17.0 University of Washington Facilities Services Site Tests

Additional chapter coauthor: ZT Taylor − Battelle Memorial Institute

The University of Washington (UW) at the Seattle campus is a subproject participating in the Pacific Northwest Smart Grid Demonstration (PNWSGD) project, a project that spans 5 years and includes five Pacific Northwest States (Idaho, Montana, Oregon, Washington and Wyoming). The UW's goals in the project is to monitor and manage more than fifteen million square feet of space, serve over 40,000 students daily, and provide the university with the expectation of saving over $350,000 annually in energy consumption costs.

The following asset systems were demonstrated at the UW site:

- enabling assets, consisting primarily of data collection infrastructure
- power generation assets, including one steam turbine (Section 17.1), two diesel standby generators (Section 17.2), and two small-scale solar photovoltaic (PV) facilities (Section 17.3)
- building heating, ventilation, and air-conditioning (HVAC) controls and lighting controls (Section 17.4)
- student residence and university facilities pilot sub-metering (Section 17.5)
- a facility energy management system (FEMS) (Section 17.6).

Those asset systems were exploited to conduct six experiments that are the focus of this report, each test case comprising one major subsection of this chapter. Figure 17.1 summarizes the layout of the UW asset systems and the organization of test cases.

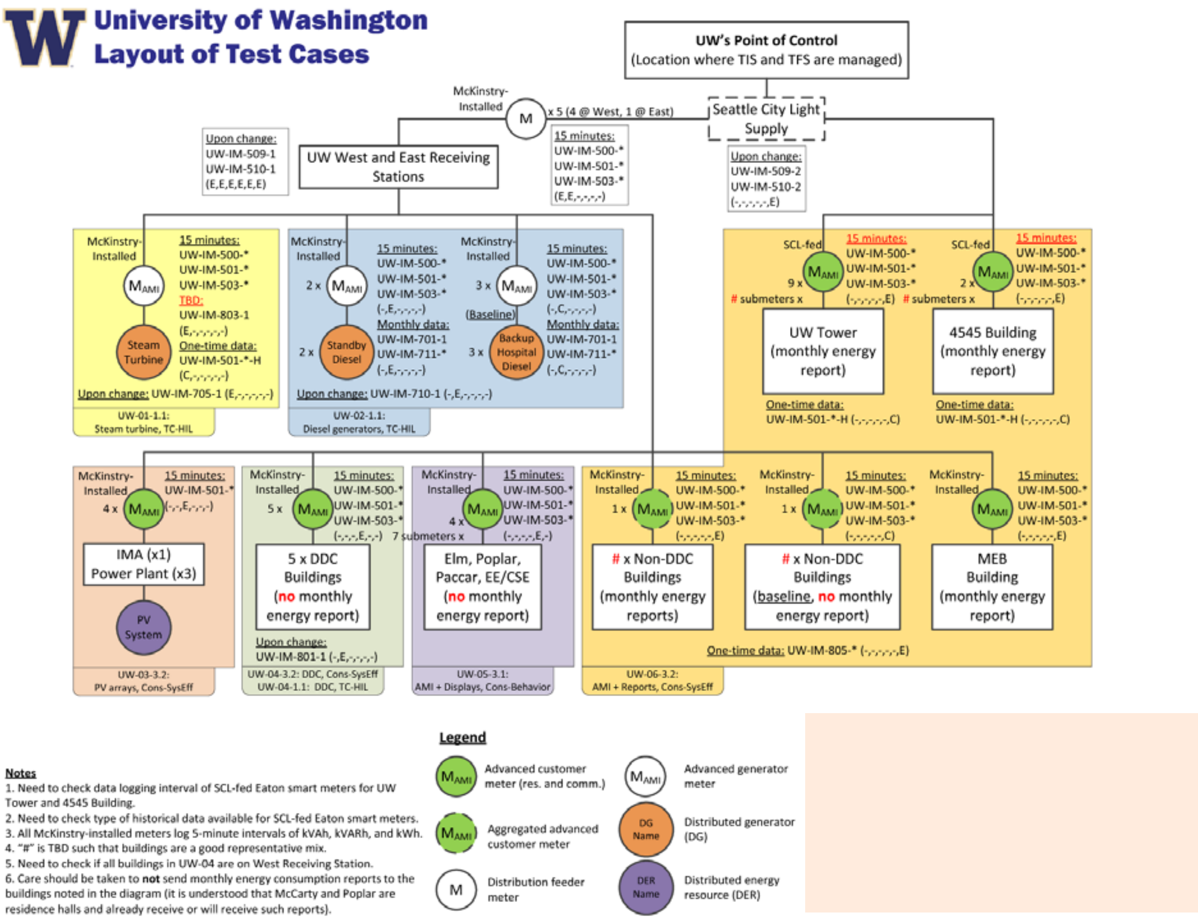


Figure 17.1. Layout of UW Test Cases

17.1 Steam Turbine

The UW deployed an existing 5 MW steam turbine generator with provision to respond to transactive control signals from the PNWSGD project. Availability of the turbine generator was expected to be mostly limited to the fall/winter/spring seasons, as capacity is limited by the exhaust/extraction steam demand from the campus heating systems, which have low demand during the summer season. As with all the UW generation assets, the objective for the steam generator was to test the demand-response (DR) operation and identify opportunities for sustained generation increases in response to pricing incentives or regional renewable energy integration strategies.

Table 17.1 lists the system's components and their annualized costs. To estimate the system's yearly costs, the cost of each individual system component has been annualized according to its expected useful lifespan.

Table 17.1. Annualized Costs of the UW Steam Turbine System and its Components

	Component Allocation (%)	Annualized Component Cost ($K)	Allocated Component Cost ($K)
Transactive Node System	33	155.6	51.8
5 MW Steam Turbine Generator (existing)	100	617.4	617.4
Secure, Virtual Private Campus Network (VPN)	17	257.6	43.0
Advanced Meters (at generator)			38.7
• Software and Systems (774 hours)	100	18.9	18.9
• Installation and Integration (1,415 hours)	100	13.4	13.4
• Operations and Maintenance (1 year)	100	6.0	6.0
• Equipment - One Industrial Meter	100	0.2	0.2
• Engineering	50	0.3	0.2
• Equipment - Branch Circuit Monitor	50	0.2	0.1
FEMS			37.2
• Software and Systems (800 hours)	100	19.5	19.5
• Installation and Integration (400 hours)	100	10.0	10.0
• Operations and Maintenance (200 hours)	100	4.9	4.9
• Equipment – VPN Interface Servers	33	6.2	2.1
• Energy Data Collection and Processing Servers	33	2.4	0.8
• Engineering (6 hours)	100	0.0	0.1
Administrative	100	0.4	0.4
Total Annualized Asset Cost			**$788.1K**

17.1.1 System Operation and Data Concerning the 5 MW Steam Turbine Generator

In the earlier stages of the project, the UW planned to manually engage its 5 MW steam turbine generator based on the transactive incentive signal, with the option to automate the control in a direct-DR fashion at some point. The project received from UW a status signal indicating time periods when generator output was engaged. The reported engagement status differentiated whether the turbine was operating normally, with increased output (as would be expected when the transactive signal requested it), with decreased output (a condition the project team does not believe ever occurred), or unavailable. The periods of increased output represent the test "events" during which generator output can be compared against the remaining normal generation periods.

The reported engagement status is shown in Figure 17.2. Note that only the increased-generation event periods and the unavailable periods are plotted; during all other time periods the generator was operated normally. Engagement of the asset occurred only during the winter of 2013–2014 and briefly in the summer of 2014. The limited engagement during the summer was expected since turbine capacity is limited by the exhaust/extraction steam demand by the campus heating systems, which have very low demand in the summer. In all, there were 136 engagement events totaling about 450 hours of operation.

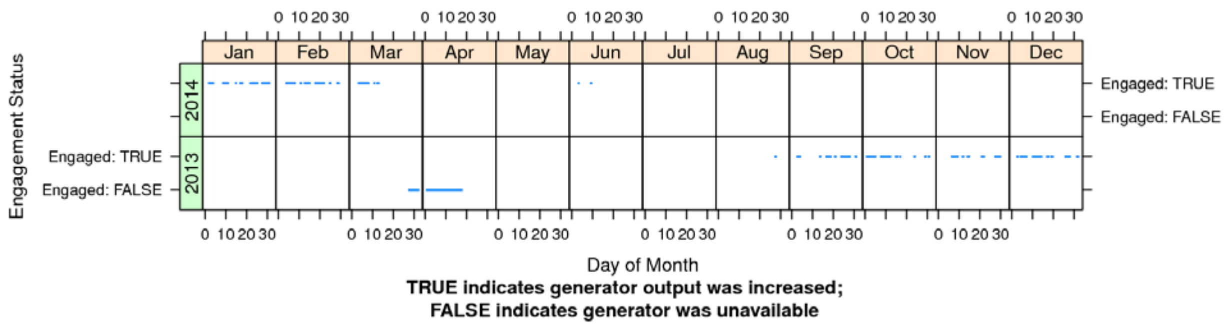


Figure 17.2. Reported Engagement Status of the UW Steam Turbine Generator. Engagement status "true" indicates that the generator output was increased; engagement status "false" indicates that the generator was reported to be unavailable.

Steam turbine generator output for 2013 and 2014 is shown in Figure 17.3. It is clear that the generator was operated differently in winter than in summer months. Winter operation appears to have been continuous and largely unvarying at about one-half rated capacity, while summer operation was more variable, but again topping out at about half of capacity. There was some operation at levels approaching the turbine's 5 MW capacity in the prior (2013) summer, but the project had generated no transactive engagement signals during that time.

The increased output of the turbine during engagement events is evident during the winter period in Figure 17.3, but the few summer engagements are not distinguishable, being "buried" in the cloud of normal operation points.

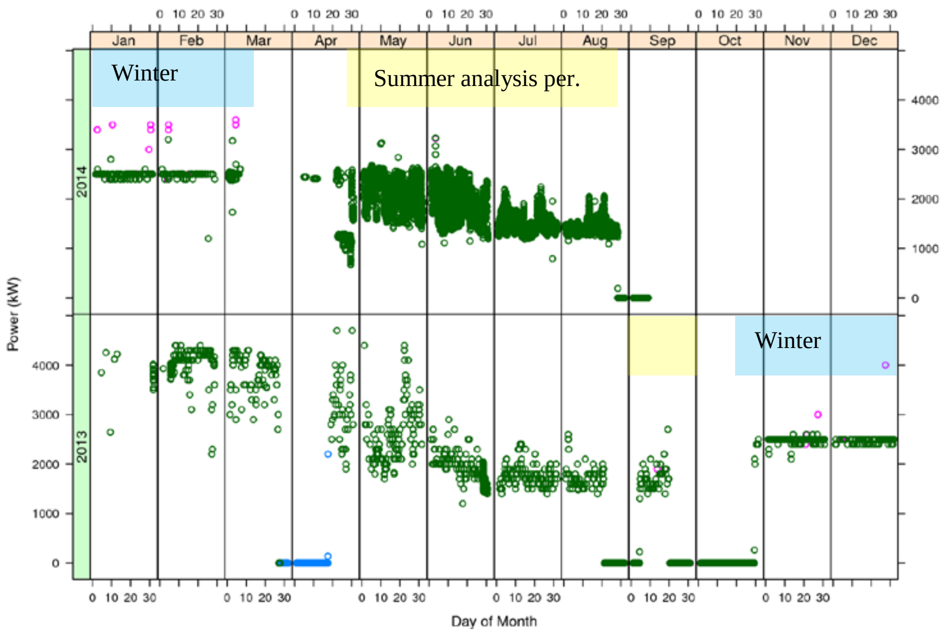


Figure 17.3. Output of the 5 MW UW Steam Turbine Generator. The summer (yellow) and winter (blue) analysis periods have been indicated by shading in the corresponding project months.

17.1.2 Analysis of the 5 MW Steam Turbine Generator

Because of the very different winter and summer operational modes, the project team developed separate models to characterize baseline operation for the two seasons. Both models were implemented as linear regressions that relate the turbine's output to relevant predictive variables. The winter model, built from data between November 1, 2013 and March 10, 2014, inclusive, was trivially represented by the mean non-engagement turbine output over the 2013–2014 winter period. The summer model, built with data from September, 2013 and between April 27, 2014 and August 20, 2014, inclusive, included terms correlating turbine output to the outdoor temperature, partitioned by month, day type (weekend vs. weekday), and hour of day. The vast majority of engagement events occurred on weekdays (131 of 136 events), and events were roughly evenly distributed across the five weekdays.

The winter regression fit characterized turbine output as a constant 2,474 kW during non-engagement periods and, as can be seen in Figure 17.3, the constant value is a reasonably good representation of the turbine's wintertime operation. Although the output data show two consistent levels very close to one another in magnitude, the project team was unable to correlate the slight difference with any pattern of time or weather. The summer regression provided a fairly clean characterization of summer generation output with an R-squared value of 0.75.

Applying the summer and winter regressions gives predicted values for the turbine's output had there been no call for engagement; these values can be compared against the actual output during the periods of engagement. The differences represent the impact estimates of engaging the turbine.

Upon applying this technique to the generated power time series, it appeared that the generation was increased by 253 ± 29 kW at the times the generation had been reported to have been increased during the winter analysis period. The standard deviation of the increase in power generation was about 420 kW. The generation had been reported to have been increased 326 hours during the winter analysis period. We saw some visibly increased data points in Figure 17.3 where the generation was increased by up to 1 MW, but there were many more events that exhibited little or no response.

Analysts then compared the steam turbine's output during times it had been reported to operate with increased and normal generation levels within the summer analysis period. The regression model for the summer analysis period was more complex than that used for the winter one, as was described above. Multiple event periods were found in September 2013 while there was no generation being reported, and these "events" are believed to have occurred while the generator was, in fact, unavailable to respond. UW confirmed that the steam turbine had been removed from service September 20, 2013. These values were removed from the analysis. The consequent analysis using the regression baseline indicated that generation had increased by 468 ± 91 kW during summer events.

17.2 Diesel Generators

The UW included two 2 MW diesel standby generators in the project. These existing generators located at the UW central Power Plant were made available for added generator output as a DR asset. Their availability for providing additional generator capacity to the grid was limited in time and duration to accommodate periodic generator testing requirements and to remain within constraints of UW's existing environmental permit requirements. These generators are normally in standby mode, in which they generate no power.

As with all generator assets included in the project, the objective for the diesel generators was to test DR operation and identify opportunities for responses to pricing incentives or regional renewable energy integration strategies. A pair of generators that does not respond to DR signals was also metered to provide a control signal for comparison with the two experimental diesel generators.

Table 17.2 lists the system's components and their annualized costs.

Table 17.2. Annualized Costs of the UW Diesel Generator System and its Components

	Component Allocation (%)	Annualized Component Cost ($K)	Allocated Component Cost ($K)	
Transactive Node System	33	155.5	51.8	
Secure, Virtual Private Campus Network (VPN)	17	257.6	43.0	
Advanced Meters (at generator)			39.6	
• Software and Systems (774 hours)	100	18.9		18.9
• Installation and Integration (1,415 hours)	100	13.4		13.4
• Equipment - Industrial Meters (5 meters)	100	1.1		1.1
• Operations and Maintenance (1 year)	100	6.0		6.0
• Engineering	50	0.3		0.2
• Equipment - Branch Circuit Monitor	50	0.2		0.1
FEMS			37.2	
• Software and Systems (800 hours)	100	19.5		19.5
• Installation and Integration (400 hours)	100	10.0		10.0
• Operations and Maintenance (200 hours)	100	4.9		4.9
• Equipment - Mediator	33	6.2		2.1
• Energy Data Collection and Processing Servers	33	2.4		0.8
• Engineering (6 hours)	100	0.1		0.1
2 MW Diesel Standby Generators (two, existing)	100	15.4	15.4	
Administrative	100	0.4	0.4	
Total Annualized Asset Cost			**$187.3K**	

17.2.1 System Operation and Data Concerning the Diesel Generators

Figure 17.4 shows the engagement status signal provided to the project by UW for the two diesel test generators, plotted by project month. There were 32 individual DR events reported to the project, occurring predominantly between August 2013 and March 2014, and typically lasting from one to two hours (though several events had durations less than an hour).

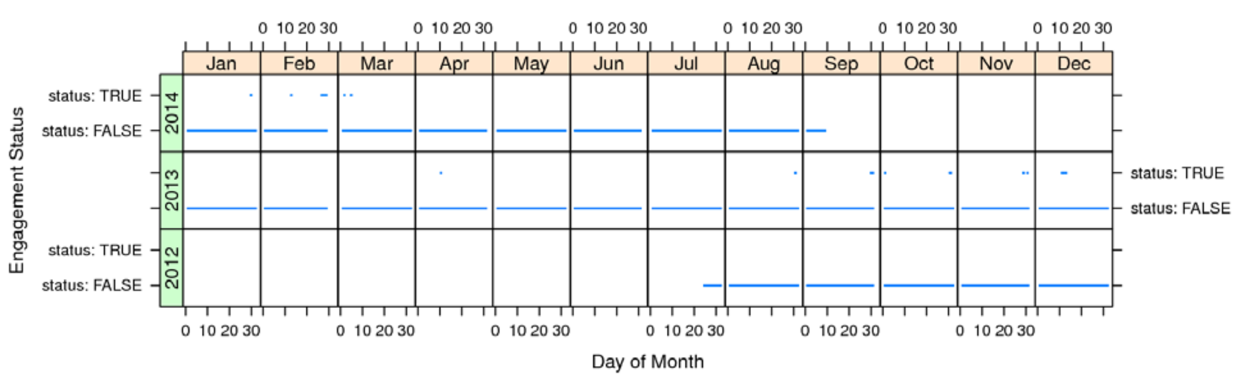


Figure 17.4. Reported Engagement Status for Two Diesel Generators

Analysts compared the times that the PNWSGD transactive system advised transactive events and the times that the UW campus had, in fact, reported to have engaged the diesel generators. Throughout the entire project, the two types of events coincided for 2 hours 10 minutes. That was about 7% of the total duration of UW-initiated events and 3% of the total duration of advised transactive events.

Figure 17.5 shows the reported total power output of the two test generators by project month. It also shows the power that was generated by a baseline, or control, set of three diesel backup generators that were not eligible to be controlled by DR. These backup generators are still subjected to periodic monthly tests to make sure they will respond when they are needed. The backup generators remain idle and produce no energy most of the time.

The behaviors of the two generator sets are similar, as would be expected, but the baseline generators appear to have been active in fewer months. There are very few DR events from Figure 17.4 that are coincident with nonzero power generation. In fact, only one such event exists in the project data. On April 10, the test generators were run for 15 minutes while a 1-hour DR event was active. The generators' output during this event was only about 120 kW.

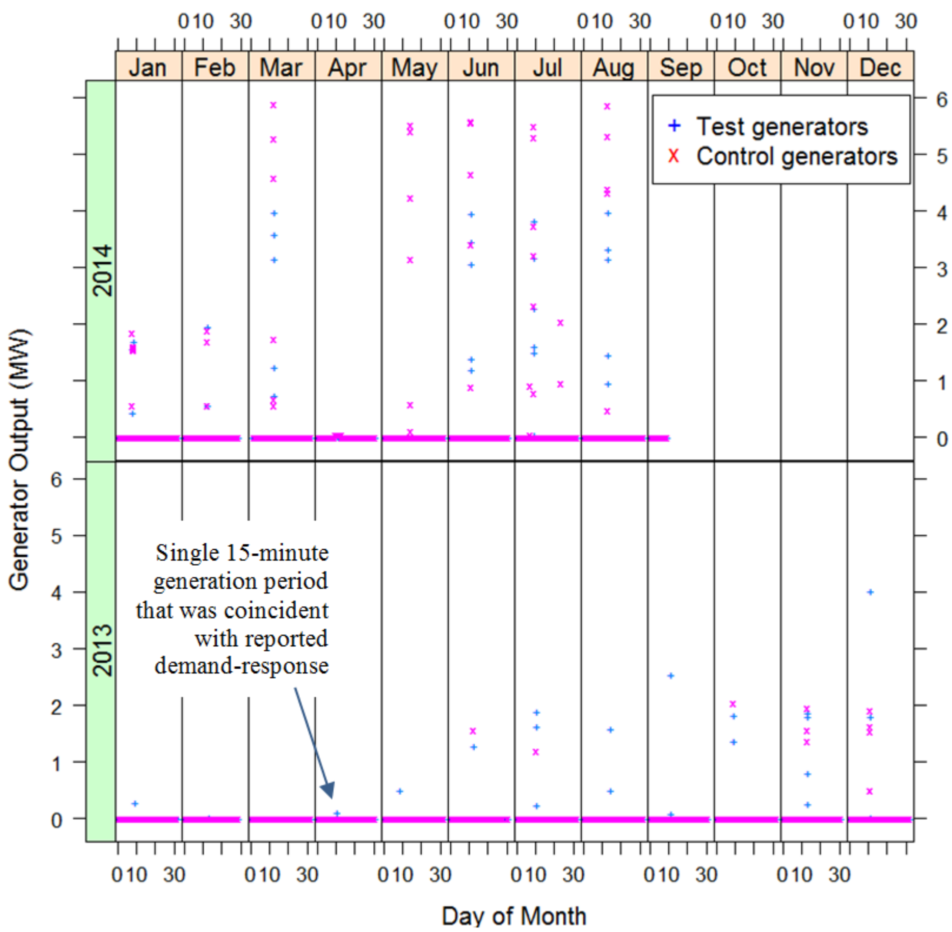
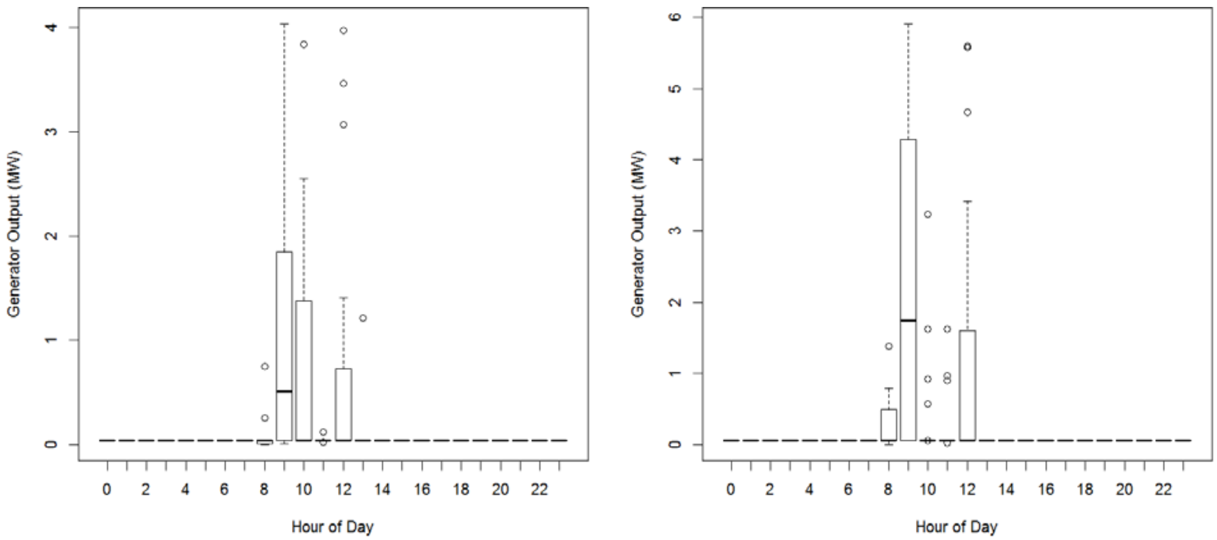


Figure 17.5. Diesel Generator (Test and Baseline Control) Power Output during 2013 and 2014. There was only one 15-minute period when the test generators produced energy coincident with a reported event.

Further characterization of the experimental and baseline control generators' operation is given by Figure 17.6, which shows box-and-whisker plots of the nonzero power generation from the test generators (left) and baseline control generators (right) during 2013 and 2014 as functions of the hours that the nonzero generation occurred. Again, the experimental and baseline control generator sets seem to have been operated similarly throughout the project period, though the baseline control generators may have been operated slightly earlier in the day.



(a) Test Generators (b) Baseline Control Generators

Figure 17.6. Quartile Plots of the Nonzero Power that was Generated by the (a) Test and (b) Control Generators during 2013 and 2014 by Hour of Day

17.2.2 Analysis of the Diesel Generators

The project has little evidence that the UW campus changed the way it engaged its diesel generators in light of either the events that were advised by the PNWSGD transactive system or the events that were reported by UW to have affected the diesel generators. The project can, however, confirm that the two 2 MW generators achieved their total nameplate ratings, more than 4 MW, during the PNWSGD.

17.3 Solar Renewable Generation

The university provisioned two small-scale solar PV panel facilities (existing), at Merrill Hall and the Mechanical Engineering Building, for inclusion in the PNWSGD. The solar PV facilities were installed to inform the UW regarding costs and benefits of future deployment of larger-scale solar PV facilities. The total capacity of the two PV facilities was 73.4 kW, though at times the larger of the two facilities was found to be offline.

Table 17.3 lists the system's components and their annualized costs.

Table 17.3. Annualized Costs of the UW PV System and its Components

	Component Allocation (%)	Annualized Component Cost ($K)	Allocated Component Cost ($K)
FacNet	17	257.6	43.0
Advanced Meters (at PV arrays)	100	38.9	38.9
FEMS			35.7
• Software and Systems (800 hours)	100	19.5	19.5
• Installation and Integration (400 hours)	100	10.0	10.0
• Operations and Maintenance (140 hours)	100	3.4	3.4
• Equipment - Mediator	33	6.2	2.1
• Energy Data Collection and Processing Servers	33	2.4	0.8
• Engineering (6 hours)	100	0.1	0.1
Administrative	100	0.4	0.4
Small-Scale PV Arrays (existing)	100	0.0	0.0
Total Annualized Asset Cost			**$118.0K**

17.3.1 System Operation and Data Concerning the Solar Renewable Generation

Solar PV energy production is primarily governed by solar availability. The coincidence of PV generation and Seattle City Light (SCL) heavy-load hours (HLHs) and light-load hours (LLHs) determined the value of the energy supply that was displaced by the PV generation.[1] Figure 17.7 shows the power-output time series of the PV panels during the project. Two operating modes are evident: one in which the bulk of the total 73.4 kW capacity is online and operating, and another in which a large portion of the capacity is apparently not online. Full capacity was available from June 29, 2013 through March 7, 2014. This time period will be used for much of the project's analysis and is shown in Figure 17.7 by yellow shading. The blue and red colors in Figure 17.7 represent SCL HLHs and LLHs, respectively. The regular pattern of LLHs on Sundays and overnight is apparent.

[1] The SCL HLH rate applies to energy used between 06:00 and 22:00 Pacific Time, Monday through Saturday, excluding major holidays. All other hours are LLH.

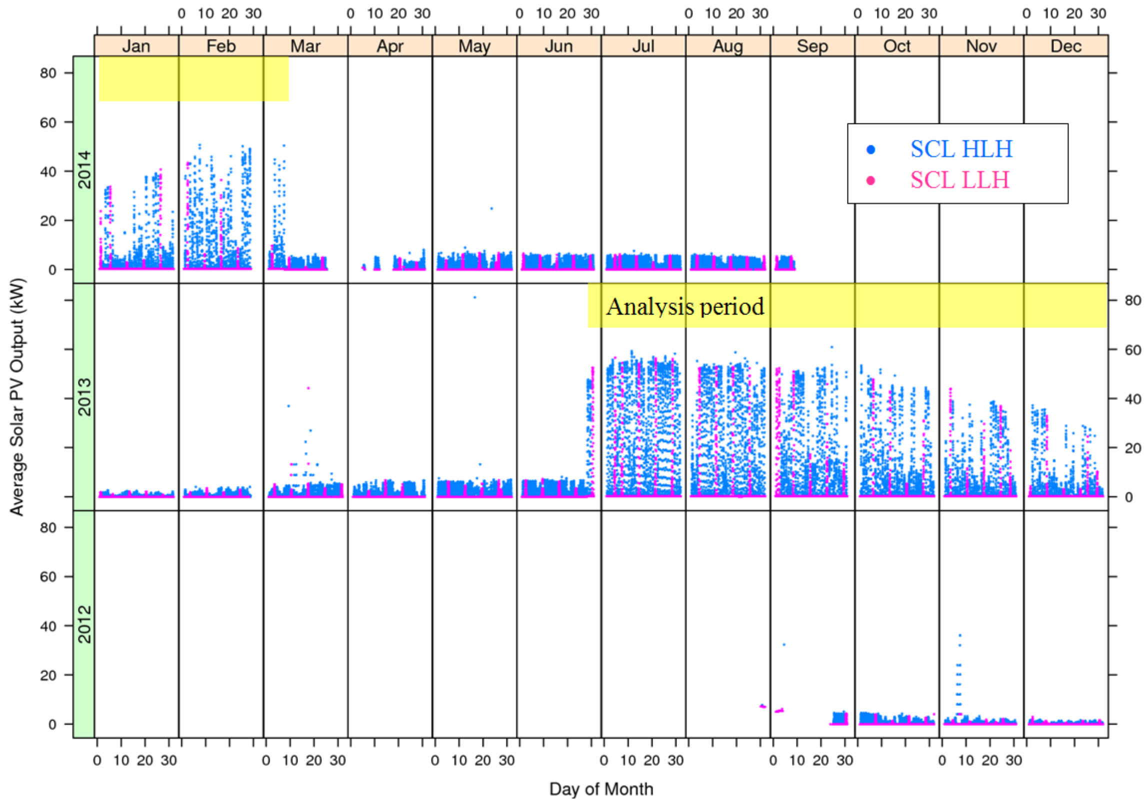


Figure 17.7. Total Power Produced by the UW PV Panels. The color coding refers to power that was produced during the SCL HLL (blue) and LLH (red) periods. An analysis period, when all the PV assets appear to be online and active, is indicated by yellow shading.

The HLH/LLH pattern, as well as the nature of the diurnal solar output by month, is more clearly shown in Figure 17.8, which presents the months of the defined analysis period by hour of day for every day in the period. The regular Sunday/nighttime LLH pattern is clearly visible, and the inclusion of holidays such as Labor Day on September 2 is clear, as are the lower available peak solar irradiation and more frequent cloudy days in the winter months.

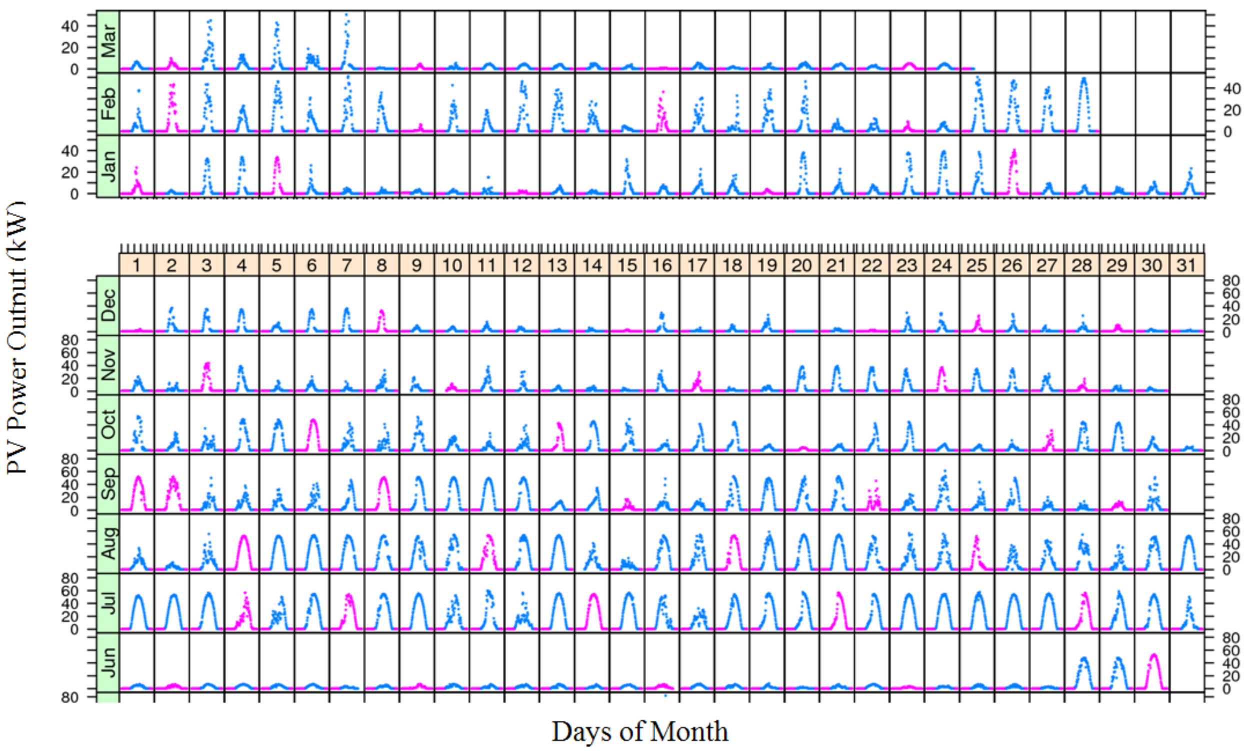


Figure 17.8. Real Power Output of Photovoltaic Panels during the Narrowed Analysis Period of 2013 and 2014. The color coding refers to power produced during the SCL HLH (blue) and LLH (red) periods.

One phenomenon not apparent from Figure 17.8 is an anomalous nighttime generation during the time periods when the bulk of the PV capacity was online and reporting. There is unexpected energy generation during the nighttime hours, amounting to a not-quite-constant reading of about 120 W. Figure 17.9 illustrates this with data from a single day, July 26, 2013. The apparent nighttime output is slightly higher before midnight (about 141 W) than after midnight (about 108 W). The project team was not able to discern the source of this anomaly, which results in an apparent overstatement of total project energy produced by 39 to 51 kWh each of the night hours, and possibly all hours (if the anomaly represents an overall offset). Beyond noting the anomaly, we have not attempted to correct the data.

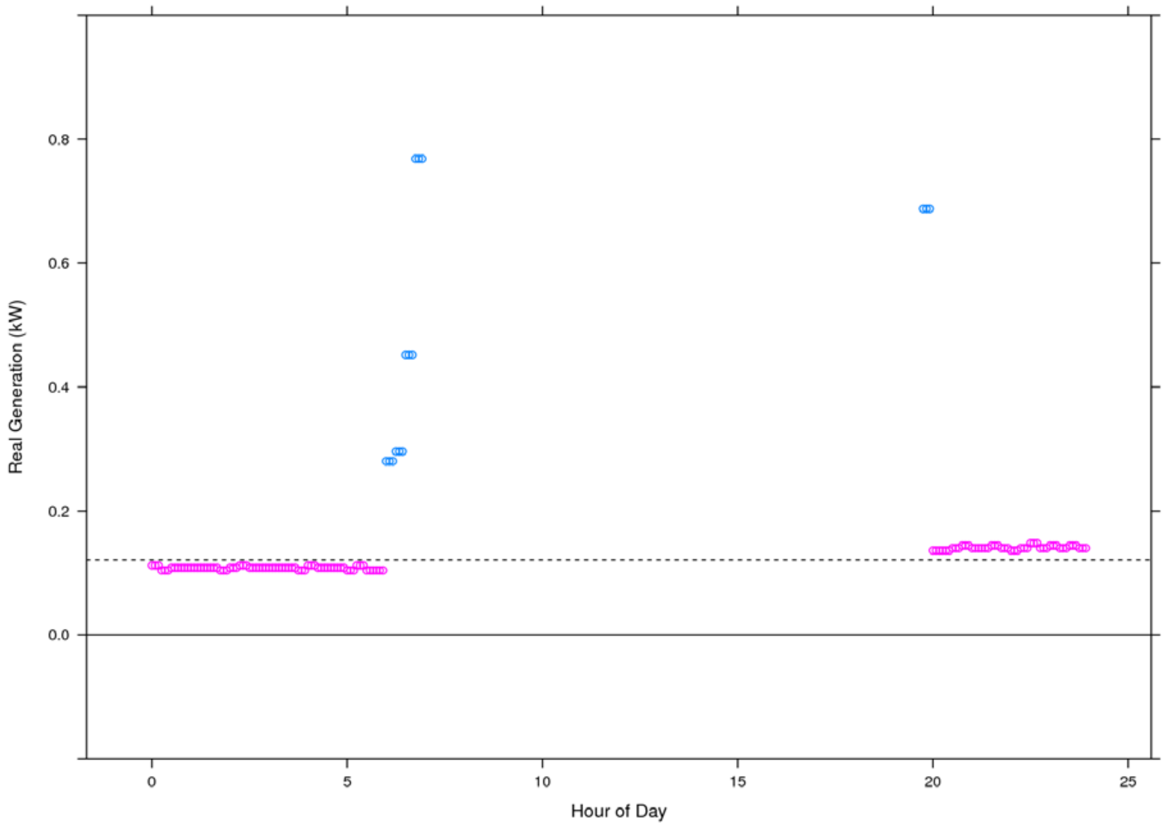
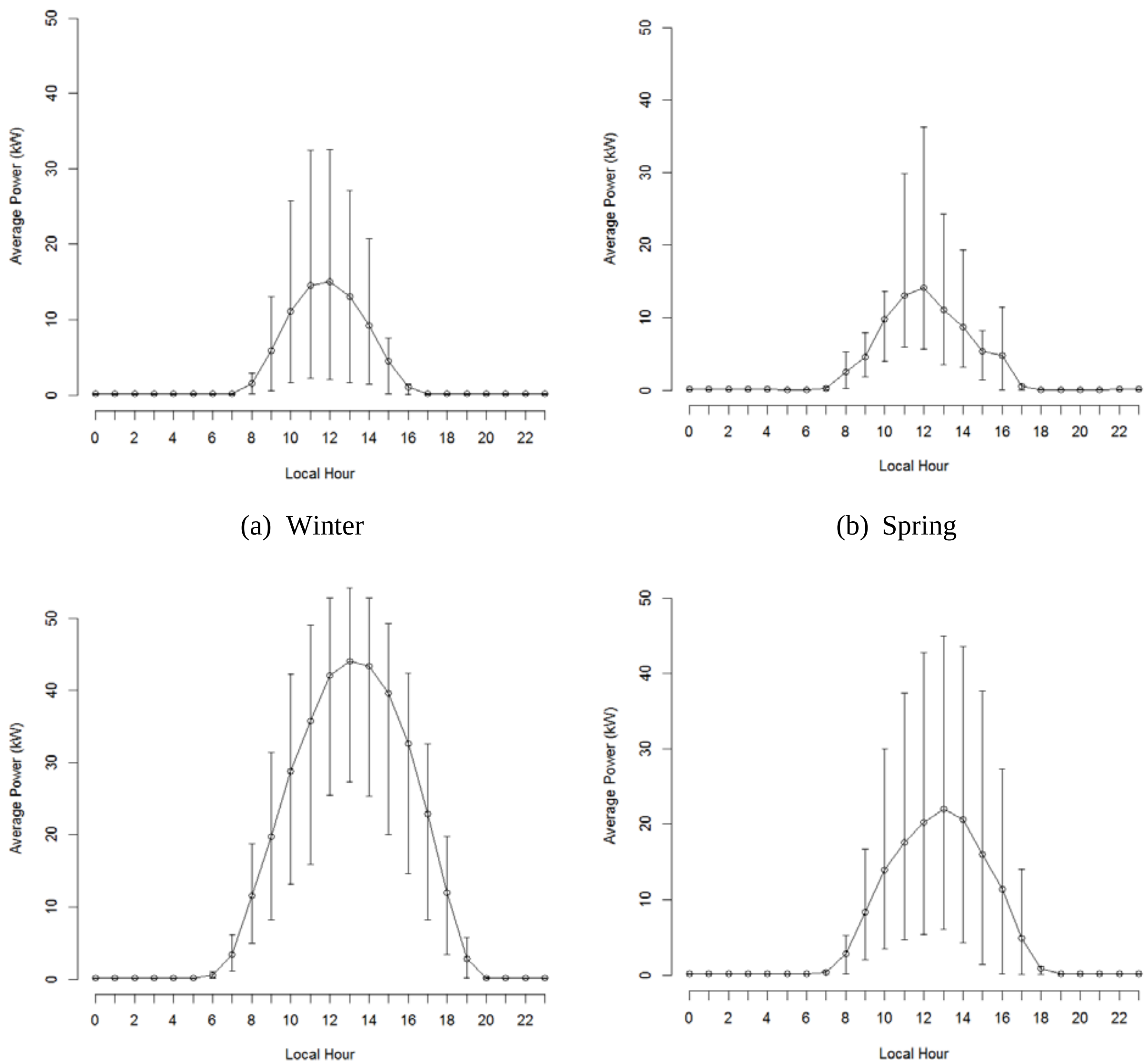


Figure 17.9. Example Plot from July 26, 2013 Showing Anomalous Nighttime PV Generation. The color coding refers to power produced during the SCL HLL (blue) and LLH (red) periods. The dotted line shows a power level of 120 W.

17.3.2 Analysis of the Potential Power Output from the UW PV Arrays

Figure 17.10 shows the average hourly PV power generation by season. The project defined its seasons by three-month periods. Winter, for example, includes the months December through February. The plots include only the data from June 29, 2013 through March 7, 2014, when all the UW PV systems were presumed to be active. The whiskers extend from the 16th to 84th percentiles of the data in the corresponding hour and season. Percentiles were used instead of standard deviation because the data sets do not have Gaussian distributions. The plots were all completed with the same vertical axis ranges to facilitate comparisons. About 44 kW of power generation should be expected during midday hours in summers. Less than 15 kW should be expected those hours in the spring. Generation is quite variable due to the frequent cloud cover in Seattle, Washington.

The spring season was represented by only one week, at the beginning of March 2014. The average power that is reported for spring is probably conservative. Furthermore, the short data period might have caused the small anomaly at Hour 16 in Figure 17.10b.



(a) Winter (b) Spring

(c) Summer (d) Fall

Figure 17.10. Average Hourly Solar Power Generation during (a) Winter, (b) Spring, (c) Summer, and (d) Fall Seasons. These results are based on the time period from June 29, 2013 through March 7, 2014, when all the UW PV systems appeared to be active. The spring season is poorly represented by only one week of early spring data.

Table 17.4 lists the total energy that might be produced each month, based on the observed power generation from June 29, 2013 through March 7, 2014, when all the UW PV systems appeared to have been active. The entire months of April and May were not represented in this set, and only the first week of March 2014 was used. To reduce the influences of missing data, the average power generation each month and for the two hour types were calculated first. Then these average power values were multiplied by the number of HLH or LLH hours in those months of 2013. This method allowed the project to estimate a value for March, although the value is likely conservative because the data were from early in the month.

The values of the HLH and LLH hours were calculated from the published SCL rates from 2012 (SCL 2012). In that schedule, the HLH rate was $0.0681/kWh, and the LLH rate was $0.0454/kWh.

Because the full contingency of PV generation resources was not active for a full year, there was no good method for estimating the variability that should be expected in these energies and values from year to year. The totals at the bottom of Table 17.4 have been extrapolated to estimate the total yearly energies and dollar values. The values from the months having missing data have been assigned the average value from the ten months for which data is available. The project estimates that the current PV generation resources on the UW campus (~72.4 kW) could generate about 68 MW per year that would displace about $4,300 worth of energy that the campus must presently purchase from SCL. To do this, all the PV resources would need to be online throughout the year, which did not appear to have been the case during the PNWSGD.

Table 17.4. Energy Generated by the UW PV Generators Summed by Month and SCL Hour Type. These calculations used only the power data from June 29, 2013 through March 7, 2014, when all the UW PV systems appeared to have been active.

	HLH		LLH		**Totals**	
Month	(kWh)[a]	($)[b]	(kWh)[a]	($)[b]	**(kWh)[a]**	**($)[b]**
Jan	1,470	100	423	19	**1,890**	**119**
Feb	3,170	216	331	15	**3,500**	**231**
Mar[c]	2,180	149	194	9	**2,380**	**157**
Apr	-	-	-	-	**-**	**-**
May	-	-	-	-	**-**	**-**
Jun	8,950	610	4,360	198	**13,300**	**808**
Jul	9,800	667	1,790	81	**11,600**	**748**
Aug	8,030	547	1,430	65	**9,460**	**612**
Sep	4,670	318	1,340	61	**6,010**	**379**
Oct	3,640	248	620	28	**4,260**	**276**
Nov	1,990	135	554	25	**2,540**	**161**
Dec	1,320	90	273	12	**1,600**	**103**
Totals[d]	**54,300**	**3,697**	**13,600**	**616**	**67,800**	**4,313**

(a) Energy column entries have been rounded to three significant digits. The monthly energy sum was estimated by multiplying the average power generation that month and hour type by the number of hours of that type in the month of 2013.

(b) Dollar amounts have been rounded to the nearest dollar. Recent SCL HLH and LLH rates were found to be $0.0681/kWh and $0.0454/kWh, respectively.

(c) March was represented by only a week's worth of data.

(d) These totals have been projected to represent an entire your by presuming that the data from unavailable months April and May are the average of data from the ten months that data were available.

The project might have adequate data to estimate the impacts that the PV generators have on demand charges that UW incurs from SCL, but that calculation could not be completed during the project.

17.4 Direct Digital Controls in UW Buildings

Five buildings on the UW campus (Conibear Shellhouse, Intramural Activities, Architecture, Fisheries Science, and Gates Law) received direct digital controls (DDCs) that allow HVAC and lighting to be controlled using a "human-in-loop" transactive control strategy. These buildings were made available for operation at reduced load during low occupancy periods, as a DR asset. These buildings have no energy displays (Section 17.5), and no monthly energy reports (Section 17.6) are delivered to their building managers.

Table 17.5 lists the system's components and their annualized costs.

Table 17.5. Annualized Costs of the UW DDC System and its Components

	Component Allocation (%)	Annualized Component Cost ($K)	Allocated Component Cost ($K)
Transactive Node System	33	155.5	51.8
Secure, Virtual Private Campus Network (VPN)	17	257.6	43.0
Advanced (smart) Meters			21.3
• Equipment - Commercial Meters (17 meters)	100	8.7	8.7
• Operations and Maintenance (60 hours)	100	6.6	6.6
• Integration (480 hours)	100	4.5	4.5
• Software and Systems (60 hours)	100	1.5	1.5
• Engineering (4 hours)	100	0.0	0.0
FEMS			16.2
• Installation and Integration (480 hours)	100	11.7	11.7
• Software and Systems (60 hours)	100	1.5	1.5
• Operations and Maintenance (60 hours)	100	1.5	1.5
• Energy Data Collection and Processing Servers	33	2.4	0.8
• Equipment - VPN Interface Servers	33	2.1	0.7
• Engineering (4 hours)	100	0.1	0.1
Administrative	100	0.4	0.4
Outreach and Education	33	1.2	0.4
HVAC Systems (existing)	100	0.0	0.0
Total Annualized Asset Cost			**$133.1K**

17.4.1 System Operation and Data Concerning DDC in UW Buildings

Figure 17.11 shows the DDC engagement signals that were reported by the UW for the duration of the project. There were 26 individual events during which the buildings responded to calls for load reduction. The events typically lasted between a half hour and 3.25 hours, with the shorter events being more common. The events were fairly widely spaced in time, spanning roughly a one-year period, though DDC events were not initiated during either of the monitored summers.

The university defined multiple engagement levels as follows:

- Not curtailed. The system is installed, but no dispatch signal is being issued to request responses from any buildings. This idle status corresponded to the transactive advisory signal level 0.
- Tier 1. Digital HVAC controls have been dispatched at three campus buildings—Architecture Hall, Conibear Shellhouse, and Fisheries Sciences. This status corresponded to the transactive advisory signal level 42.
- Tier 2. Digital HVAC controls have been dispatched at the three Tier-1 campus buildings, plus the Intramural Activities building. This status corresponded to the transactive advisory signal level 84.
- Tier 3. Digital HVAC controls have been dispatched at the four Tier-2 campus buildings, plus the Gates Law building. This status corresponded to the transactive advisory signal level 127.

The campus's engagement procedure defined override and termination capabilities, but these features were not exercised according to the status information that was received by the project. Tier 1, Tier 2, and Tier 3 statuses may be overridden or terminated by UW Engineering staff.

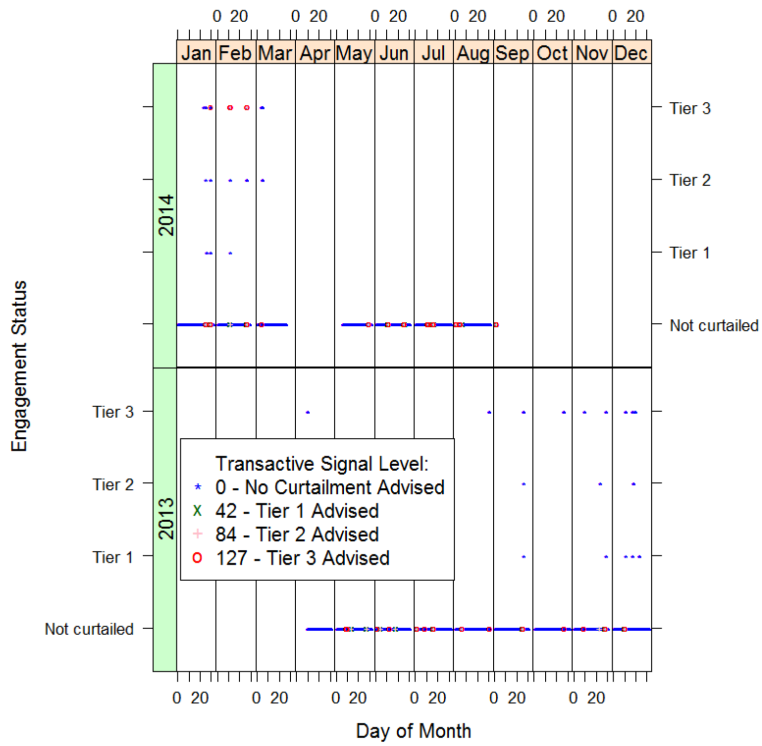


Figure 17.11. Reported Engagement Status of the Buildings with DDCs

When the reported engagement levels were compared with the PNWSGD transactive system advice for this asset system, the system was found to have remained idle during most of the events that the transactive system had advised at the various levels. Tier 3 was engaged for 45 minutes coincident with the transactive advisory signal level "84" and 5 hours 15 minutes coincident with the signal level "127." The advised status from the transactive system was also included in Figure 17.11.

Figure 17.12 shows the total power consumed by the five buildings with DDCs during the PNWSGD data collection period. Although two years of power data were available to the project, responses to the project's transactive signals did not begin until early April 2013. Incomplete power data was received for late March and early April 2014.

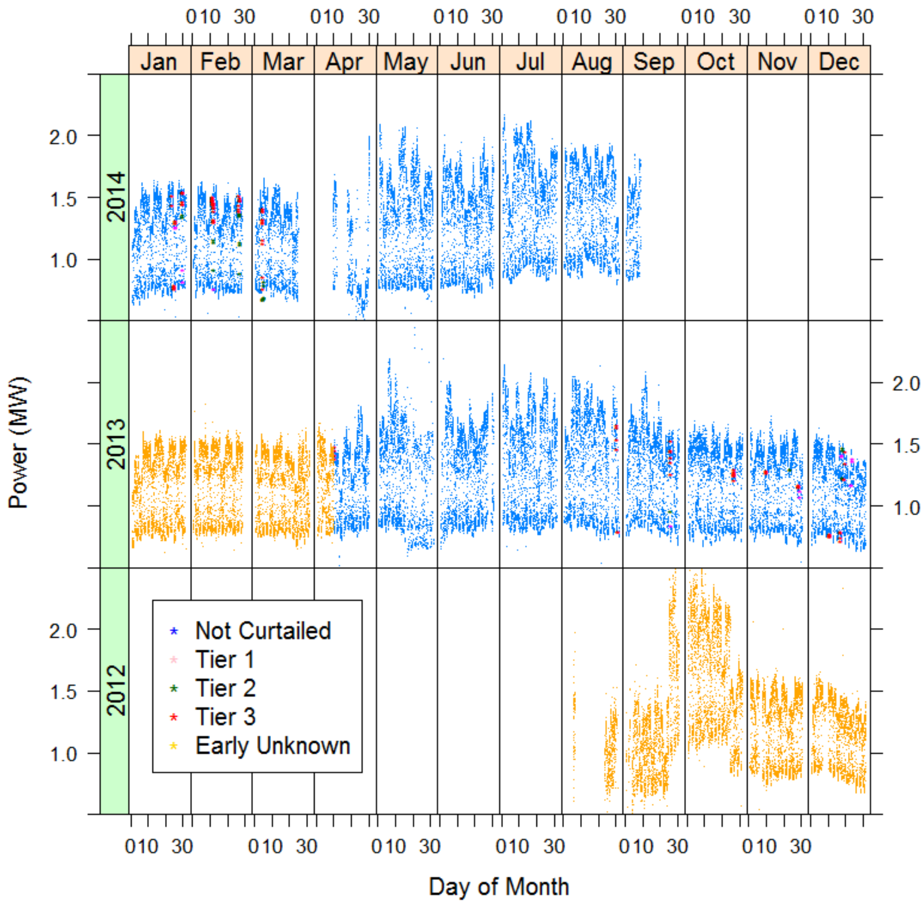


Figure 17.12. Total Power Consumed by the UW Buildings with DDCs during the PNWSGD. The legend includes colors that indicate the reported status of the system as the data was being collected.

Any of the tier levels of engagement is a candidate for analysis, but Tier 3 was chosen because it was said to have affected all the buildings and should therefore create the easiest impact to verify. A histogram of the hours in which these Tier 3 events occurred is shown in Figure 17.13. The high frequency of late and early hour occurrences was unexpected.

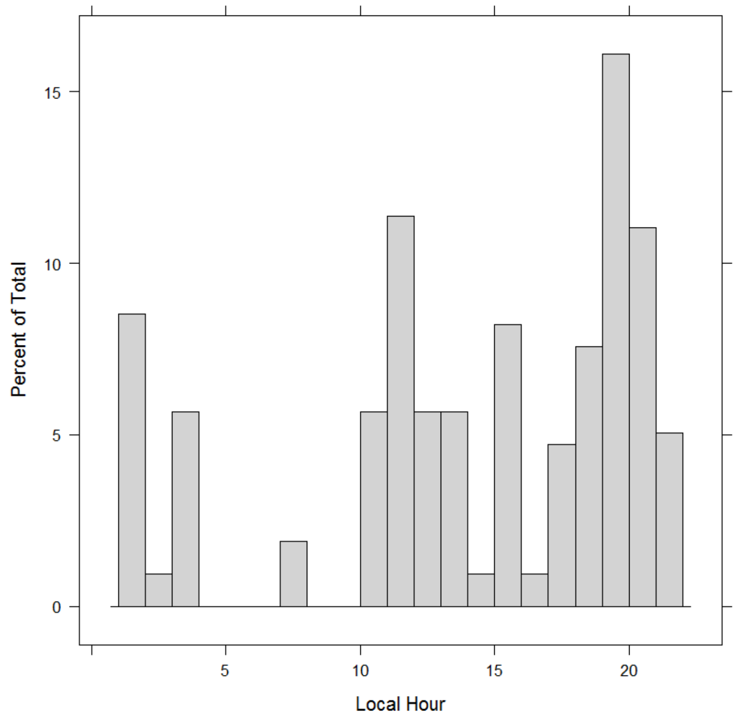


Figure 17.13. Histogram of Local Pacific Time Zone Hours in which Tier 3 Event Periods Occurred during the PNWSGD

17.4.2 Analysis of the DDC Building Controls

Analysts first plotted and observed the buildings’ aggregate power data in the time periods that surround and include the Tier 3 events. No impact (e.g., a notch) was evident by inspection.

The project conducted linear regression as a function of ambient temperature for the months, days of week, and local hours that the Tier 3 events had been reported. The regression model was used to construct a baseline. No significant impact could be found.

17.5 Building Advanced Metering Displays and EnergyHub© Devices

The UW provisioned and installed electrical sub-metering and EnergyHub switch controls (EnergyHub 2015) for two residential dormitories and two academic facilities that have a combined mix of laboratories, classrooms, and offices. The sub-meters collected data, sent data to the central data warehouse, and provided the ability to retrieve the data by the residents and authorized researchers. It was postulated that demand reduction would occur by providing near-real-time consumption data to the end users, which in turn would encourage behavioral conservation.

This asset consists of several distinct scopes. First, a newly constructed dormitory was to implement floor-by-floor energy monitoring of the lighting and plug loads to each of the four individual floors. Total near-real-time power consumption for each floor would then be made available for viewing by residents on each floor on a common-area display screen, and by individual resident login to a Website display.

Second, 240 select rooms in McCarty Hall "Engineering House" were to be outfitted with room-by-room electrical power monitoring and dashboard display kits. These kits would consist of one portable room monitor (dashboard), two plug-in style smart outlets, and one power strip containing six smart outlets. These smart kits were to be distributed by the dormitory management to the current residents of the select dorm rooms. Third, floor-by-floor monitoring of receptacle plug-load energy usage was to be provisioned in the newly constructed PACCAR Hall. Fourth, branch circuit monitoring for plug loads was to be provisioned in select laboratories in the existing Electrical Engineering/Computer Science Building. All of the described sub-meters were to collect and send consumption data to the data warehouse. This sub-metering was also expected to facilitate follow-on research to be conducted outside the scope of the PNWSGD.

Table 17.6 lists the system's components and their annualized costs.

Table 17.6. Annualized Costs of the UW System of Displays and EnergyHub Devices and its Component Costs

	Component Allocation (%)	Annualized Component Cost ($K)	Allocated Component Cost ($K)	
Advanced (smart) Meters			65.9	
• Operations and Maintenance (320 hours)	100	35.0		35.0
• Integration (2,400 hours)	100	22.7		22.7
• Software and Systems (300 hours)	100	7.3		7.3
• Equipment - Residential (four meters)	100	0.9		0.9
FacNet	17	257.6	43.0	
FEMS			36.6	
• Software and Systems (800 hours)	100	19.5		19.5
• Installation and Integration (400 hours)	100	10.0		10.0
• Operations and Maintenance (200 hours)	100	4.9		4.9
• Engineering (40 hours)	100	1.0		1.0
• Energy Data Collection and Processing Servers	33	2.4		0.8
• Equipment - Mediator	33	2.1		0.7
Dormitory Individual Room Plug Loads (McCarty)	100	32.8	32.8	
Outreach and Education	33	1.2	0.4	
Administrative	100	0.4	0.4	
Electrical Sub-Meters within Select Building (Poplar)	100	0.0	0.0	
Dormitory Floor-by-Floor Energy Monitoring (Poplar)	100	0.0	0.0	
Total Annualized Asset Cost			**$179.1K**	

17.5.1 System Operation and Data Concerning Building Advanced Metering Displays and EnergyHub Devices

Building power data was submitted by UW for the period from mid-November 2012 through August 2014, when the PNWSGD data collection was ended. According to the installation status that was reported to the project by the university, the system of displays and EnergyHub devices was installed and active by January 21, 2013.

Figure 17.14 shows the total power consumption of the set of four campus buildings—Elm, Poplar, PACCAR, and the Electrical Engineering and Computer Science building—where the advanced metering displays and EnergyHub devices were installed. The figure also shows the total power from another set of six “control” buildings—Odegaard, Kincaid, Gould, Lewis, Roberts, and Wilcox—that did not receive the displays and EnergyHub devices but were otherwise similar to the treatment group. The treatment and control-group member buildings were selected to minimize interactions with other asset systems installed on the UW campus (Figure 17.1).

The control buildings exhibited large step discontinuities in their total power. The reported power nearly doubled during a period from December 2012 into March 2013. The largest reported values were larger than the apparent power values that were also reported to the project by the campus (not shown). This, of course, is physically impossible. The treatment buildings exhibited some discontinuities, too, in March and April 2014. The project elected to focus on the power measurements at a single treatment building—Poplar—that had fairly complete power data and exhibited few discontinuities in its power consumption. The power at the Poplar building is also shown in Figure 17.14. The data from the control buildings was not used.

According to the UW Residence Hall Energy Conservation Study (Black et al. 2014), students on two of Poplar Hall’s floors were given weekly energy tips displayed on a monitor in one of its common areas and were later surveyed. That is the extent of the students’ involvement.

The seasonal influences appear to be weak in the power consumption data from these campus buildings, but the plots reveal some strong weekday and weekend patterns. The limited variability by season is probably attributable to the use of steam heating on the campus, making electrical consumption less temperature dependent.

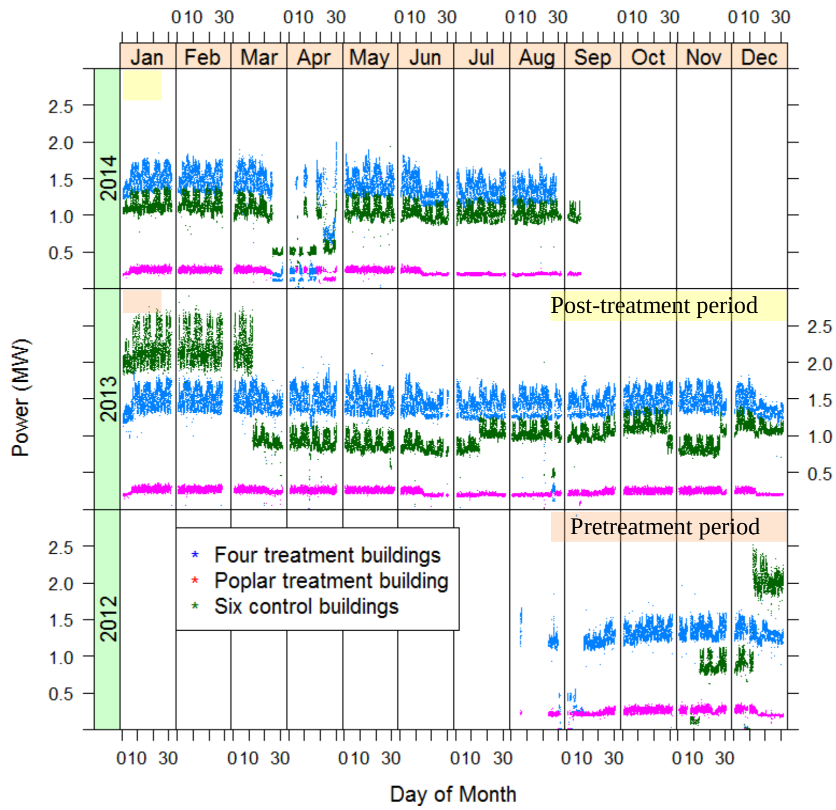


Figure 17.14. Power Consumption of Buildings with Advanced Metering Displays and EnergyHub Devices and of a Set of Six Control Buildings that Have No Advanced Metering Displays or EnergyHub Devices. Pre- and post-treatment analysis periods are shown by shaded boxes.

17.5.2 Analysis of Building Advanced Metering Displays and EnergyHub Devices

Approximately 5-½ months' historical data was available from the *pretreatment* period for comparison with the *post-treatment* period, when building occupants had access to their energy information. Given that the load on a university campus may be strongly affected by student occupancy and class schedules, the project selected a post-treatment analysis period that was precisely one year after the pretreatment analysis period and of the same duration. Therefore, the impacts of seasons and school schedules should be similar between the two groups, but the post-treatment period was well after the devices had been installed.

Even though the buildings' temperature dependence was expected to be weak, analysts corrected for the impact of temperature by calculating degree-days for each day of the pre- and post-treatment periods. The calculated degree-days are equivalent to the average daily temperature. The total energy consumption by the Poplar building from each day in the pre- and post-treatment periods is plotted against the day's corresponding average temperature in Figure 17.15.

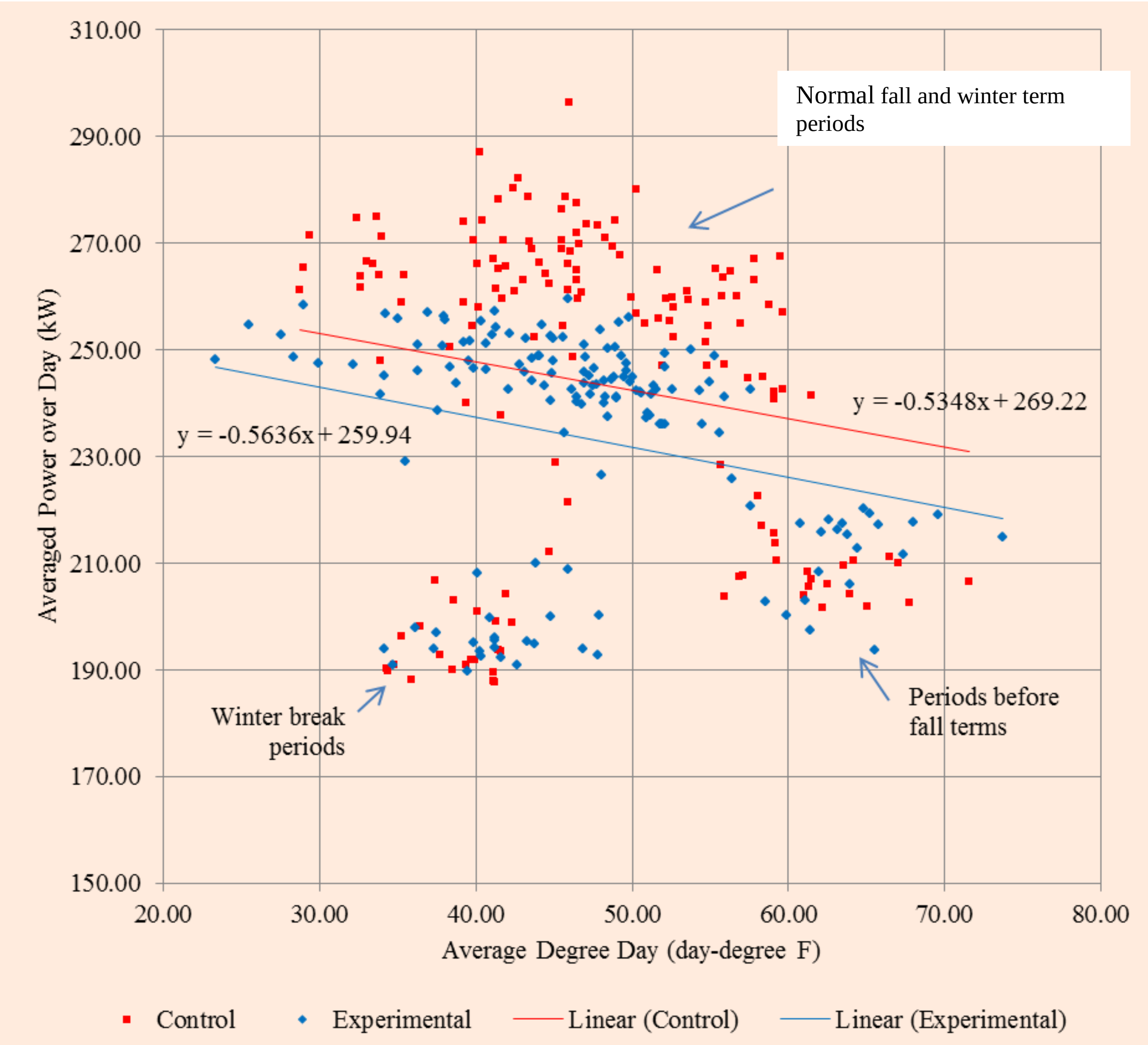


Figure 17.15. Regression Analysis of the Poplar Building with its Advanced Metering Displays and EnergyHub Devices during Pretreatment (blue) and Post-Treatment (red) Periods. The lines show linear regression trends for all the corresponding pre- (blue) and post-treatment (red) days.

Additionally, the linear fit from all the pretreatment days is shown in Figure 17.15 and compared with a corresponding line for the post-treatment days. The differences between the two periods are remarkable, and are evident by visual inspection of the two data sets. The regression lines are parallel to one another, but they are separated by about 9 kW. Most of the impact appears (by inspection) to have occurred during the normal fall and winter school term periods at the center, top of the figure. The campus took steps each year during winter breaks in the school schedule to reduce the building's energy consumption, as is shown at the bottom, left of the figure. A similar reduction is evident from periods prior to fall terms on the bottom right. The reduction in power consumption that was evident during school terms was not evident during the break periods.

So, the application of energy displays and EnergyHub devices at this building might have caused about 9.25 kW power reduction on average, or 222 kWh per day, for the Poplar building. The campus was actively pursuing energy conservation during these years, so it is possible that the observed impact might have been caused instead by other of the campus's conservation efforts that were unknown to the project analysts. If a similar impact were observable at the other three campus buildings where these devices were installed, the impact might be about four times as great.

A group of UW graduate students conducted a more detailed analysis of the impacts from providing energy information and EnergyHub switch devices to student dormitory residents of Poplar Hall and Elm Hall (Black et al. 2014). Their analysis of energy impacts was inconclusive. Survey results suggested that students had not been motivated to change their energy consumption through education or the automation that had been provided them. The study advises that the EnergyHub devices are not currently cost effective for use on the campus. The study contains much rich information and discussion. Based on the more complete description of the participation of Poplar Hall in this study, the project should conclude that the impacts observed in Figure 17.15 were from other facilities energy management and not the system of displays and EnergyHub devices.

17.6 Facilities Energy Management System Data for Campus Building Managers

The UW designed, procured, and installed a FEMS to facilitate system efficiency and conservation. The FEMS is an enterprise platform interface and information system. It was designed to receive sub-metering information from all of the enabling and responsive assets associated with the subproject. Using information stored by the sub-meters in the database warehouse, the FEMS provided access to reports and data, and now provides dashboard visualizations and energy comparison graphics for Web-based displays. The FEMS was listed as a subsystem component of all the five asset systems that have already been discussed in this chapter. The purpose of this section is to assess whether the FEMS as a real-time display system creates a more educated set of building managers and achieves some degree of energy conservation for the campus.

Table 17.7 lists the system's components and their annualized costs.

Table 17.7. Annualized Costs of the UW FEMS and its Components

	Component Allocation (%)	Annualized Component Cost ($K)	Allocated Component Cost ($K)
Advanced (smart) Meters			134.3
• Equipment - Commercial Meters (200 meters)	100	101.9	101.9
• Software and Systems (774 hours)	100	18.9	18.9
• Integration (1,415 hours)	100	13.4	13.4
• Operations and Maintenance (1 hour)	100	0.1	0.1
• Engineering (4 hours)	100	0.0	0.0
FEMS			55.3
• Installation and Integration (1,450 hours)	100	35.6	35.6
• Software and Systems (557 hours)	100	13.6	13.6
• Engineering (200 hours)	100	4.9	4.9
• Energy Data Collection and Processing Servers	33	2.4	0.8
• Equipment - Mediator	33	2.1	0.7
FacNet	17	257.6	43.0
Server and Data Warehouse	100	13.5	13.5
Administrative	100	0.4	0.4
Outreach and Education	33	1.2	0.4
Total Annualized Asset Cost			**$247.0K**

17.6.1 System Operation and Data Concerning the Facilities Energy Management System Data for Campus Building Managers

Figure 17.16 is a snapshot of the UW Energy Dashboard[1] that it constructed during the PNWSGD. This Webpage report includes information about building consumption or campus solar energy generation currently, in the current day, the past week, and past years. The figure shows, for example, 12 hours of energy consumption by the Gates Law building on the UW campus.

[1] The Dashboard is openly viewable to all at http://dashboard.mckinstry.com/uw/.

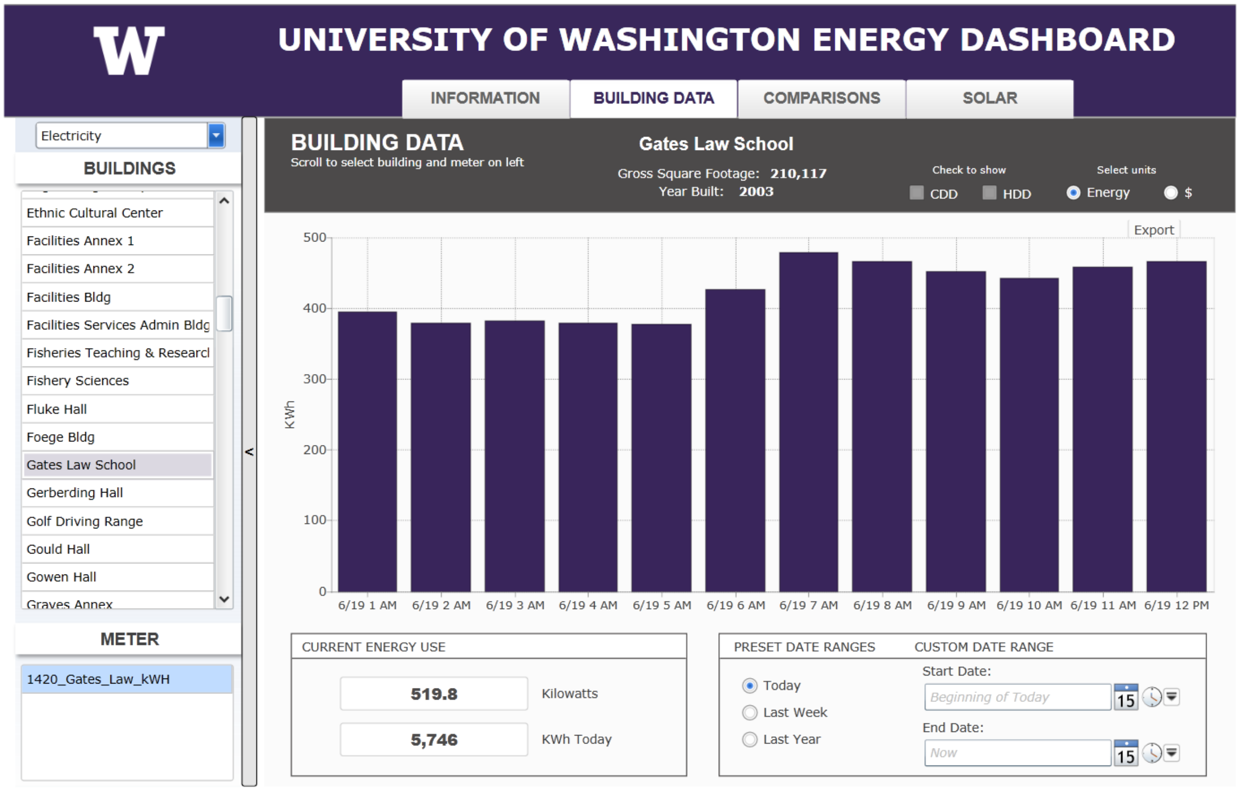


Figure 17.16. Snapshot of the UW Energy Dashboard

17.6.2 Analysis of the Facilities Energy Management System Data for Campus Building Managers

The project was not able to devise a way to separately determine the impact from real-time energy information using the data supplied by UW. The university researched the impact that its energy dashboards had on its building coordinators.[1] The respondents had a wide range of building management experience, from none to over 25 years, and managed a range of buildings aged new to over 120 years. Six respondents eventually were interviewed, and only one of them reported that he had viewed the dashboard as had been requested. The researcher concluded that the UW Energy Dashboard did not appear to have affected the energy behavior of the building coordinators.

[1] M Ostergren. 2013. UW Energy Dashboard Study Final Report. University of Washington technical report dated December 2013, unpublished.