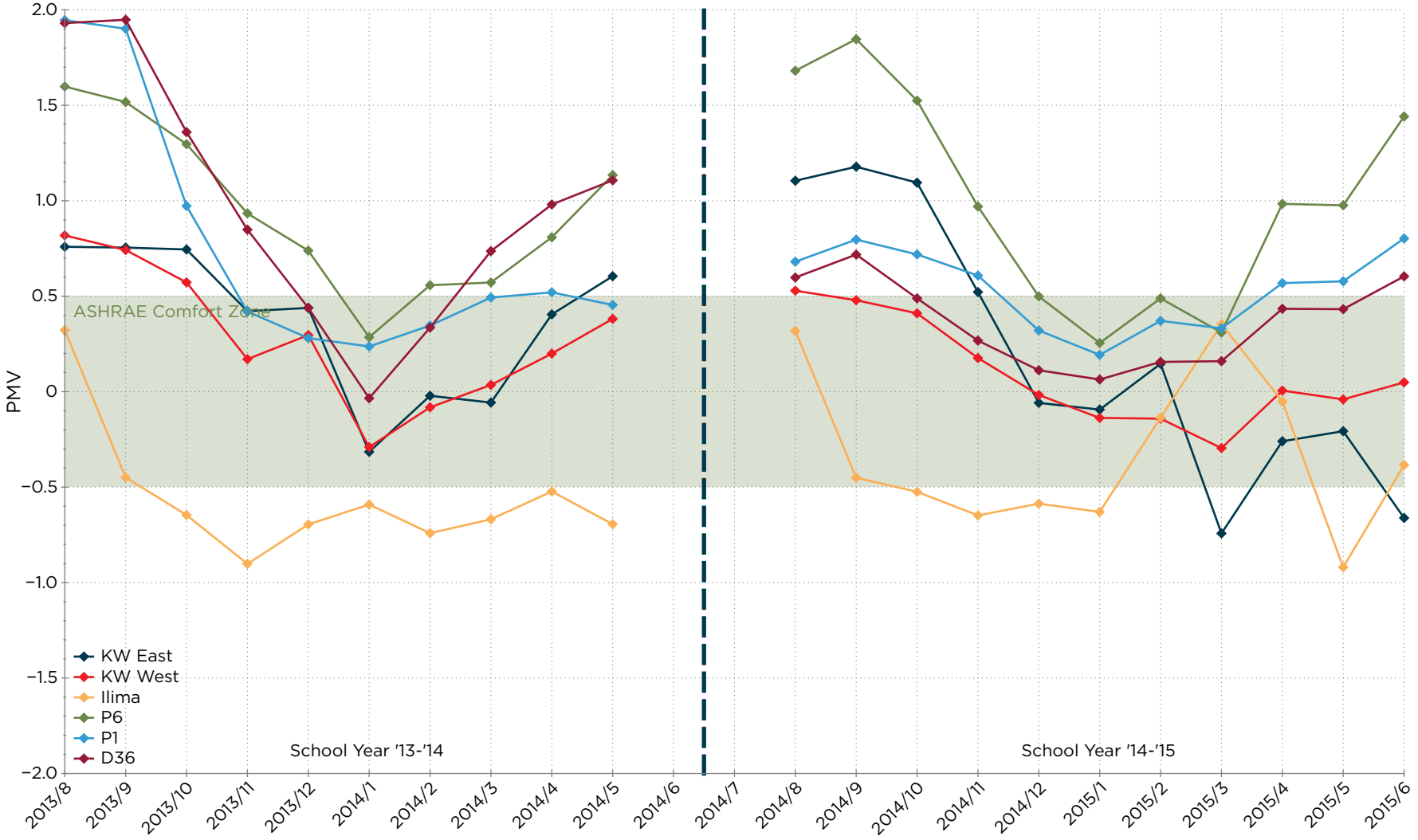
1: More information on the extrapolated AC use can be found in the Methodology section of the main report.

Monthly Average PMV Scores: School Hours

Description: Average monthly PMV scores from school hours only, for each classroom. There were little to no school days in June and July 2014.

Findings: KW West had average monthly PMV scores (school hours only) within the ASHRAE Comfort Zone the most frequently out of the six classrooms. Its average PMV score was within the Comfort Zone for 17 out of 21 months.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

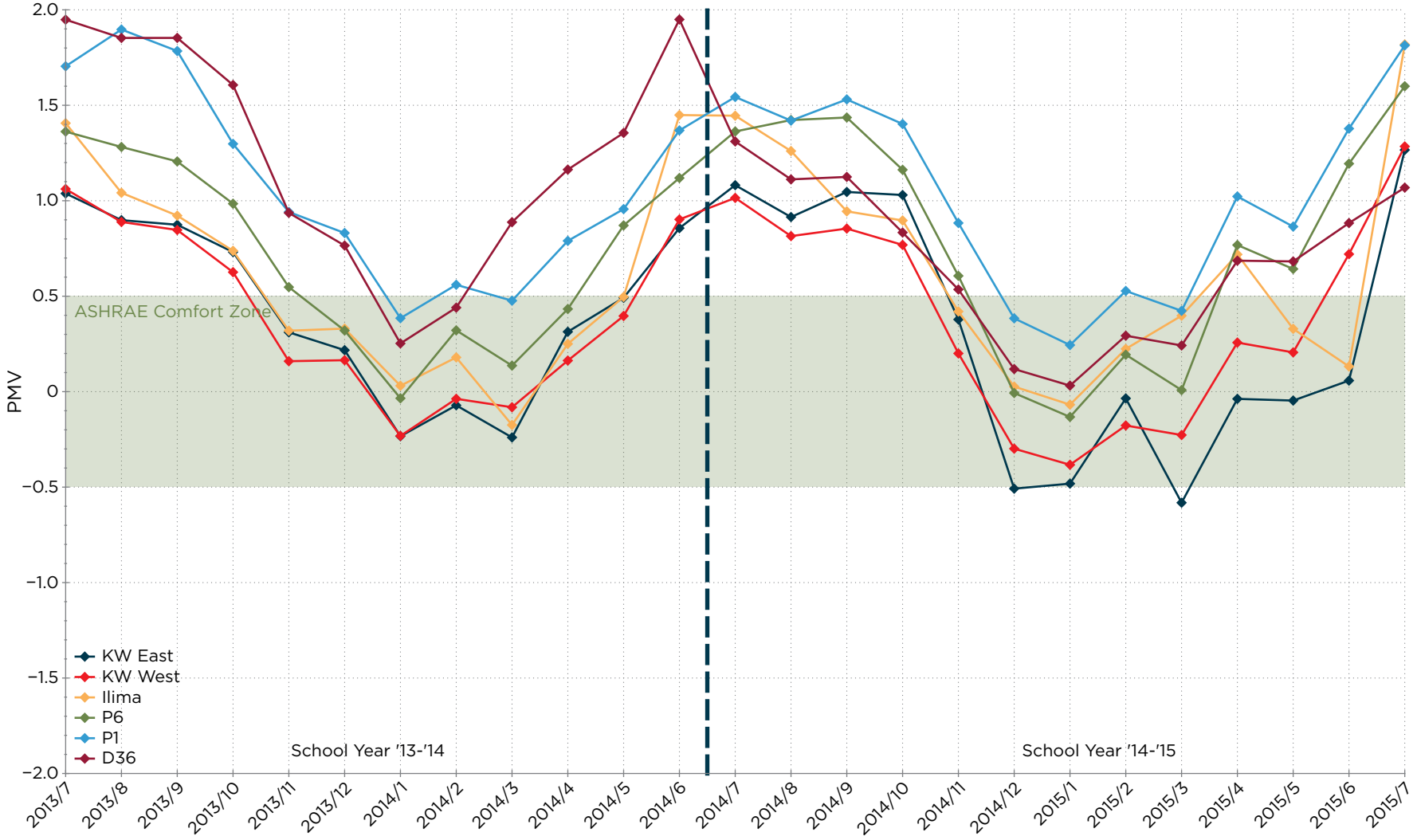


Monthly Average PMV Scores: Non-School Hours

Description: Average monthly PMV scores from non-school hours only for each classroom

Study Period: 07/16/2013 - 07/16/2015
Days: Non-School Days
Hours: Non-School Hours

Findings: P1 had average monthly PMV scores (non-school hours only) within the ASHRAE Comfort Zone the least frequently out of the six classrooms. Its average PMV score was within the Comfort Zone for only 5 out of the 25 months.

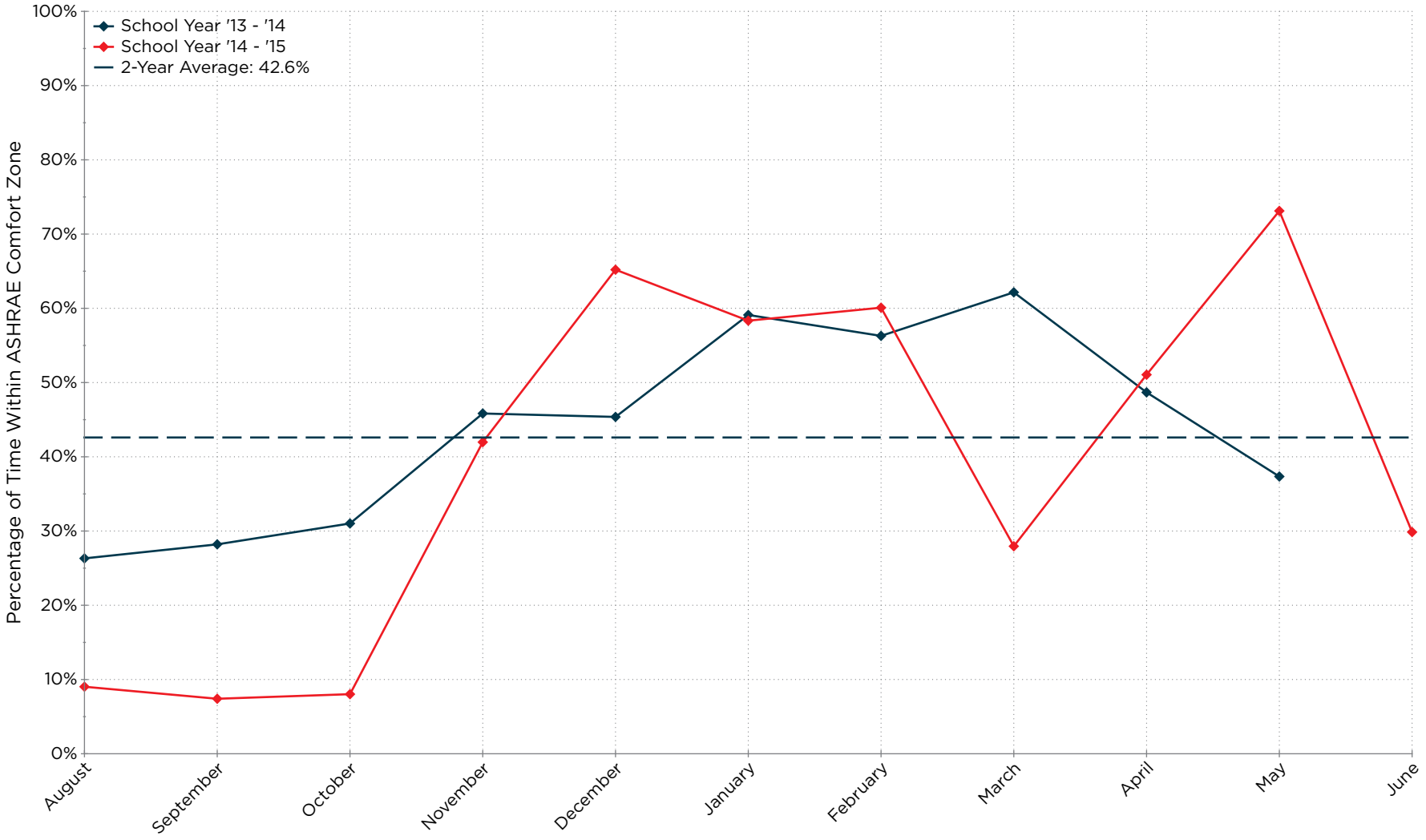


Monthly School Hours within PMV Comfort Zone by Percent: Kawaikini East

Description: The percentage of school hours that Kawaikini East's PMV score was within the ASHRAE Comfort Zone (+/- 0.5) for each month.

Findings: Over the full study period, Kawaikini East had PMV scores within the ASHRAE Comfort Zone for 42.6% of school hours.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

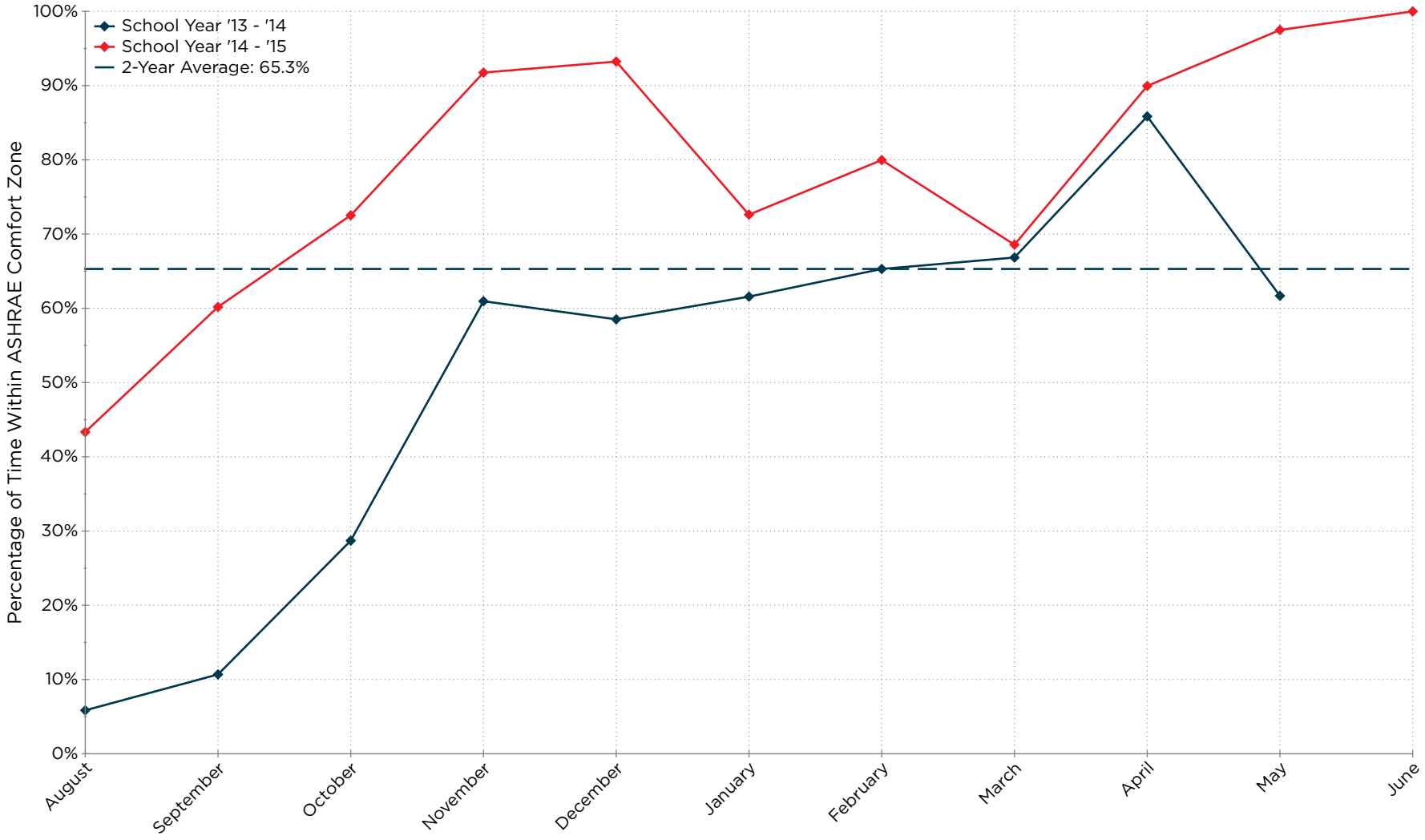


Monthly School Hours within PMV Comfort Zone by Percent: Kawaikini West

Description: The percentage of school hours that Kawaikini West's PMV score was within the ASHRAE Comfort Zone, (+/- 0.5) for each month.

Findings: Over the full study period, Kawaikini West had PMV scores within the ASHRAE Comfort Zone for 65.3% of school hours.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

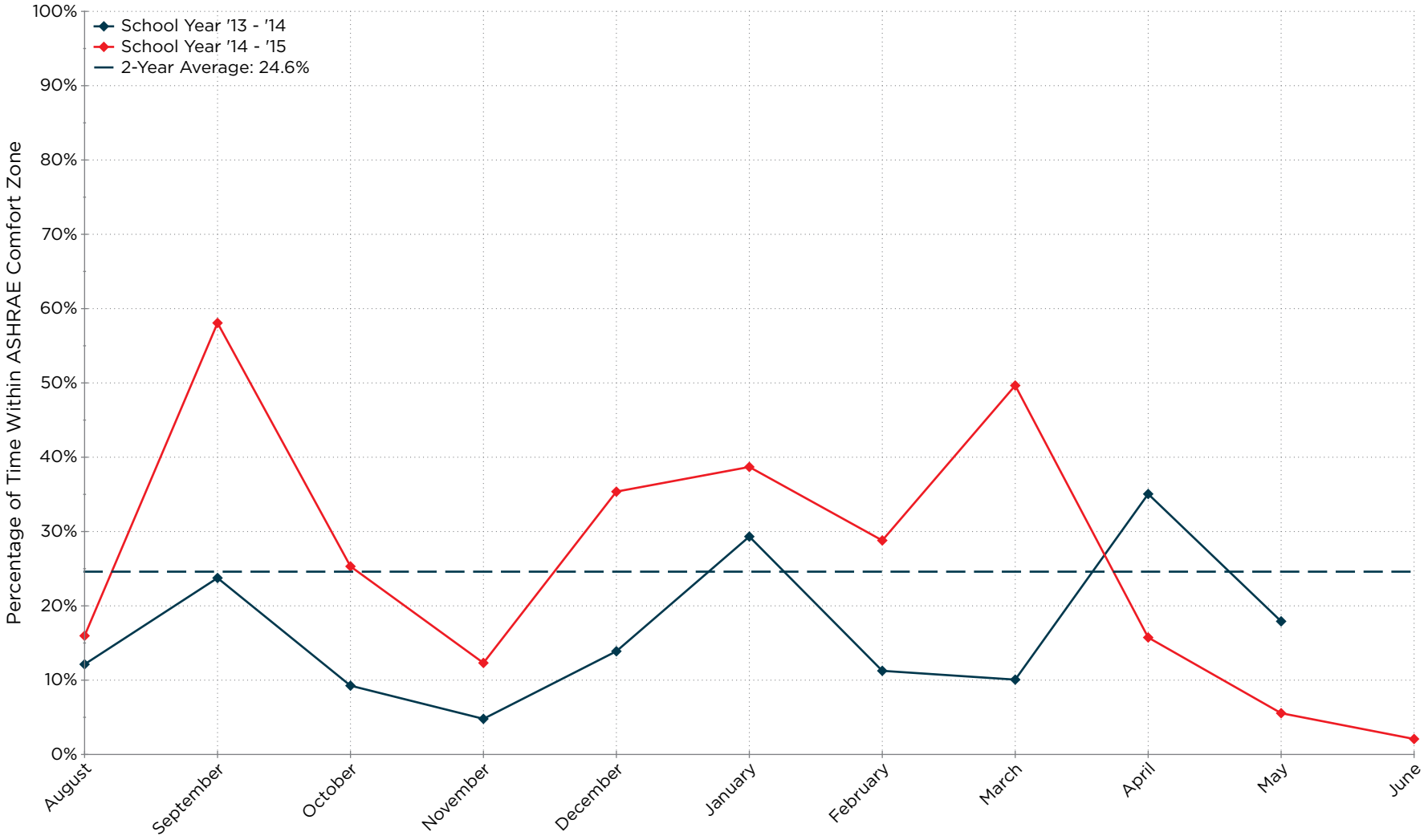


Monthly School Hours within PMV Comfort Zone by Percent: Ilima

Description: The percentage of school hours that Ilima's PMV score was within the ASHRAE Comfort Zone (+/-0.5) for each month.

Findings: Over the full study period, Ilima had PMV scores within the ASHRAE Comfort Zone for 24.6% of school hours.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

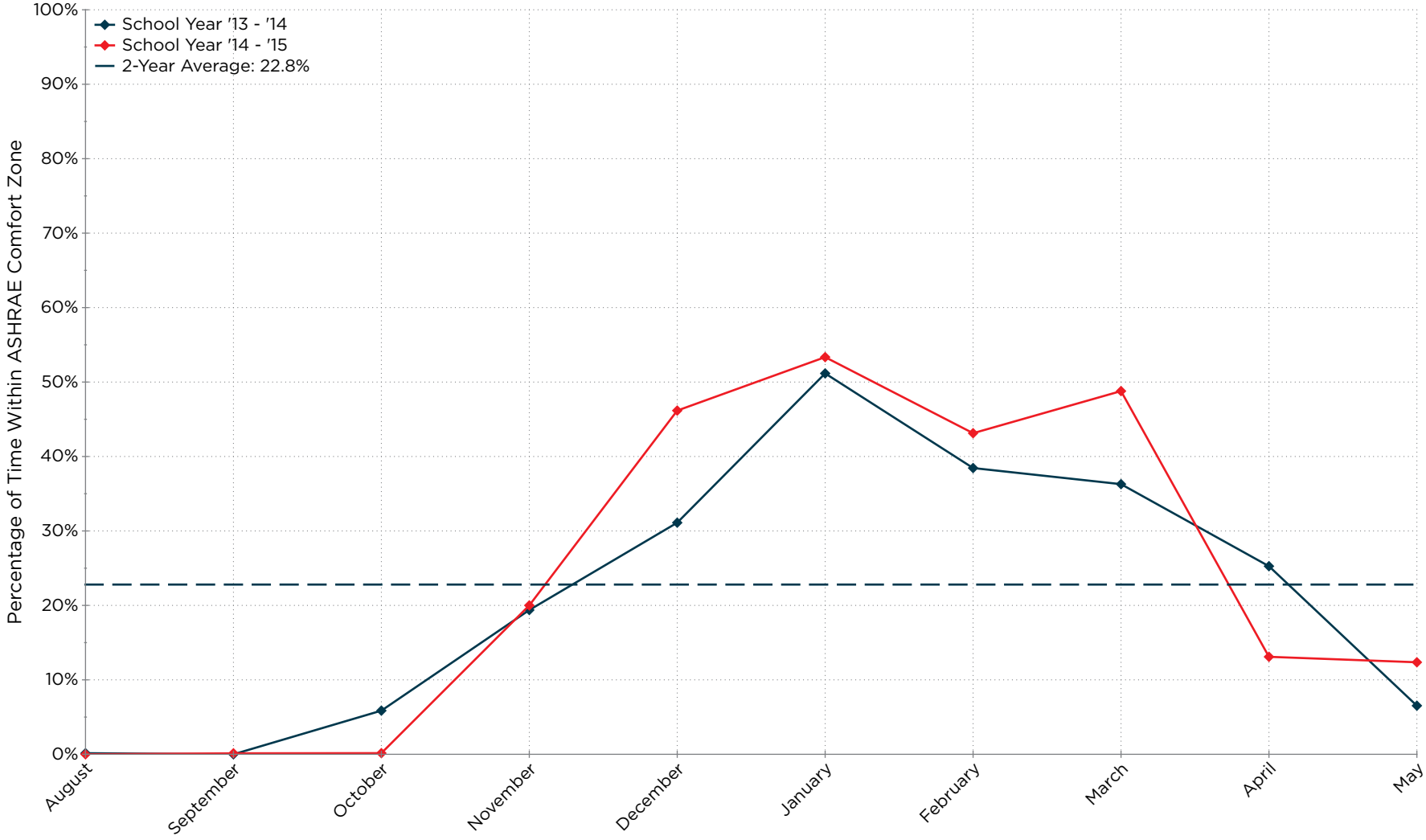


Monthly School Hours within PMV Comfort Zone by Percent: Ewa P6

Description: The percentage of school hours that the Ewa P6's PMV score was within the ASHRAE Comfort Zone (+/- 0.5) for each month.

Findings: Over the full study period, Ewa P6 had PMV scores within the ASHRAE Comfort Zone for 22.8% of school hours.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

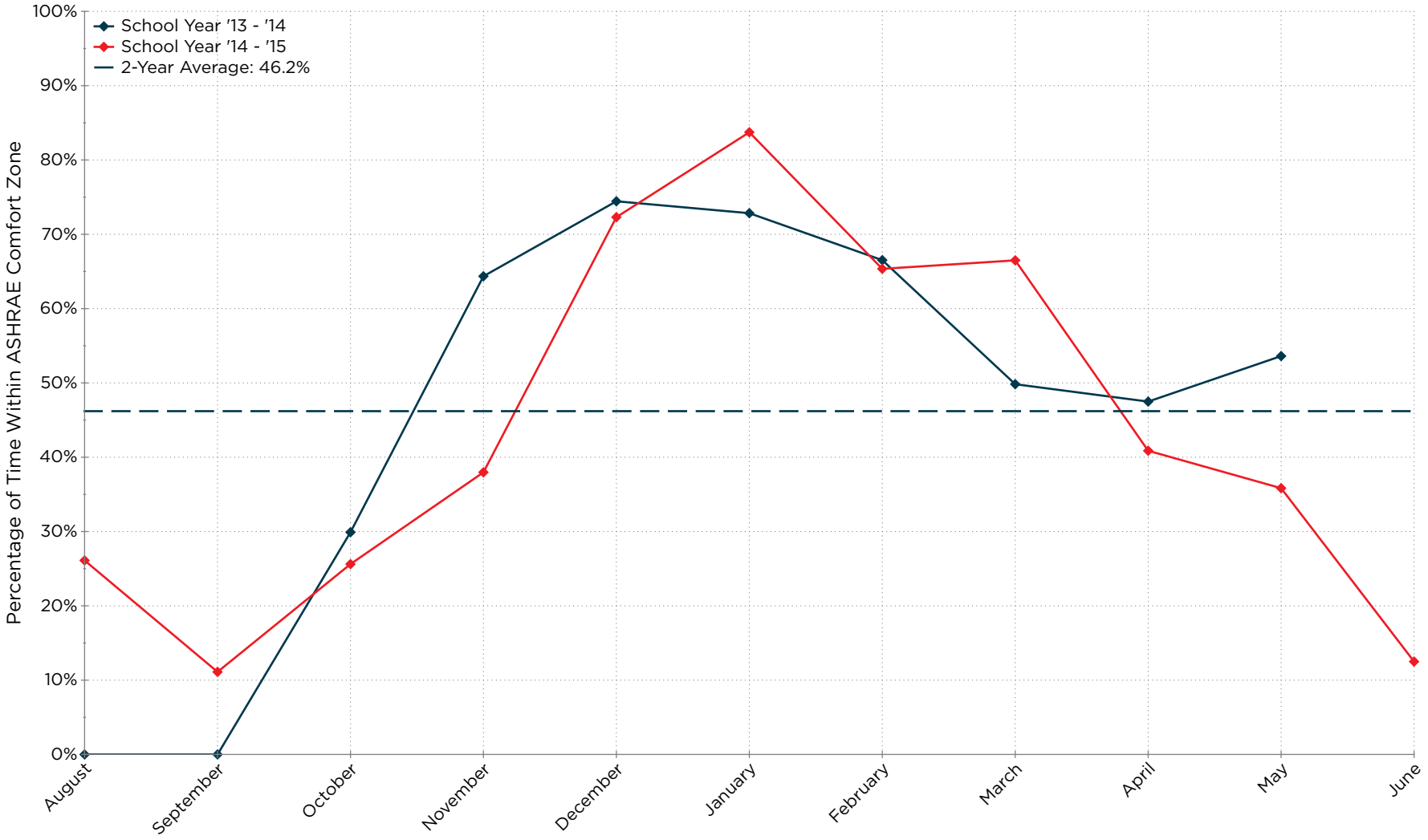


Monthly School Hours within PMV Comfort Zone by Percent: Ewa P1

Description: The percentage of school hours that Ewa P1's PMV score was within the ASHRAE Comfort Zone (+/- 0.5) for each month.

Findings: Over the full study period, Ewa P1 had PMV scores within the ASHRAE Comfort Zone for 46.2% of school hours.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

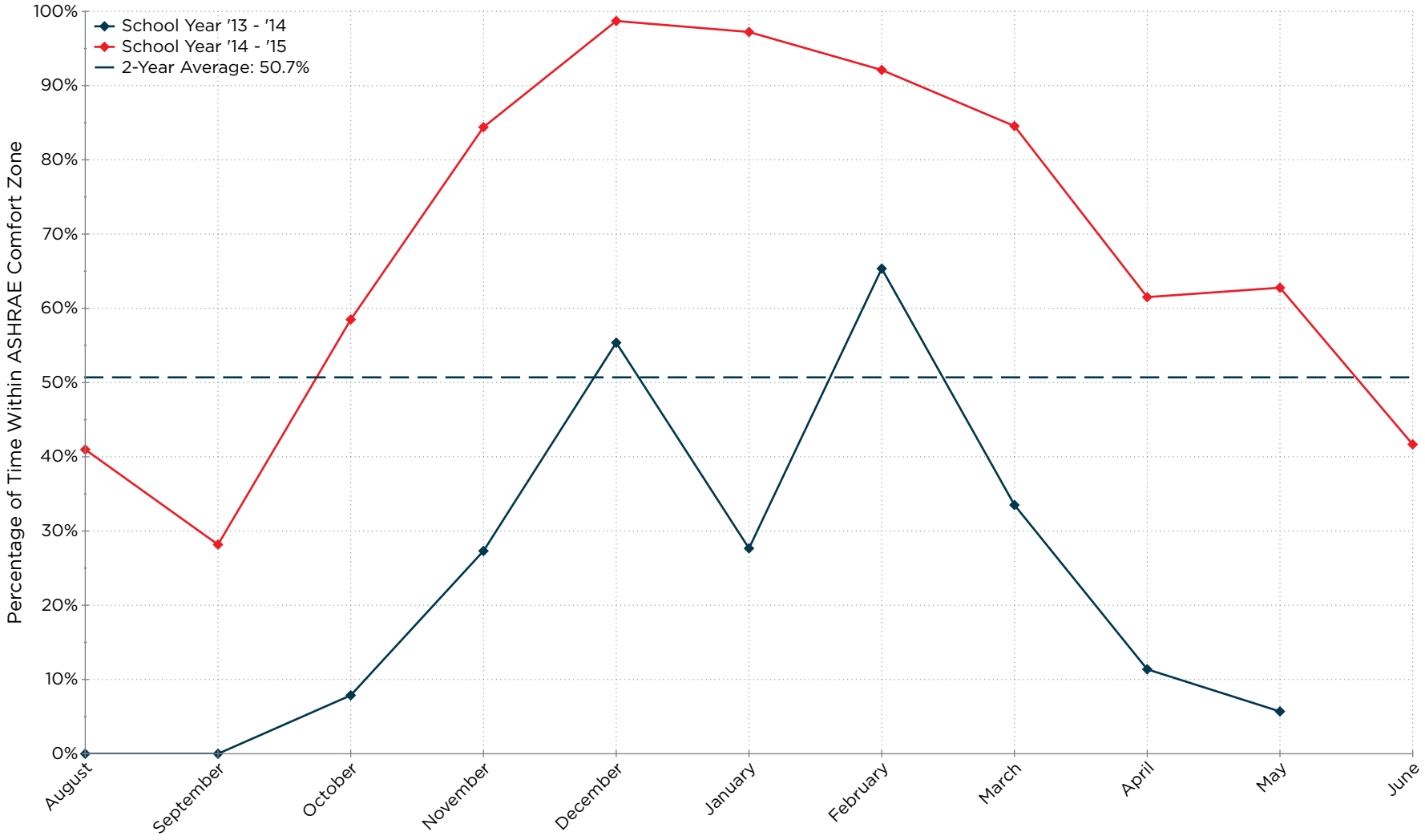


Monthly School Hours within PMV Comfort Zone by Percent: Ewa D36

Description: The percentage of school hours that Ewa D36's PMV score was within the ASHRAE Comfort Zone (+/- 0.5) for each month.

Findings: Over the full study period, Ewa D36 had PMV scores within the ASHRAE Comfort Zone for 50.7% of school hours.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

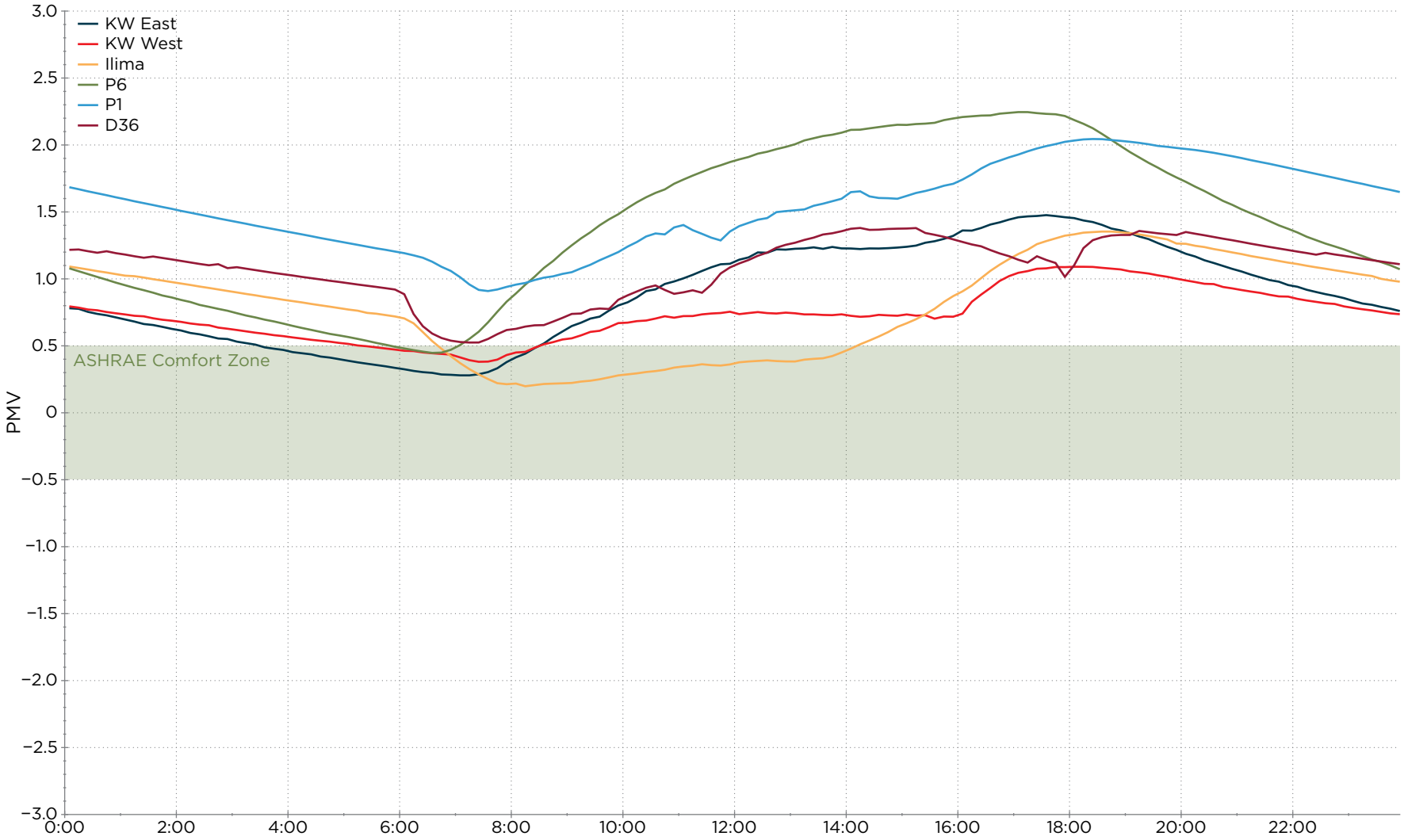


Hourly Average August PMV Profiles: School Days

Description: The average daily profile of PMV scores from school days in August for each classroom. August was chosen to show PMV impacts during hot temperatures.

Findings: Ilima was the only classroom which had average PMV scores within the Comfort Zone after 9:00am. On average the Ilima PMV scores stayed within the Comfort Zone between 7:00am - 2:00pm.

Study Period: 08/01/2013 - 08/31/2013, 08/01/2014 - 08/31/2014
Days: School Days
Hours: All Hours

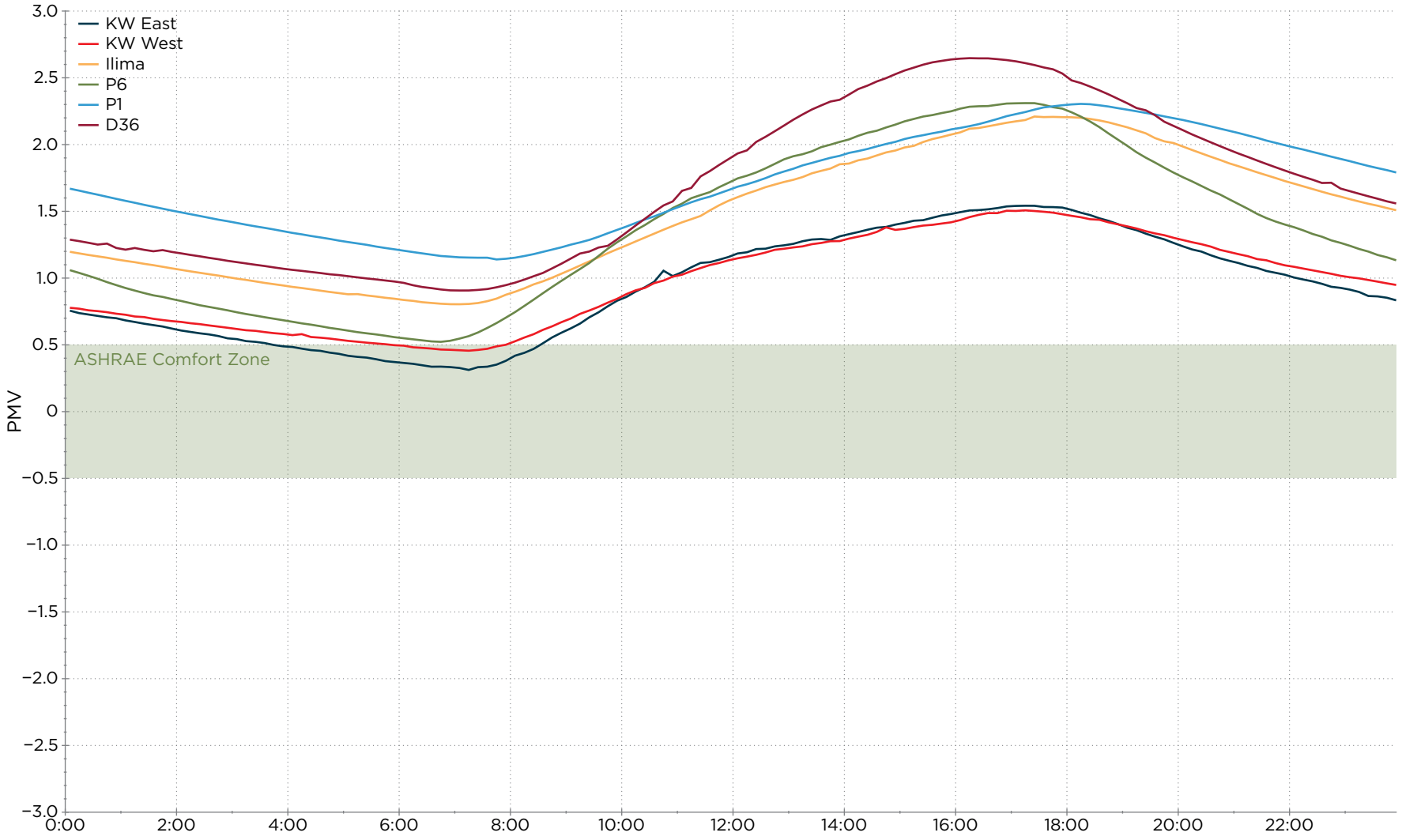


Hourly Average August PMV Profiles: Non-School Days

Description: The average daily profile of PMV scores from school days in August for each classroom. August was chosen to show PMV impacts during hot temperatures.

Findings: D36 reached the highest average PMV score out of the six classrooms, and it reached its peak between 3:00pm - 4:00pm. KW East and West were the only classrooms with average PMV scores within the Comfort Zone which occurred in the morning before 9am.

Study Period: 08/01/2013 - 08/31/2013, 08/01/2014 - 08/31/2014
Days: Non-School Days
Hours: All Hours

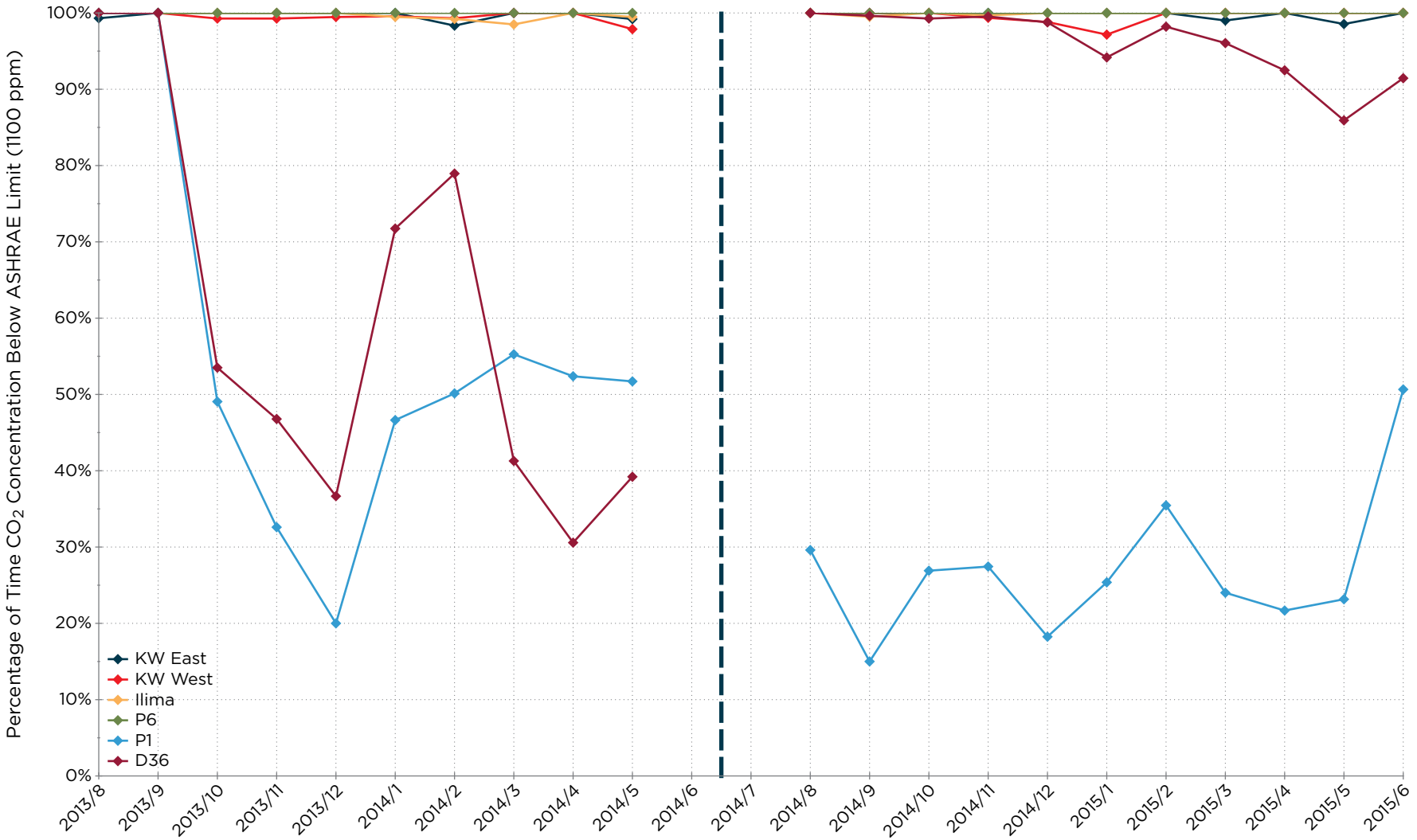


Monthly Air Quality, CO_2, Below ASHRAE Limit by Percent

Description: The percentage of school hours when the CO_2 concentration was below the ASHRAE limit for adequate air circulation (1100 ppm) for each month and for each classroom.

Findings: During the '13-'14 school year, D36 had CO_2 concentrations below the ASHRAE limit of 1100 ppm for less than half of school hours during 5 out of 10 months. However during the '14-'15 school year, D36 had CO_2 concentrations below 1100ppm for over 80% of school hours during every month.

Study Period: 07/16/2013 - 07/16/2015
Days: School Days
Hours: School Hours

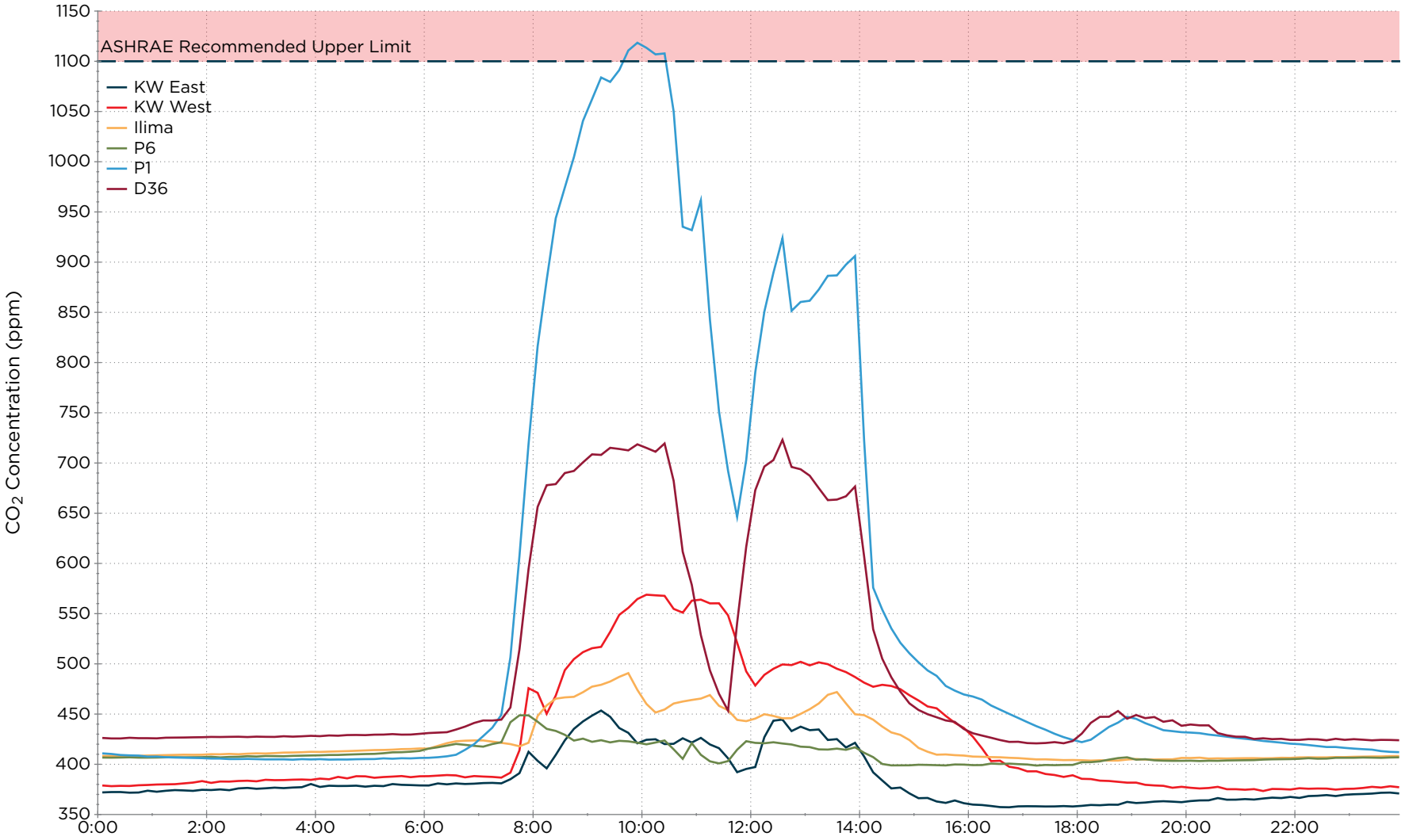


Hourly Average August Air Quality, CO_2, Concentrations

Description: Daily profiles of CO_2 concentration for school days in August. August was chosen to show air quality impacts during hot temperatures.

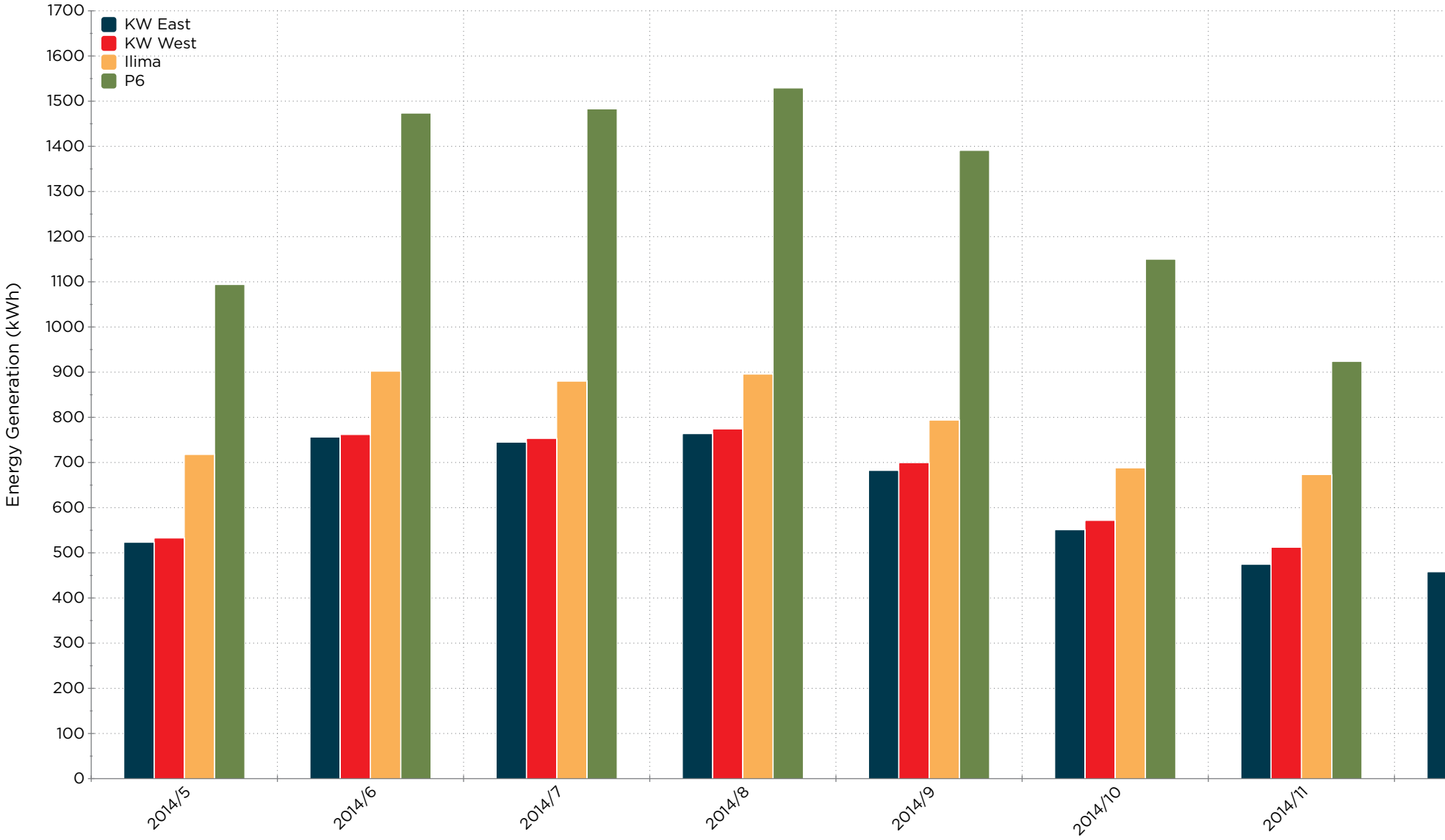
Findings: The only classroom to have CO_2 concentrations exceeding the ASHRAE limit on average was P1, and it occurred between 9:30am - 10:30am.

Study Period: 08/01/2013 - 08/31/2013, 08/01/2014 - 08/31/2014
Days: School Days
Hours: All Hours



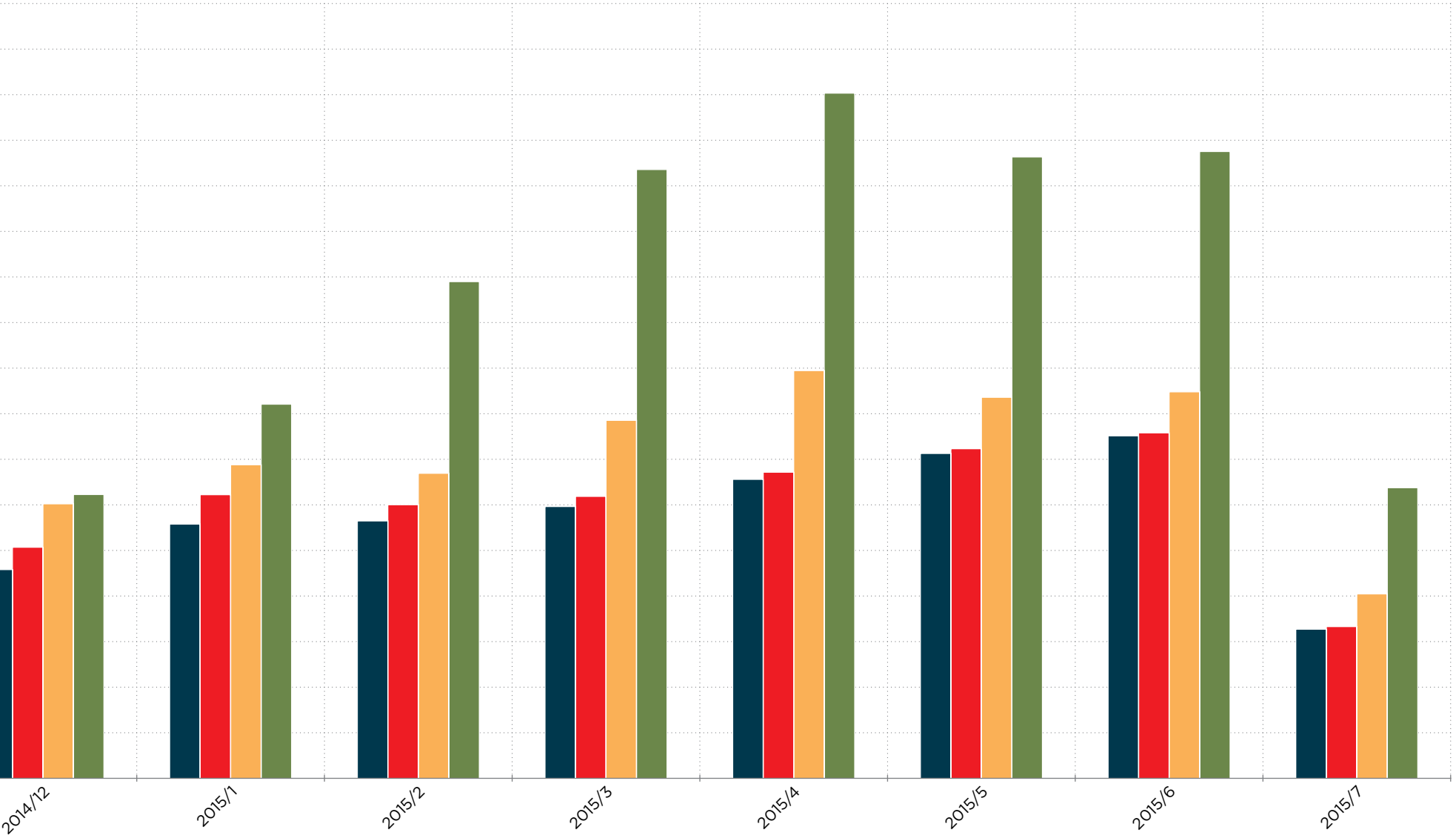
Monthly PV Total Energy Generation

Description: Monthly totals of energy generated by PV systems, for each of the four Test Platforms.



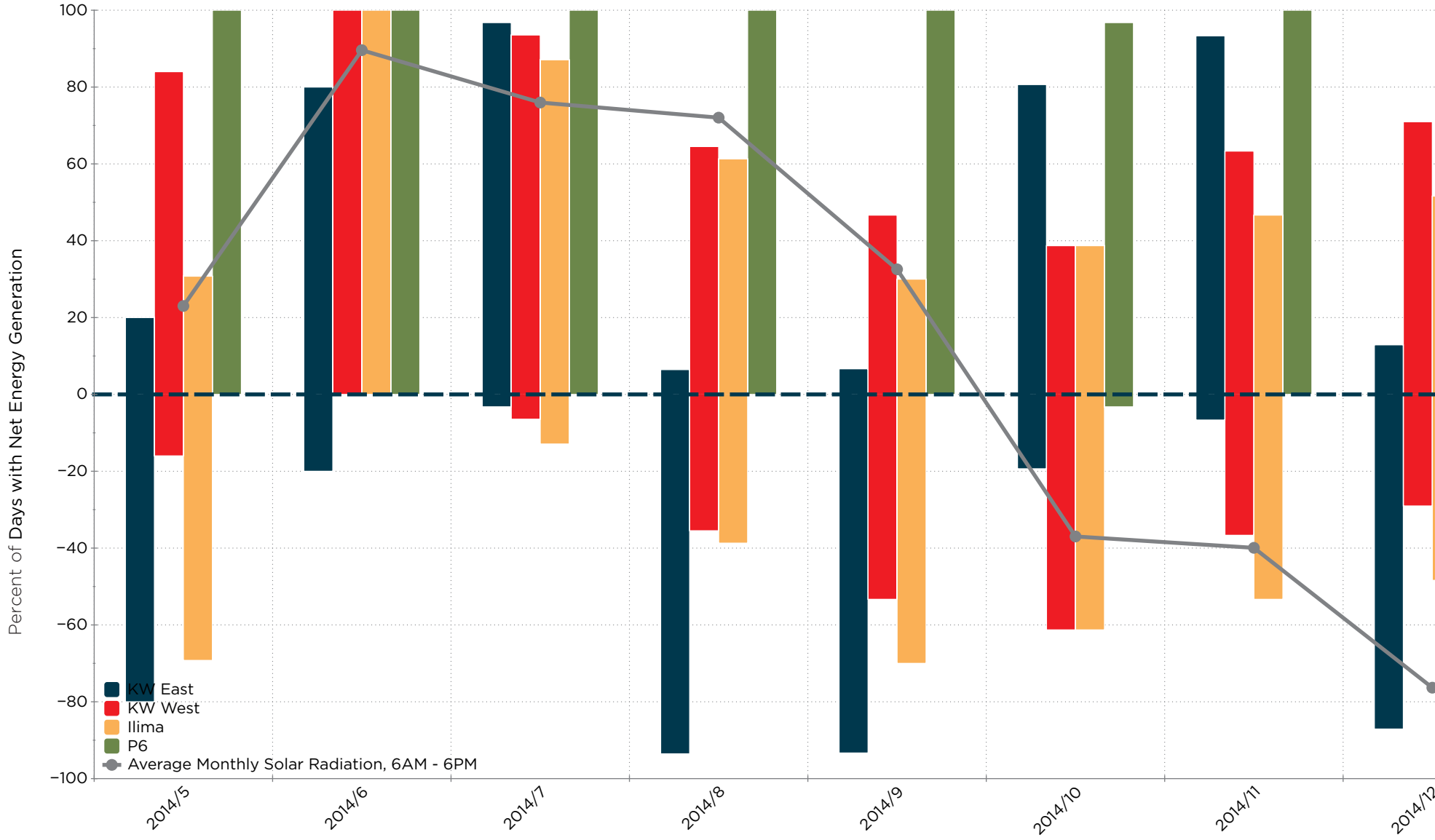
Findings: The P6 PV system is 2.3x larger in capacity than the other three systems but it has a larger variability. For the Kawaikini and Ilima systems, the total electricity production decreased by 40% in December 2014 from peak production compared to 60% for the P6 system.

Study Period: 05/07/2014 - 07/16/2015
Days: All Days
Hours: All Hours



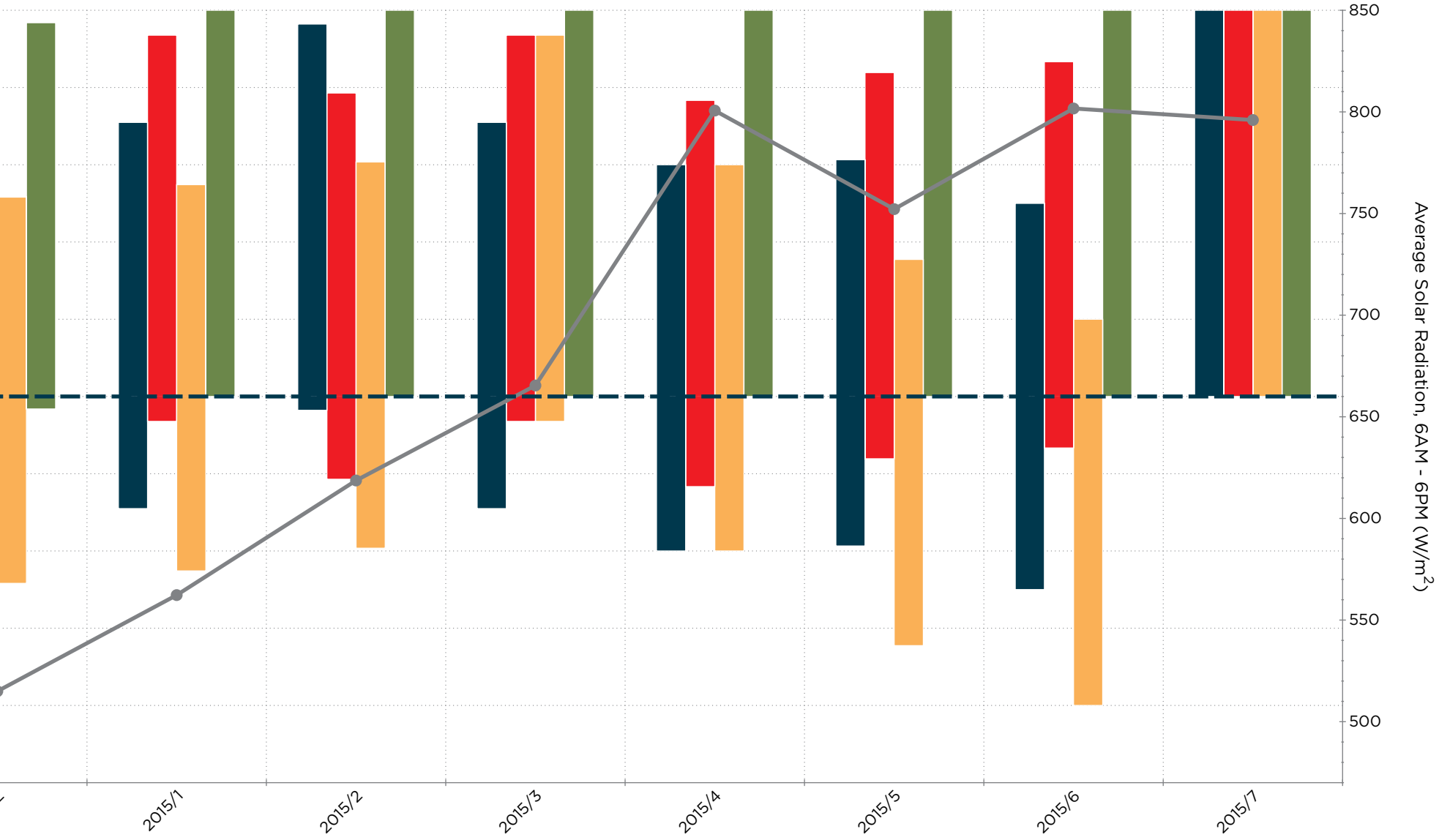
Monthly Net Zero Energy Comparison by Percent & Average Monthly Solar Radiation

Description: The percentage of days with net energy generation (positive) and net energy consumption (negative), for every month and for each of the four test platforms. Also displayed on the right y-axis is the average monthly solar radiation (6am - 6pm only).



Findings: P6 had at least 95% of days each month that were a net generator (i.e. net exporter) of electricity across each month. As solar radiation increased, the other 3 Test Platforms' had a higher percent of days which were a net generator.

Study Period: 05/07/2014 - 07/16/2015
Days: All Days
Hours: All Hours

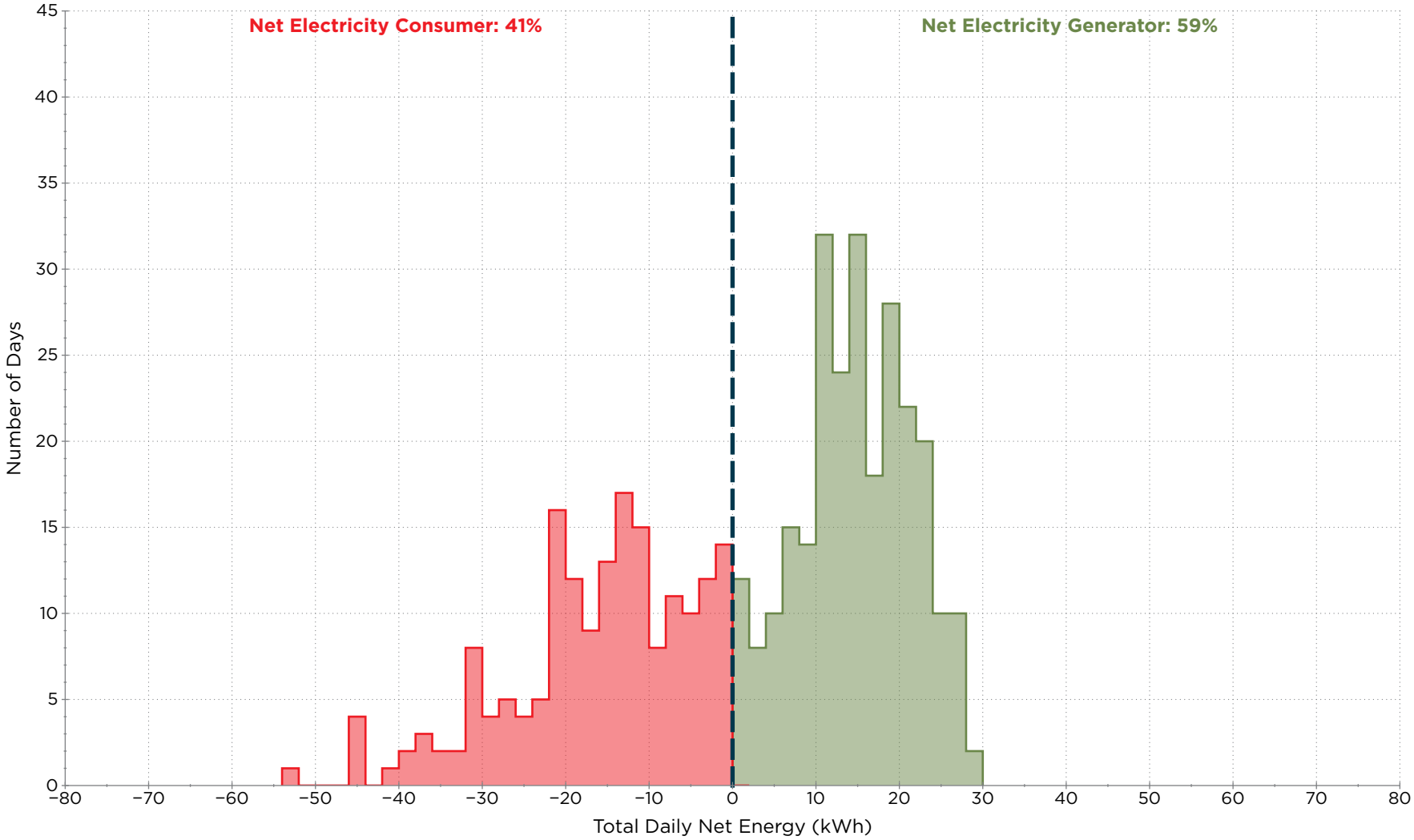


Daily Net Zero Energy Comparison: Kawaikini East

Description: The chart shows the number of days between total daily net energy intervals at Kawaikini East. Total daily net energy is calculated by total electricity generated minus total electricity consumed in a day.

Findings: Kawaikini East had 59% of days through the year where more electricity was produced than consumed by the classroom.

Study Period: 05/07/2014 - 07/16/2015
Days: All Days
Hours: All Hours

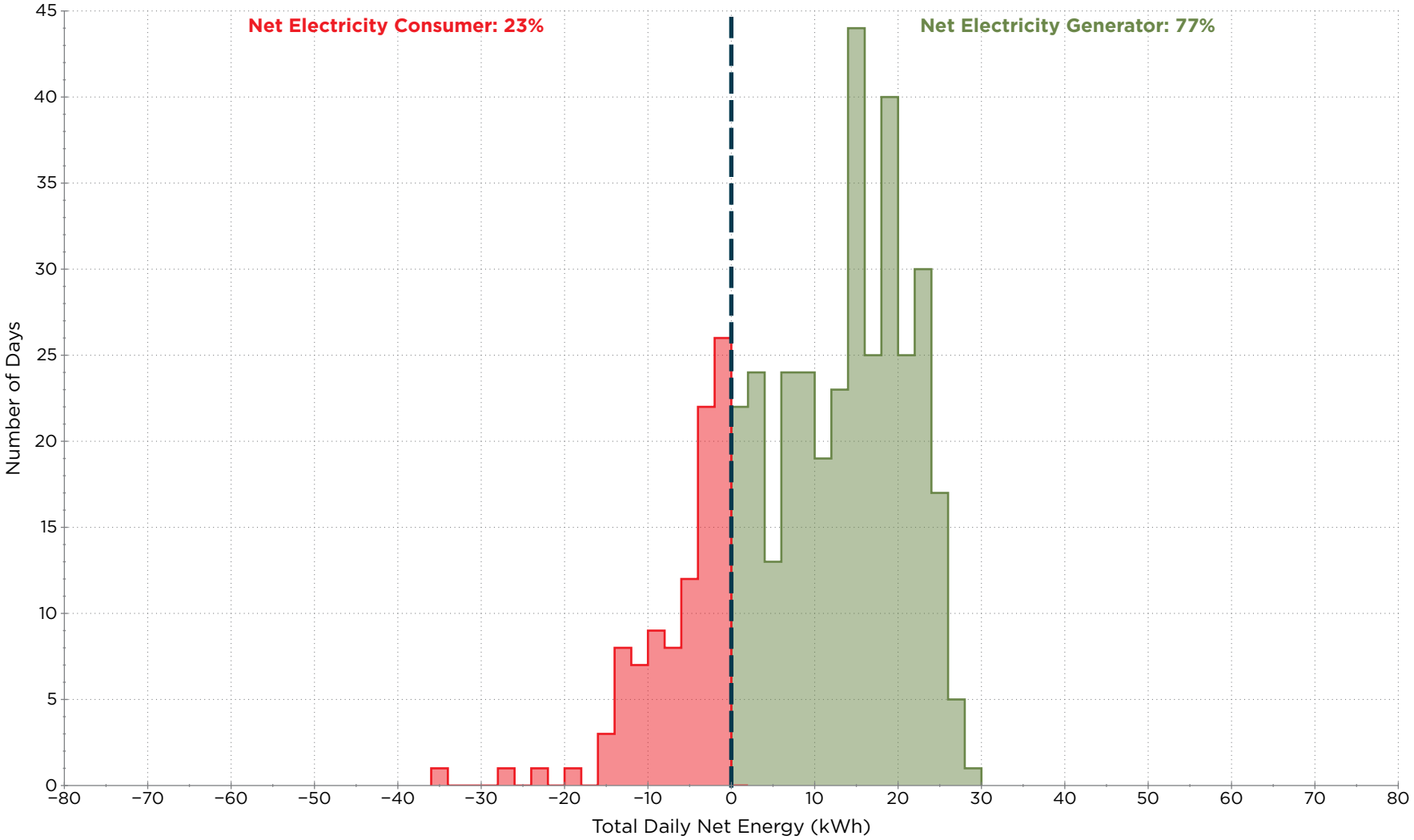


Daily Net Zero Energy Comparison: Kawaikini West

Description: The chart shows the number of days between total daily net energy intervals at Kawaikini West. Total daily net energy is calculated by total electricity generated minus total electricity consumed in a day.

Findings: Kawaikini West had 77% of days through the year where more electricity was produced than consumed by the classroom.

Study Period: 05/07/2014 - 07/16/2015
Days: All Days
Hours: All Hours

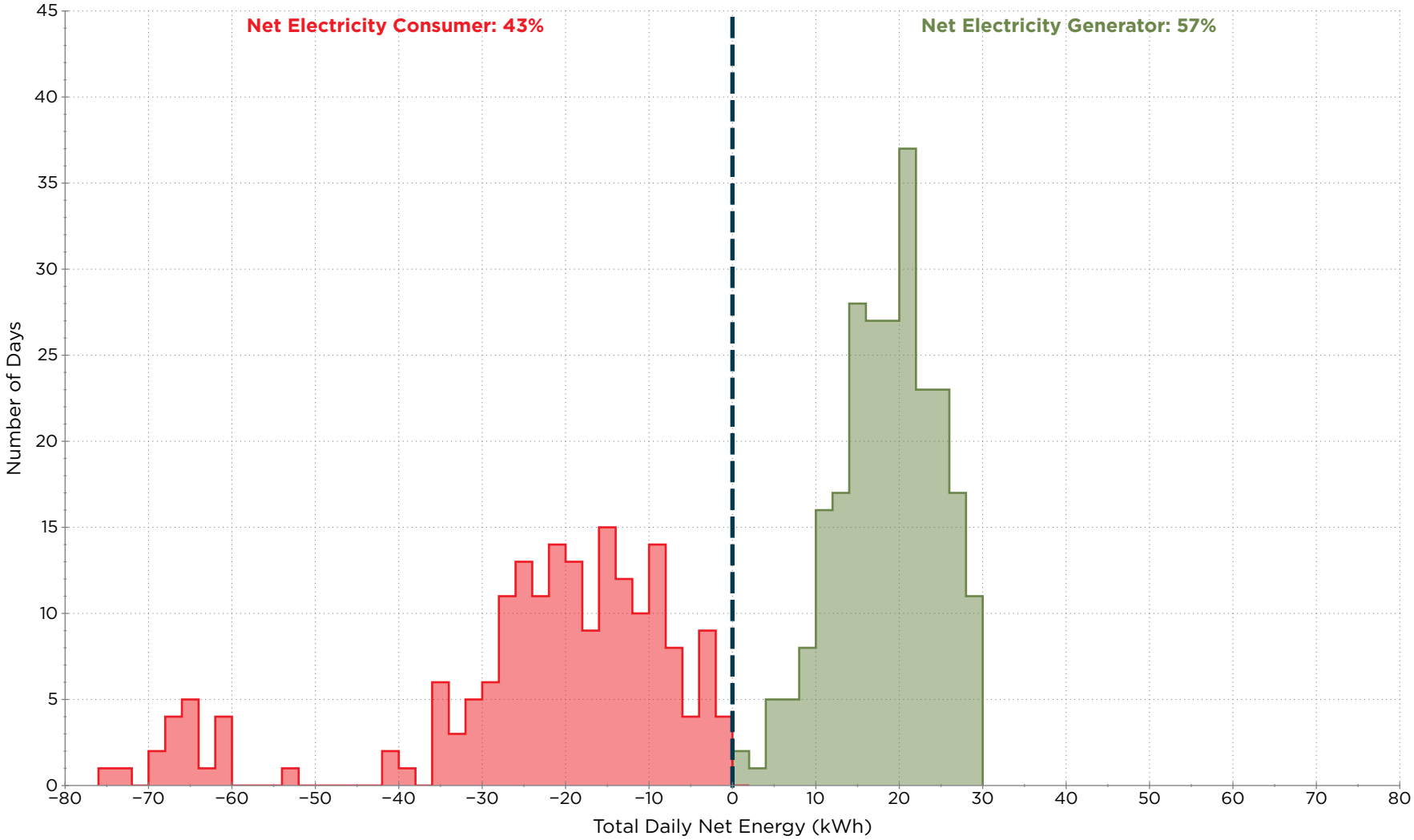


Daily Net Zero Energy Comparison: Ilima

Description: The chart shows the number of days between total daily net energy intervals at Ilima. Total daily net energy is calculated by total electricity generated minus total electricity consumed in a day.

Findings: Ilima had 57% of days through the year where more electricity was produced than consumed by the classroom.

Study Period: 05/07/2014 - 07/16/2015
Days: All Days
Hours: All Hours

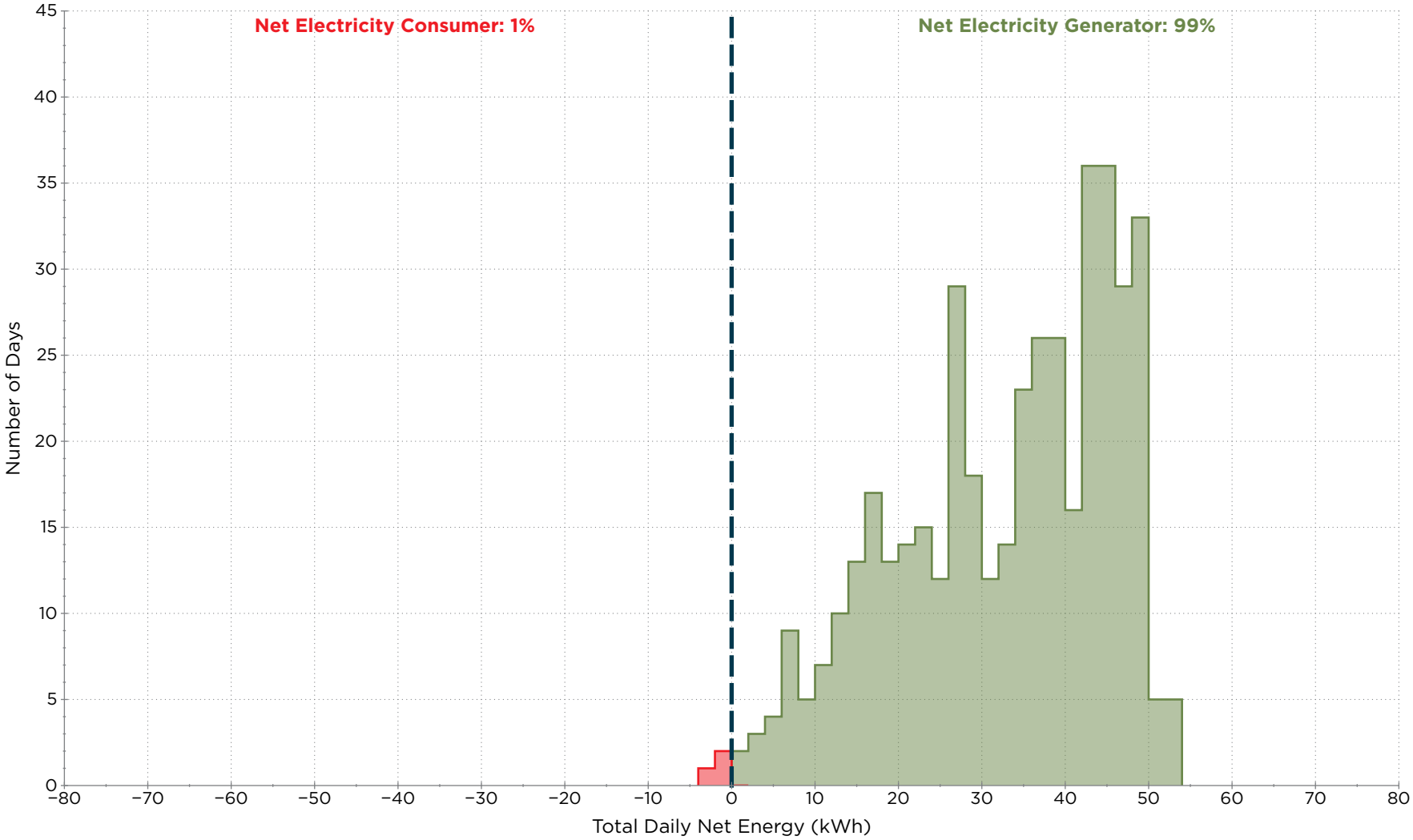


Daily Net Zero Energy Comparison: P6

Description: The chart shows the number of days between total daily net energy intervals at Ewa P6. Total daily net energy is calculated by total electricity generated minus total electricity consumed in a day.

Findings: P6 had 99% of days through the year where more electricity was produced than consumed by the classroom.

Study Period: 05/07/2014 - 07/16/2015
Days: All Days
Hours: All Hours

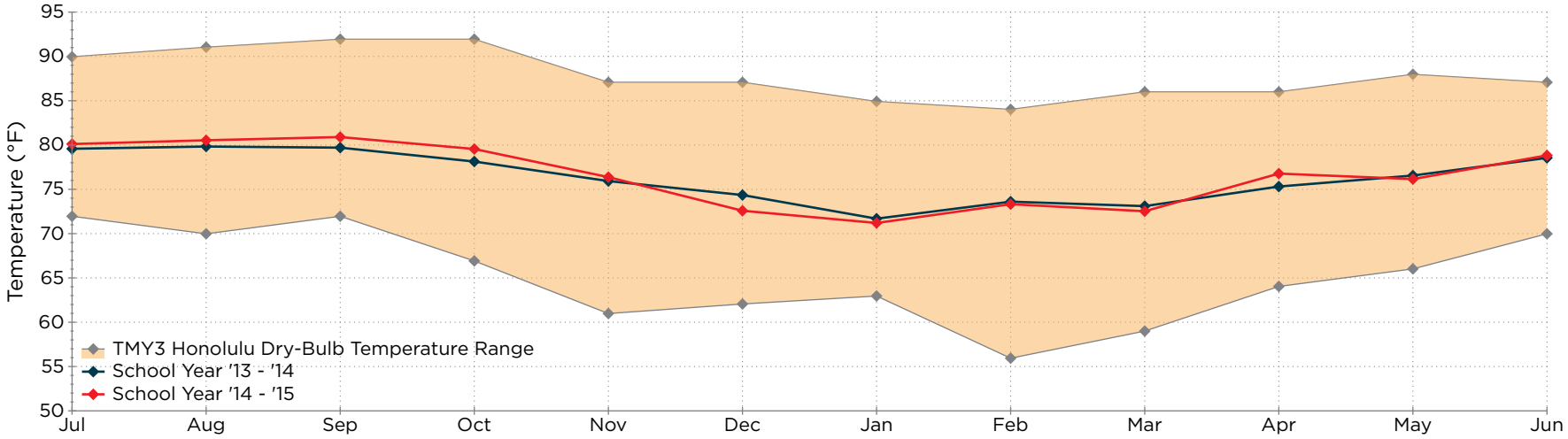


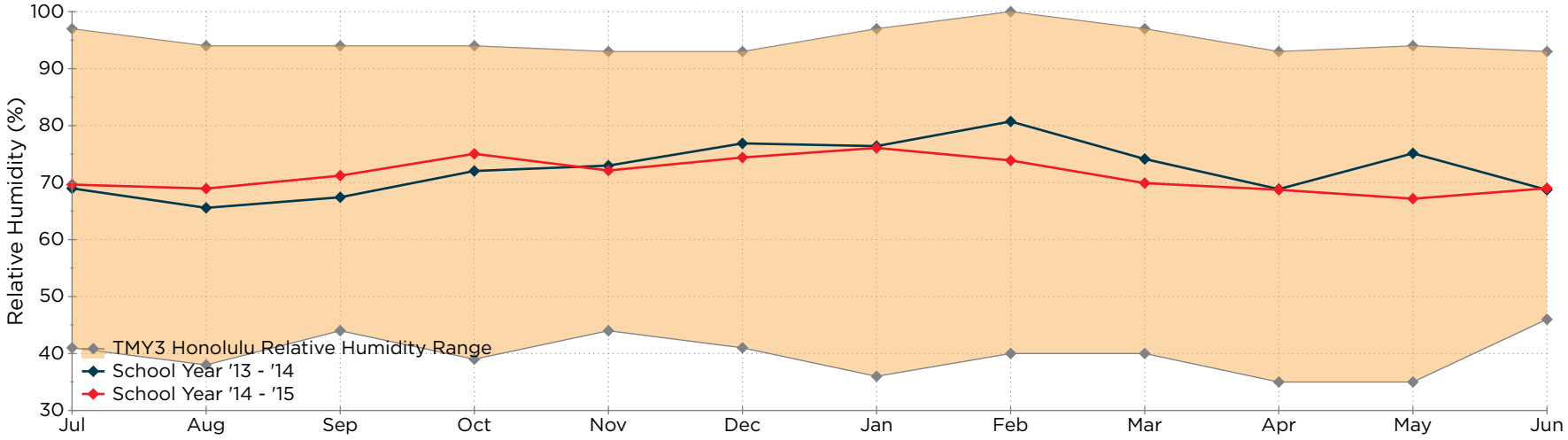
Monthly TMY3 Climate Comparison: Honolulu

Description: The graph shows measured average monthly outdoor temperature and relative humidity for Ilima, Ewa P6, Ewa P1, and Ewa D36 located in Honolulu compared with the monthly maximum and minimum values for a typical meteorological year[1].

Findings: Honolulu average monthly temperatures and relative humidities during the '13-'14 and '14-'15 school years were within the historical range.

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours





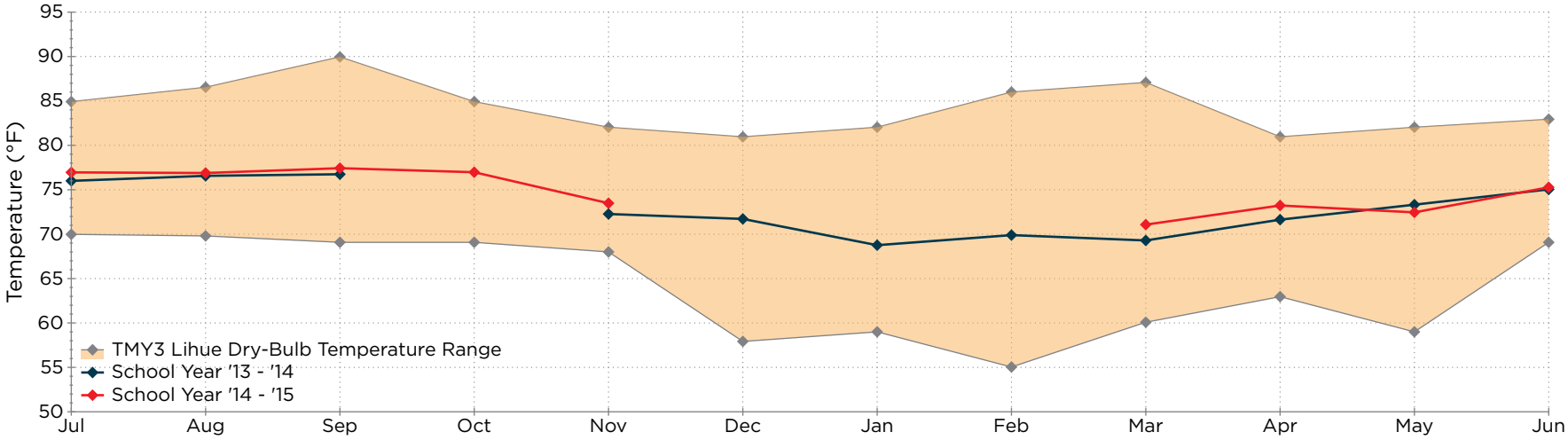
1: A typical meteorological year is an hourly weather dataset for a specific location created by the National Renewable Energy Laboratory from data collected across 30 years (1991 - 2005).

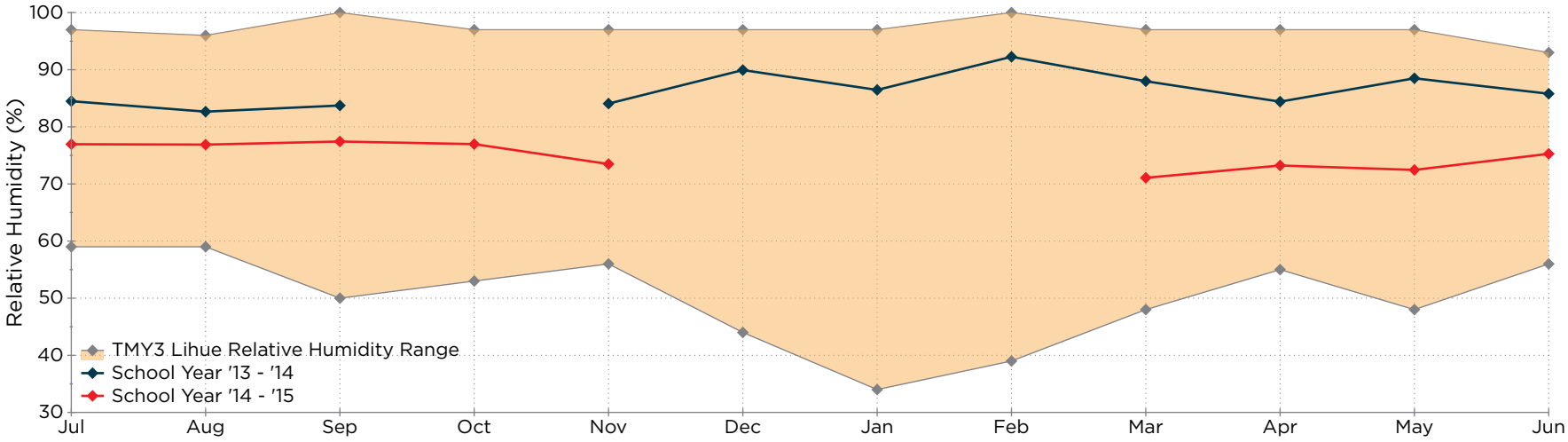
Monthly TMY3 Climate Comparison: Lihu'e

Description: The graph shows measured average monthly outdoor temperature and relative humidity for Kawaikini East and West located in Lihu'e compared with the monthly maximum and minimum values for a typical meteorological year[1]. Missing temperature and relative humidity data were from sensor hardware issues.

Findings: Lihu'e average monthly temperatures and relative humidities during the '13-'14 and '14-'15 school years were within the historical range.

Study Period: 07/16/2013 - 07/16/2015
Days: All Days
Hours: All Hours





1: A typical meteorological year is an hourly weather dataset for a specific location created by the National Renewable Energy Laboratory from data collected across 30 years (1991 - 2005).

DESCRIPTION
This section shows the sensor layout, sensor details and monitoring system typologies for each of the six classrooms.

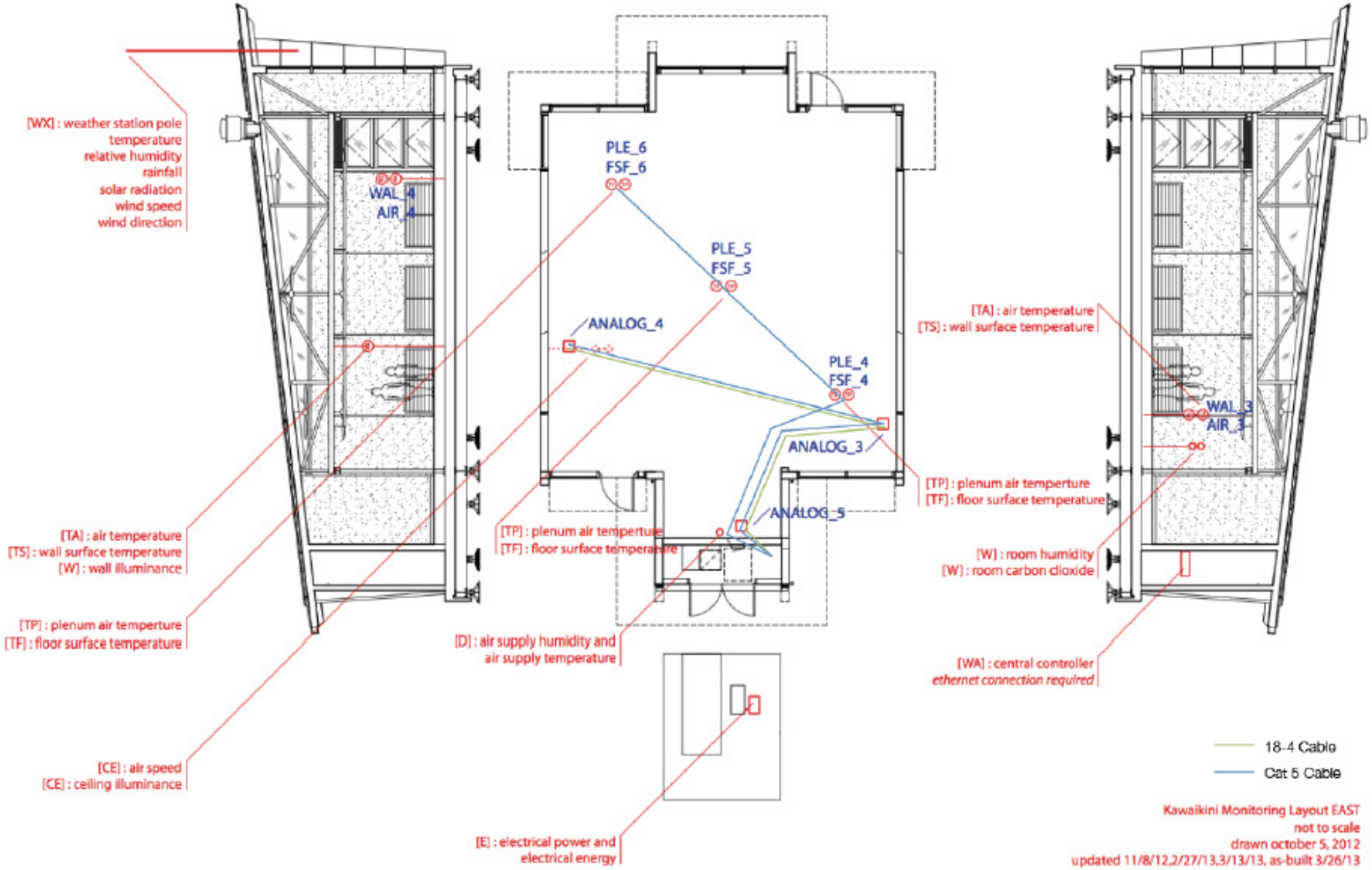
WHY IMPORTANT
This section provides context into data measurement and collection which is the foundation for all figures.

A3

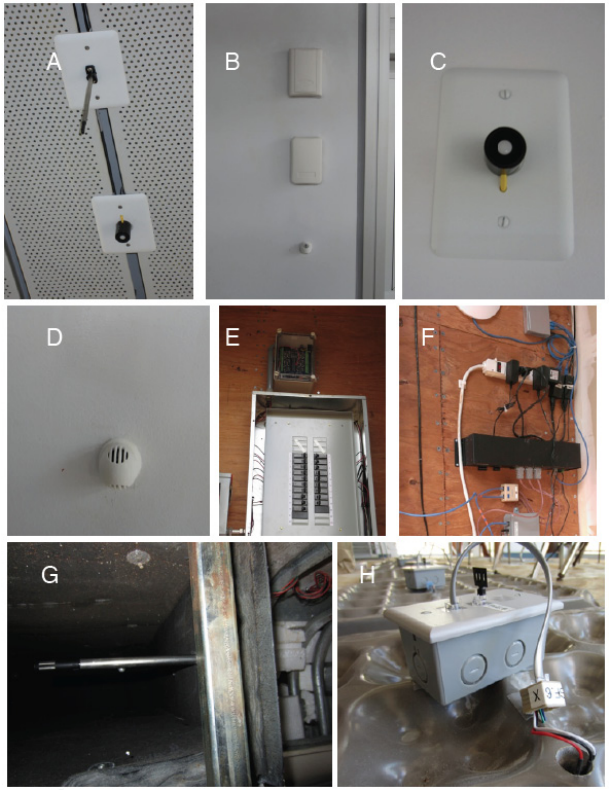
Sensor Details

Kawaikini East	96
Kawaikini West	98
Ilima	100
P6	102
P1	104
D36	106

Kawaikini East Sensor Layout

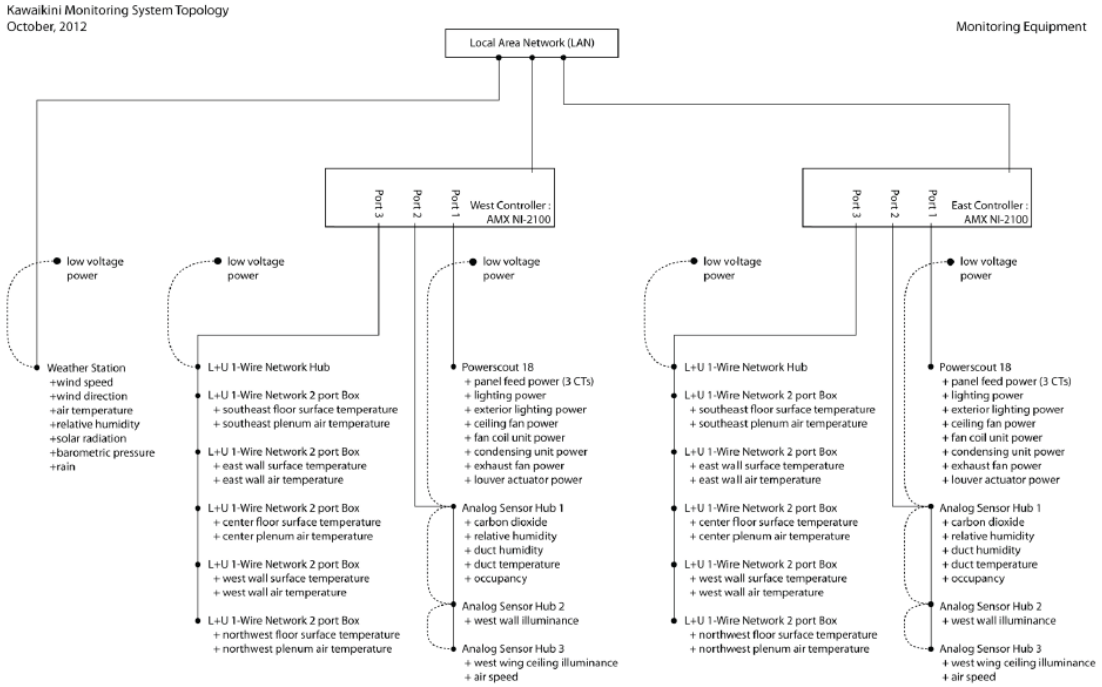


Kawaikini East Sensor Detail

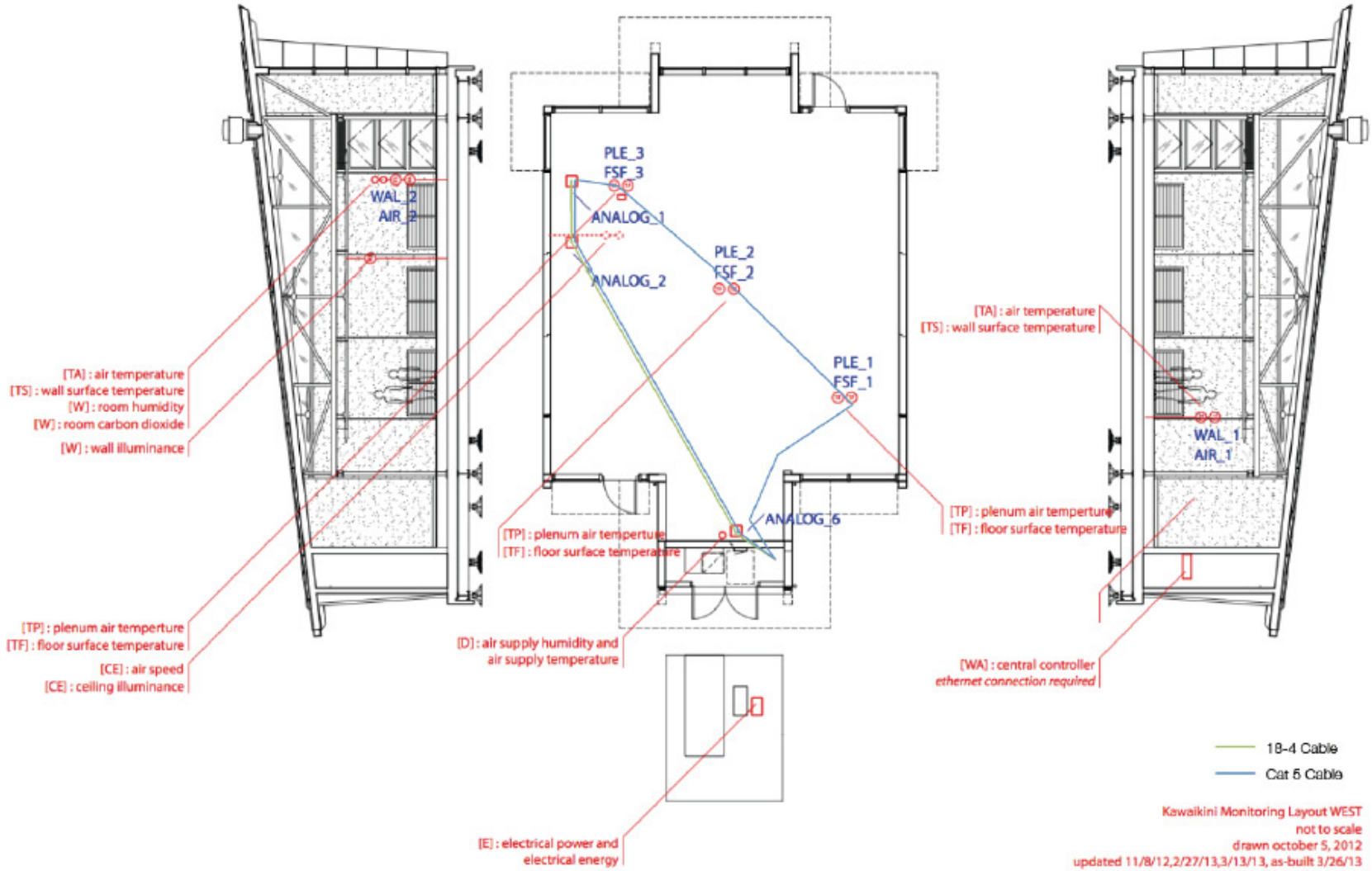


A	Ceiling: Room Air Speed, Ceiling Illuminance
B	Room CO2, Humidity & Temp, Wall Surface Temp, Air Temp
C	Wall Illuminance
D	Wall Surface Temp, Air Temp
E	Electrical Panel: Powerscout, Building System CT's
F	Communications: Central Controller and Serial Communication Adapters
G	Air Supply Humidity & Temperature
H	Plenum Air Temperature & Floor Surface Temperature

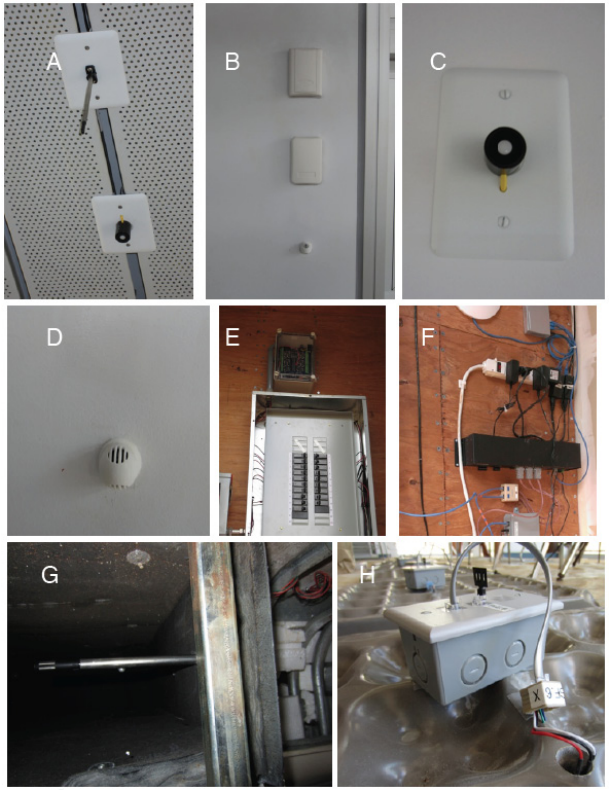
Kawaikini East Monitoring System Typology



Kawaikini West Sensor Layout

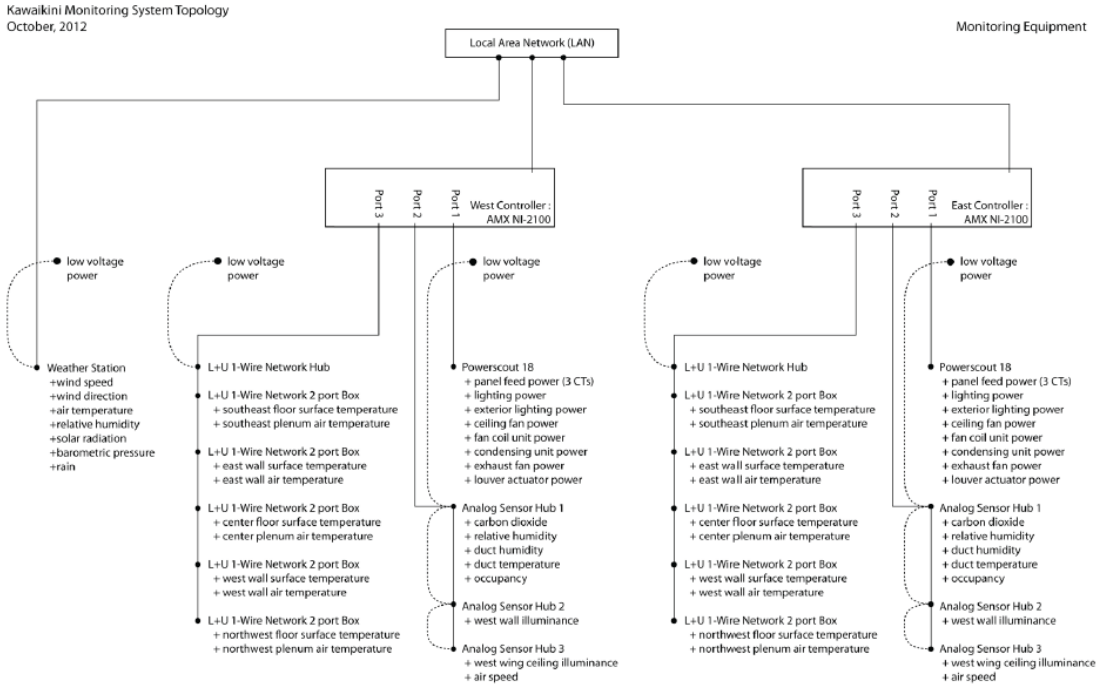


Kawaikini West Sensor Detail

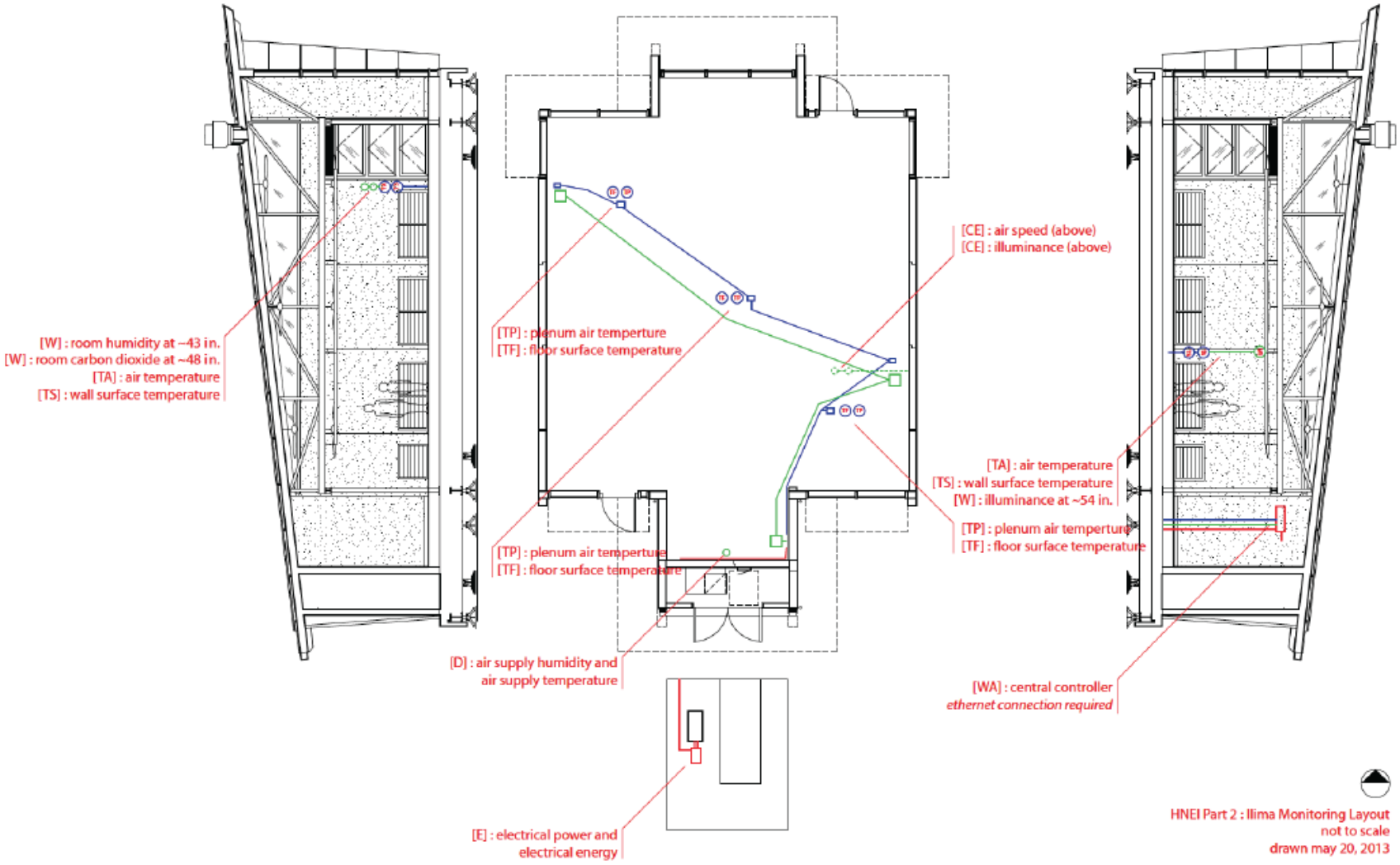


A	Ceiling: Room Air Speed, Ceiling Illuminance
B	Room CO2, Humidity & Temp, Wall Surface Temp, Air Temp
C	Wall Illuminance
D	Wall Surface Temp, Air Temp
E	Electrical Panel: Powerscout, ,Building System CT's
F	Communications: Central Controller and Serial Communication Adapters
G	Air Supply Humidity & Temperature
H	Plenum Air Temperature & Floor Surface Temperature

Kawaikini West Monitoring System Typology



Ilima Sensor Layout

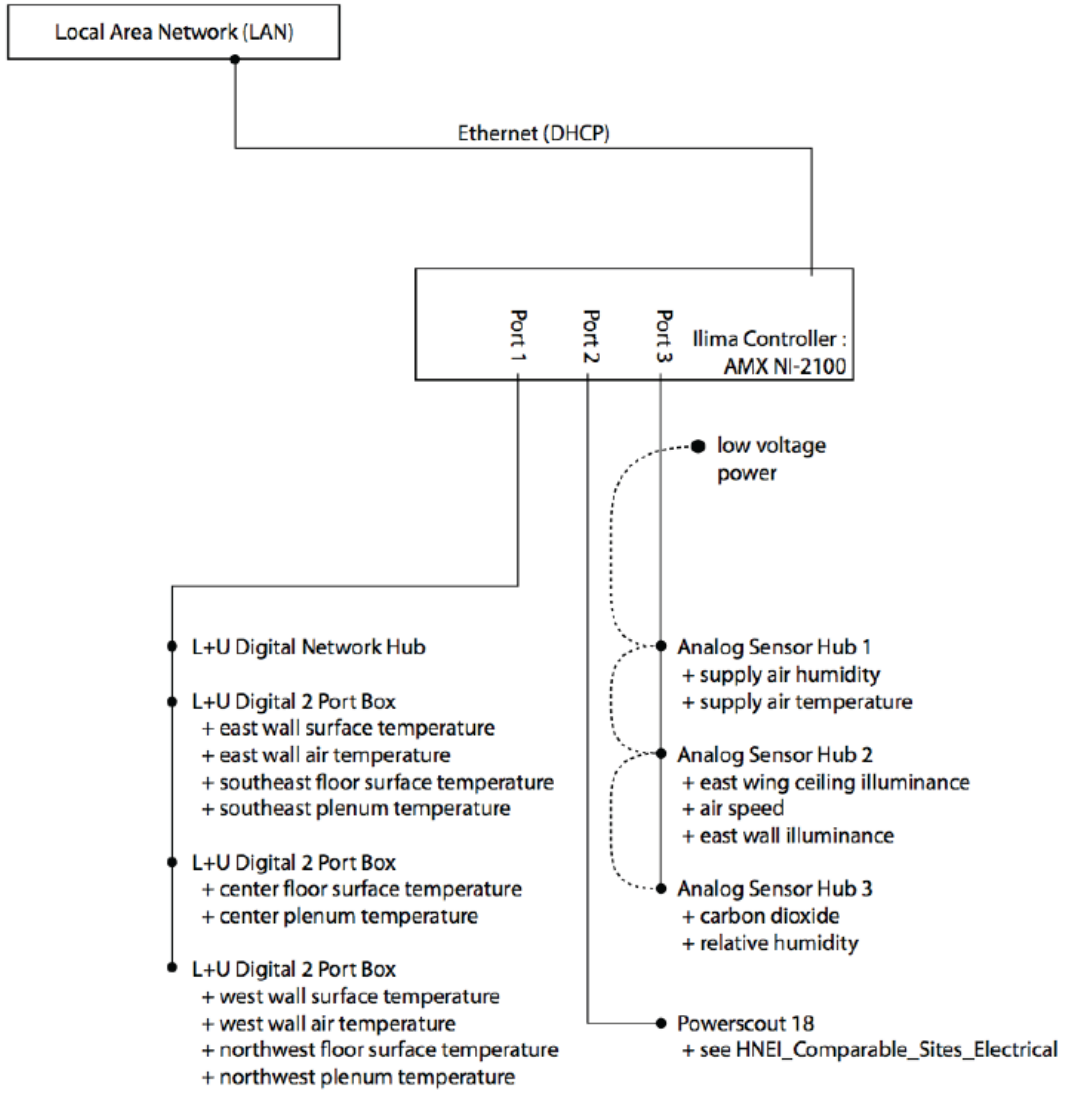


location of equipment subject to change as necessitated due to actual site conditions and installation coordination

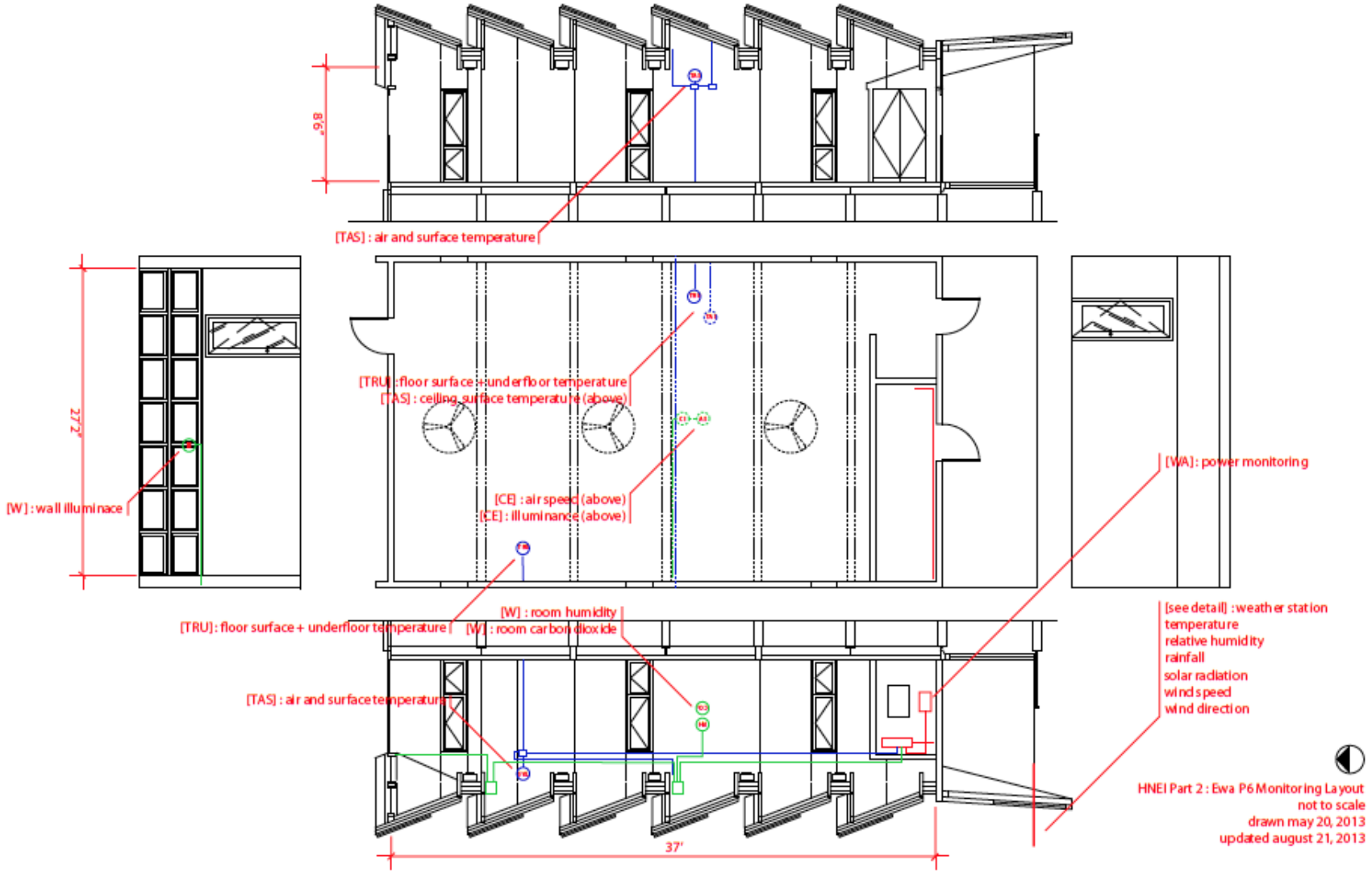
Ilima Sensor Detail

A	East Wall: Room CO2, Room Humidity & Temperature, Air Temperature, Surface Temperature
B	Floor: Plenum Air Temperature and Floor Surface Temperature
C	West Wall: Air Temperature & Wall Surface Temperature
D	West Wall: Wall Illuminance
E	Communications: Central Controller and Serial Communication Adapters
F	Electrical Panel: Building System CT's
G	Ceiling: Room Air Speed, Ceiling Illuminance
H	Air Supply Temperature

Ilima Monitoring System Typology



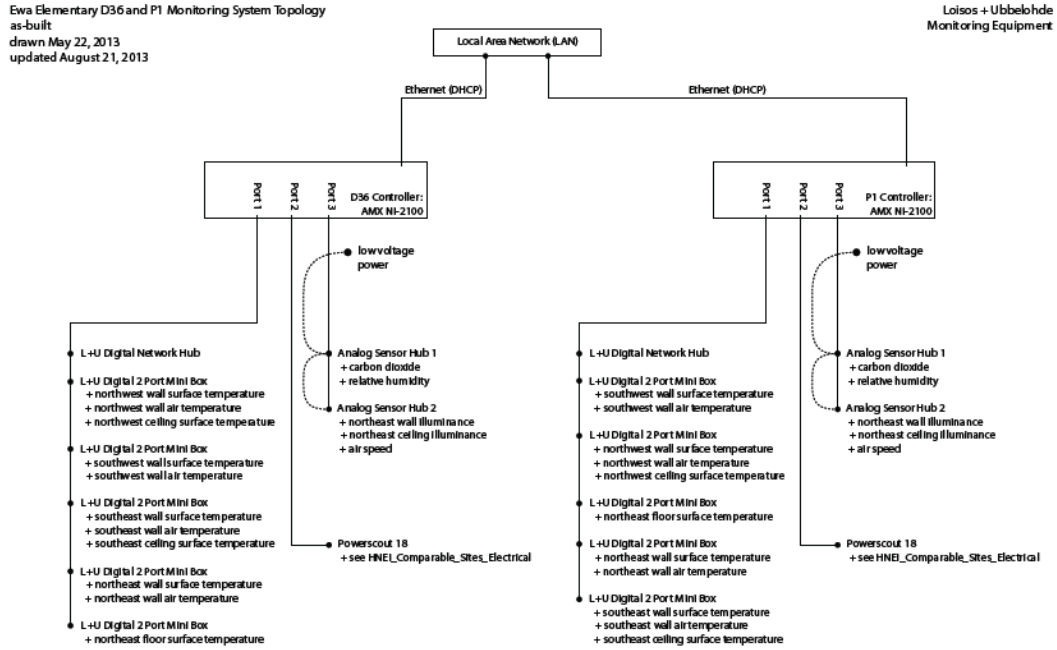
P6 Sensor Layout



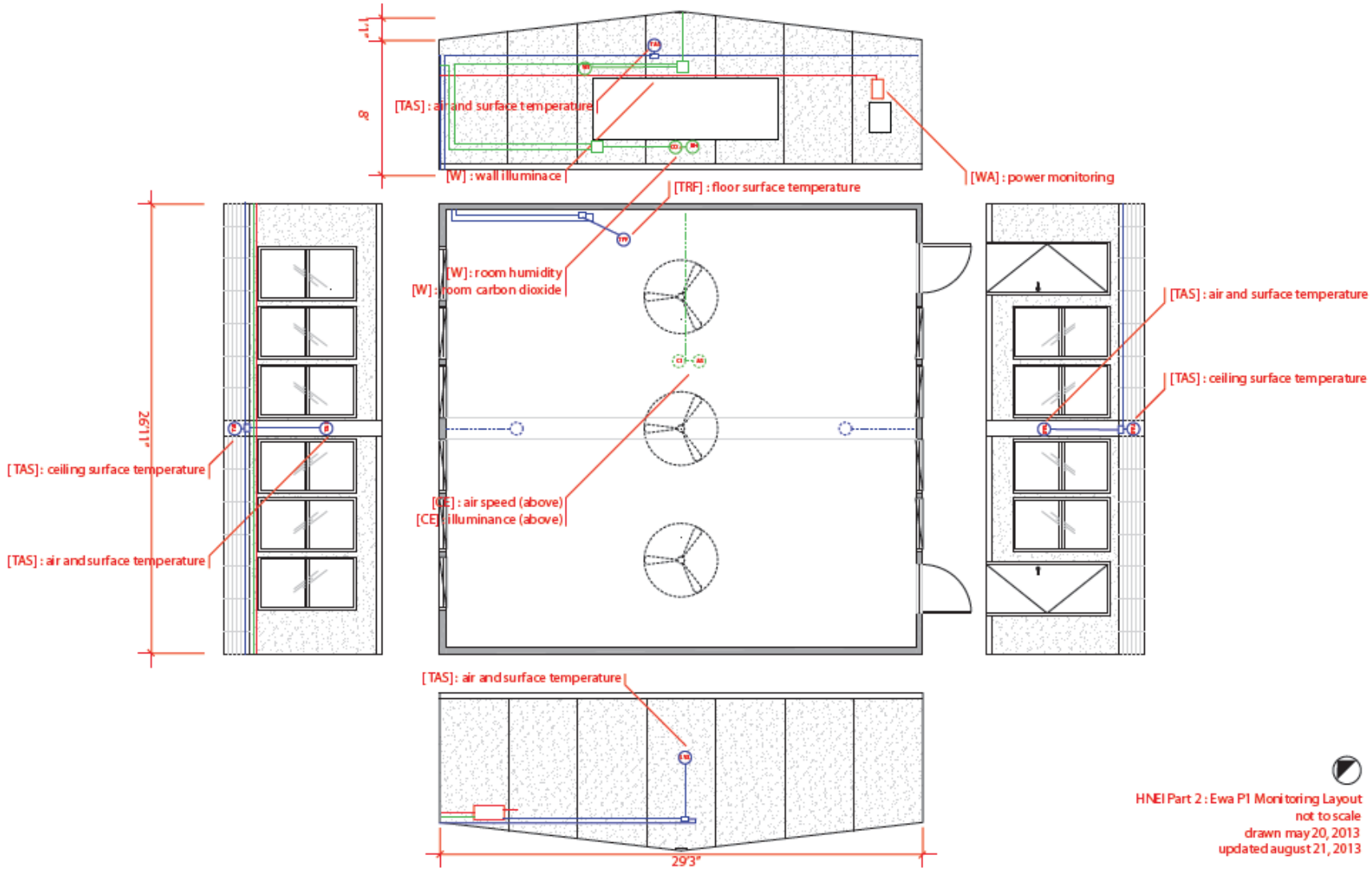
P6 Sensor Detail

A	E Wall: Room Carbon Dioxide, Room Humidity & Temperature
B	Ceiling: Illuminance & Room Air Speed
C	W & E Wall: Wall Surface Temperature & Ambient Temperature
D	Central Controller
E	N Wall: Wall Illuminance
F	W & E Floor: Floor Surface Temperature
G	Ceiling: Air Speed

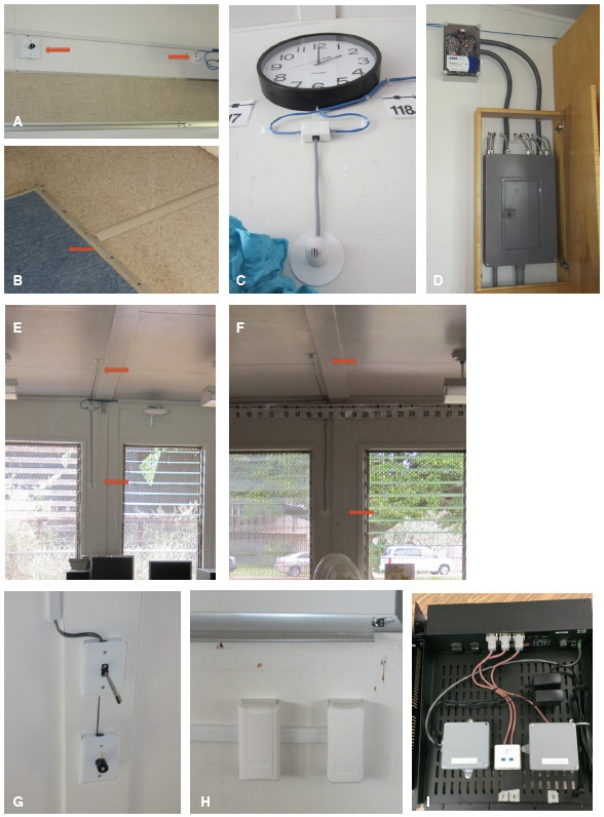
P6 Monitoring System Typology



P1 Sensor Layout

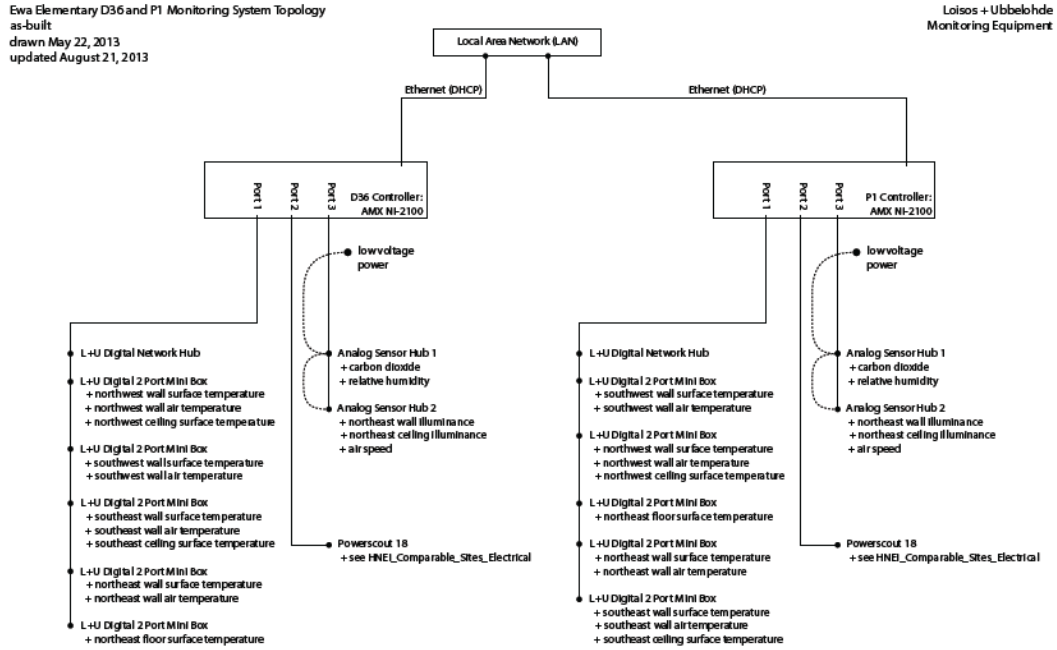


P1 Sensor Detail

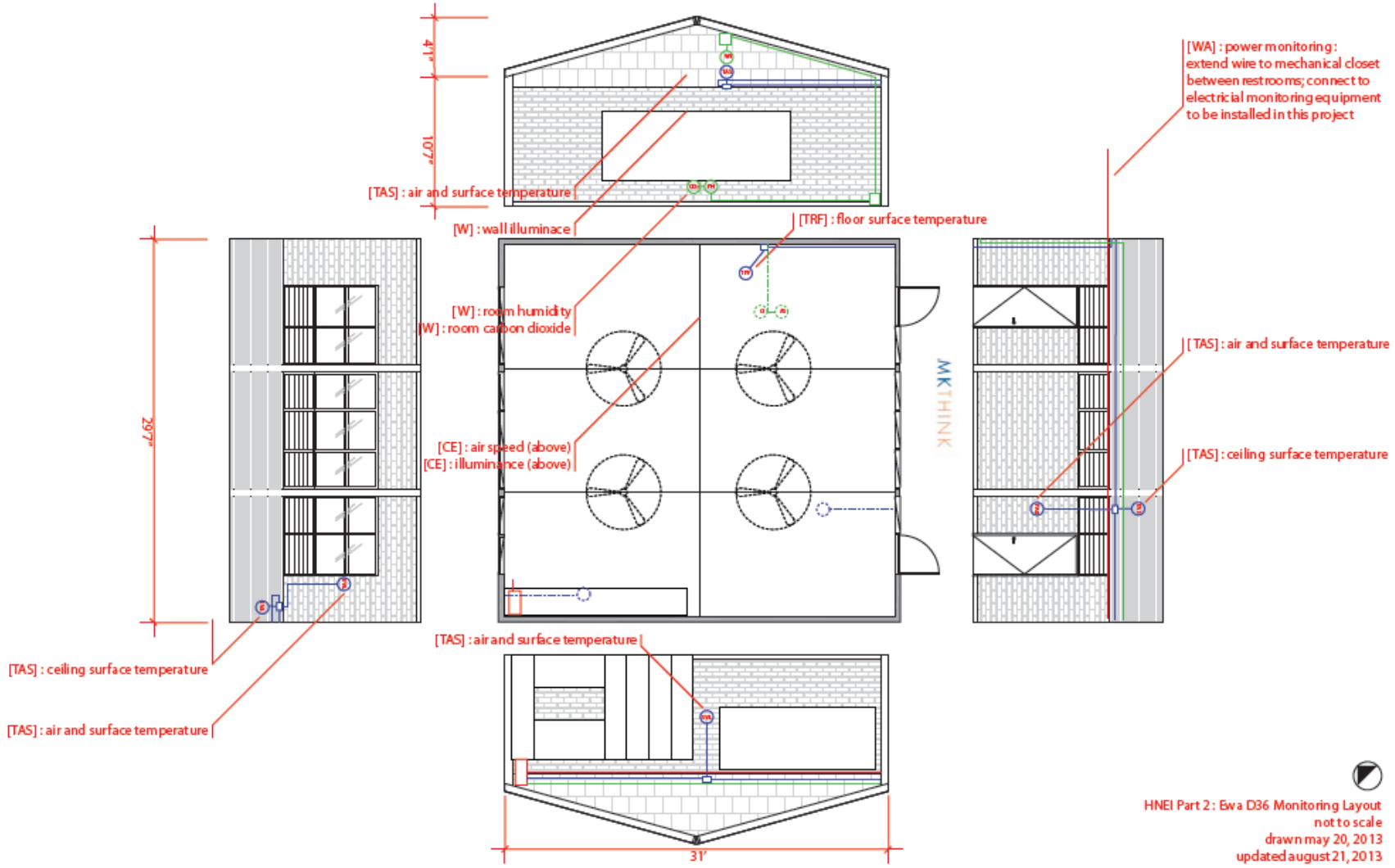


A	SW Wall: Wall Illuminance (left sensor), Wall Surface Temp, and Air Temp. (right sensor)
B	Floor: Floor Surface Temperature (under carpet)
C	SW Wall: Wall Surface Temp, and Ambient Temperature
D	Electrical Panel and Powerscout
E	NW Wall: Ceiling Surface Temp. & Wall Surface Temperature and Ambient Temperature
F	SE Wall: Ceiling Surface Temp. & Wall Surface Temperature and Ambient Temperature
G	Ceiling: Air Speed and Ceiling Illuminance
H	Room Carbon Dioxide, Room Humidity & Temperature
I	Central Controller with Serial Communications adapter & network hubs

P1 Monitoring System Typology



D36 Sensor Lavout



D36 Sensor Detail

A	E Wall: Room Carbon Dioxide, Room Humidity & Temperature
B	Ceiling: Illuminance & Room Air Speed
C	W & E Wall: Wall Surface Temperature & Ambient Temperature
D	Central Controller
E	N Wall: Wall Illuminance
F	W & E Floor: Floor Surface Temperature
G	Ceiling: Air Speed
H	Ceiling: Air Speed

D36 Monitoring System Typology