Hawai‘i Energy and Environmental Technologies (HEET) Initiative

Office of Naval Research
Grant Award Number N0014-10-1-0310

TASK 4 ALTERNATIVE ENERGY SYSTEMS
4.5 Energy Test Platforms:
Crissy Field Center Wind Power Study: Commissioning of the Data Acquisition System

Prepared by:
Golden Gate National Parks Conservancy

Prepared for:
University of Hawai‘i at Mānoa, Hawai‘i Natural Energy Institute

September 2015

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

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1907
UA MAU KE EA O KA ‘ĀINA I KA PONO

Deliverable 6: Report on Installation and Commissioning of the Data Acquisition System

Crissy Field Center Wind Power Study

HNEI Subcontract, Prime Award No. N00014-10-1-0310

Golden Gate National Parks Conservancy
9/28/2015

Background

The following summarizes the performance of the Data Acquisition System (DAS) for the Crissy Field Center wind turbine performance monitoring. This report includes documented evidence of installation and commissioning of the DAS including HNEI verification of availability of real-time data. This report also includes lessons learned that may be applicable to future projects.

1. Existing System

The DAS monitors wind turbine performance and also building performance. The components specific to wind turbine performance monitoring include wind speed and direction sensors mounted at the center turbine location as well as at the roof of the cafe, and power monitoring sensors on each wind turbine power circuit. Hardware components of the system are indicated in the as-built system diagrams (see Appendix A, As-Built Drawings).

For wind speed and direction at the center turbine, the sensors are connected to a microcontroller. This microcontroller is powered through wired low voltage power from the building and communicates via zigbee radio transmission to a receiver located near the cafe weather station, which is then in turn wired to the controller. The microcontroller located at the wind instrument holds 60 1-second interval measurements in memory, wrapping around so that the oldest readings are overwritten by the newest readings. The controller keeps time; every minute it sends a request via a serial call to the microcontroller. When prompted by a serial call, the microcontroller calculates minimum, maximum, mean, and standard deviation of the two datasets, and returns these summary statistics via serial connection. A vector average is used for the mean of wind direction. Observed response times have varied between about 1 and 6 seconds. Data are logged in flash memory at the controller.

For power, each wind turbine circuit is monitored using current transformers and reference voltage that are wired to an electrical monitoring device to calculate power use. Within 1 second of the anemometer request, the controller sends requests to the electrical monitoring device for current power use on each wind turbine circuit. The electrical monitoring device responds with current power readings. Response time is within 1 second. The controller logs these readings in its flash memory.

Data accumulated in flash memory is retrieved approximately monthly via manual FTP request. First, the file is archived with a date-specific prefix. Then this archived file is downloaded via FTP. A custom script is run to consolidate data into rows corresponding to the given time stamp. Both the original data file and the consolidated ("pivoted") data file are uploaded to a web server for distribution (see http://monitoring.projectfrog.com/cfc/wind/index.html).

The DAS for the building operates on a 10-minute interval and also reports power data for each individual turbine. These data are collected and processed automatically and are ultimately visualized using a custom dashboard interface that shows data in real time (see Appendix B, Dashboard Screenshots). This visual representation of the data has been helpful for assessing whole building performance, and it has also been helpful for identifying issues with wind turbine performance since it provides a quick way to see if wind turbines are producing power when wind is available. Several times during the project, the dashboard helped alert the team to issues with wind turbines.

2. Lessons Learned & Recommendations

Several issues arose in the commissioning and ongoing operation of the DAS. These include the following issues:

- Wind speed readings tended to be less than expected. Replacement of an anemometer unit at the rooftop of the café helped identify a likely issue with anemometer calibration for each original anemometer. Using a statistical analysis of anemometer readings before and after the replacement of this anemometer, we identified a correction factor that could be applied to the anemometer at the wind turbines to correct the calibration (see Appendix C, Anemometer Correction Factor memo). Even after the correction, the wind speed readings still tended to be lower than what was expected from a previously completed site survey.

- Wind turbines and inverters were expected to be producers of electricity, not consumers. The Tangerie turbine unit appeared to be producing a constant output of 20W. However, an analysis of Tangerie output compared with Windspire output revealed that this 20W was most likely 20W of electrical use on the Tangerie circuit (see Appendix D, Power Production of North Windspire and Tangerie Turbines, November 1–17, 2012). It is unclear whether the source of this 20W load was the inverter or another load on the same circuit.

The Hawaii Natural Energy Institute (HNEI) was able to receive the data collected from the DAS. HNEI completed an analysis of this data, during which process they collected notes on lessons learned. In particular, they identified issues as they attempted to extract performance curves from the wind and wind turbine data. The primary issue was that the power use and wind data didn't show a strong relationship at the level of the most detailed data collected due to the timing and nature of readings. Instantaneous power readings and 1-minute averaged wind data demonstrated wind turbine performance over time, but the analysis team found they wanted more detailed data that showed performance at a 1-second sample interval. Other issues were identified as well, and include gaps in the data and a bug in data processing software that omits or duplicates a line of data at the edges of monthly datasets.

HNEI provided a series of recommendations for the next phase of the project to address issues identified in the first phase. Their recommendations are as follows:

- Data Acquisition
    - We would like to record wind and energy data in synchronized 1 Hz intervals.
    - With 1 hz data for wind and turbine output, we would not require additional pre-processing (min, max, ave, std dev)
    - Synchronize time stamps across all sensors in DAQ.

    - Anemometers localized to each turbine, 1 anemometer per turbine
    - Identify sources of false signals (e.g., 10-20W signal from non-performing Tangarie)

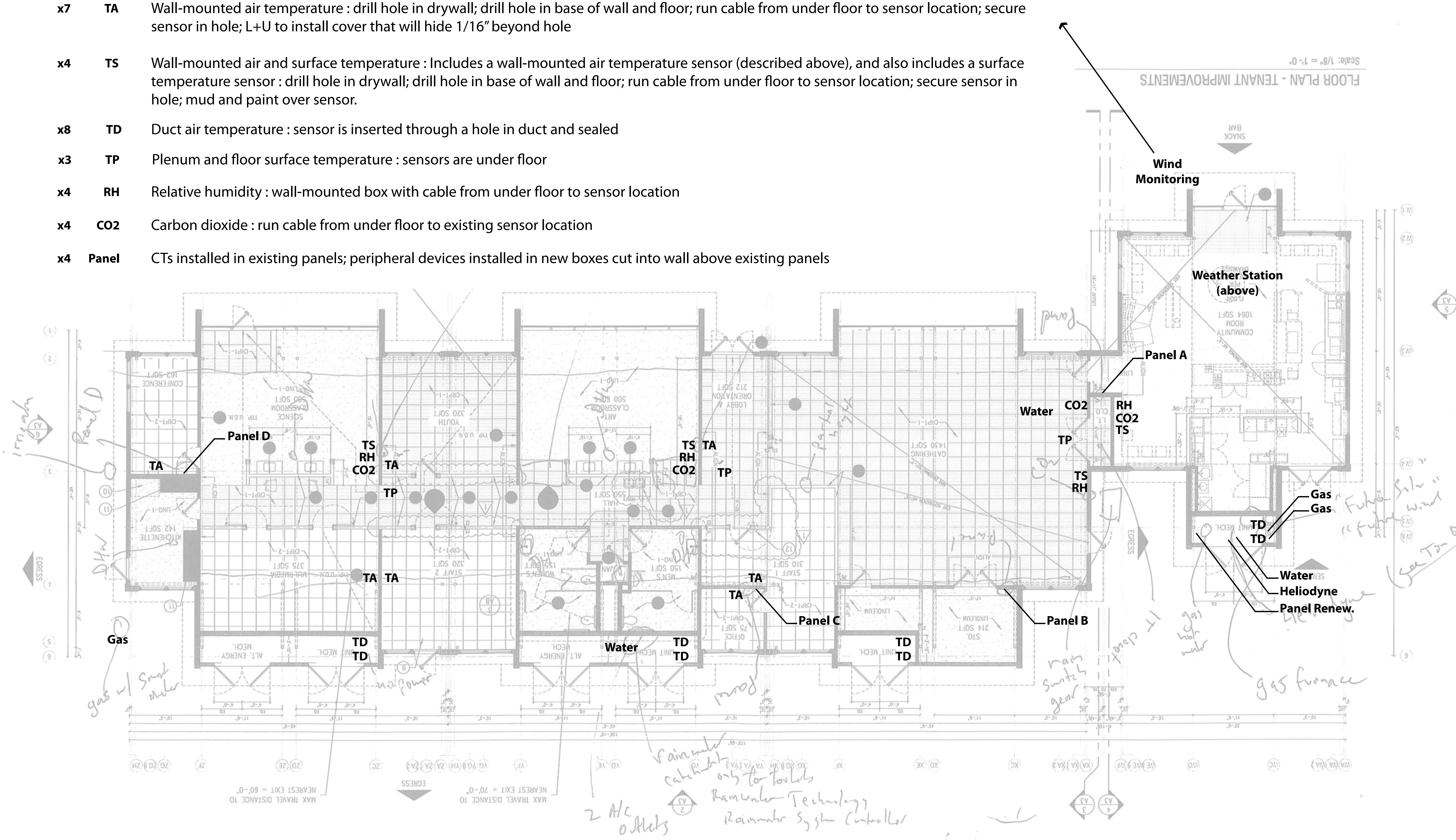
- Data Processing
    - Missing data: large amount of missing data in existing data files.
        - Troubleshoot sources of missing data
            - E.g., Network, internet, archiving, instrumentation, communication, inverter, connection, logging, etc.
    - Request direct access to raw data
    - Data formatting consistent across sub reports (monthly)
    - Eliminate redundant reporting across sub reports (monthly); double reporting of same timestamps on different reports show different data

Appendix A: As-Built Drawings

Building Monitoring Wiring As-Built
Crissy Field Center
Februrary, 2012

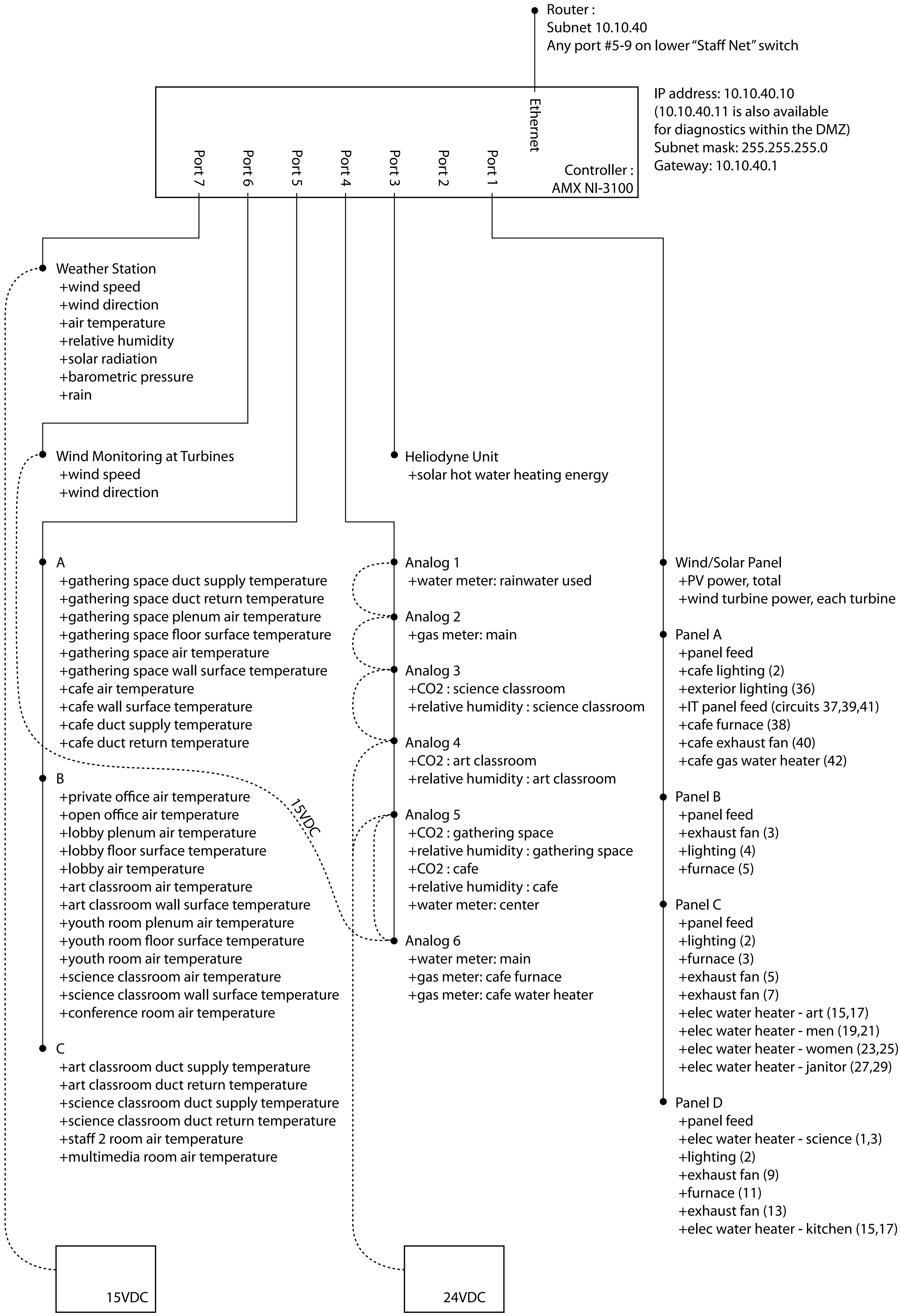
Loisos + Ubbelohde
Monitoring Equipment

x7	TA	Wall-mounted air temperature : drill hole in drywall; drill hole in base of wall and floor; run cable from under floor to sensor location; secure sensor in hole; L+U to install cover that will hide 1/16" beyond hole
x4	TS	Wall-mounted air and surface temperature : Includes a wall-mounted air temperature sensor (described above), and also includes a surface temperature sensor : drill hole in drywall; drill hole in base of wall and floor; run cable from under floor to sensor location; secure sensor in hole; mud and paint over sensor.
x8	TD	Duct air temperature : sensor is inserted through a hole in duct and sealed
x3	TP	Plenum and floor surface temperature : sensors are under floor
x4	RH	Relative humidity : wall-mounted box with cable from under floor to sensor location
x4	CO_2	Carbon dioxide : run cable from under floor to existing sensor location
x4	Panel	CTs installed in existing panels; peripheral devices installed in new boxes cut into wall above existing panels

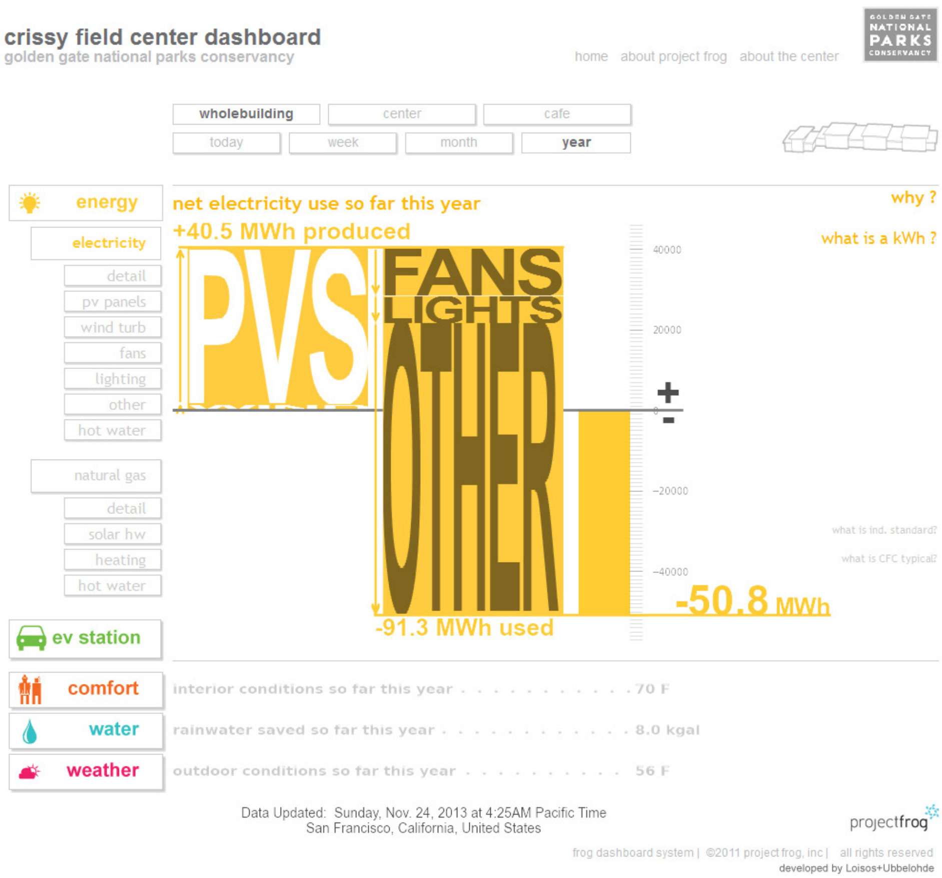


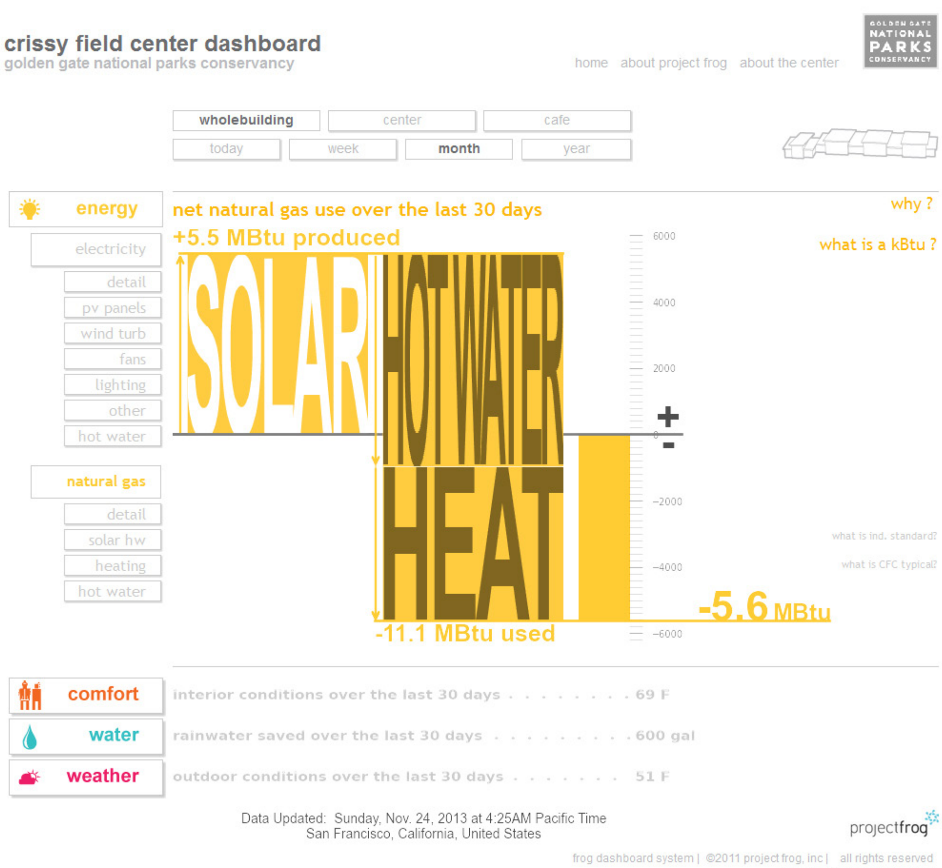
Building Monitoring Wiring As-Built
Crissy Field Center
Februrary, 2012

Loisos + Ubbelohde
Monitoring Equipment



Appendix B: Dashboard Screenshots


crissy field center dashboard
golden gate national parks conservancy
home about project frog about the center
GOLDEN GATE NATIONAL PARKS CONSERVANCY
wholebuilding center cafe
today week month year
energy
electricity
detail
pv panels
wind turb
fans
lighting
other
hot water
natural gas
detail
solar hw
heating
hot water
ev station
comfort
water
weather
net electricity use so far this year
+40.5 MWh produced
PVS
FANS
LIGHTS
OTHER
-91.3 MWh used
-50.8 MWh
40000
20000
0
-20000
-40000
why ?
what is a kWh ?
what is ind. standard?
what is CFC typical?
interior conditions so far this year . . . . 70 F
rainwater saved so far this year . . . . 8.0 kgal
outdoor conditions so far this year . . . . 56 F
Data Updated: Sunday, Nov. 24, 2013 at 4:25AM Pacific Time
San Francisco, California, United States
projectfrog
frog dashboard system | ©2011 project frog, inc | all rights reserved
developed by Loisos+Ubbelohde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hot water
natural gas
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solar hw
heating
hot water
comfort
water
weather
net natural gas use over the last 30 days
+5.5 MBtu produced
SOLAR
HOT WATER
HEAT
-11.1 MBtu used
-5.6 MBtu
6000
4000
2000
0
-2000
-4000
-6000
why ?
what is a kBtu ?
what is ind. standard?
what is CFC typical?
interior conditions over the last 30 days . . . . 69 F
rainwater saved over the last 30 days . . . . 600 gal
outdoor conditions over the last 30 days . . . . 51 F
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crissy field center dashboard

golden gate national parks conservancy

home | about project frog | about the center

GOLDEN GATE NATIONAL PARKS CONSERVANCY

whole building | center | cafe

today | week | month | year

energy

electricity

- detail
- pv panels
- wind turb
- fans
- lighting
- other
- hot water

natural gas

- detail
- solar hw
- heating
- hot water

ev station

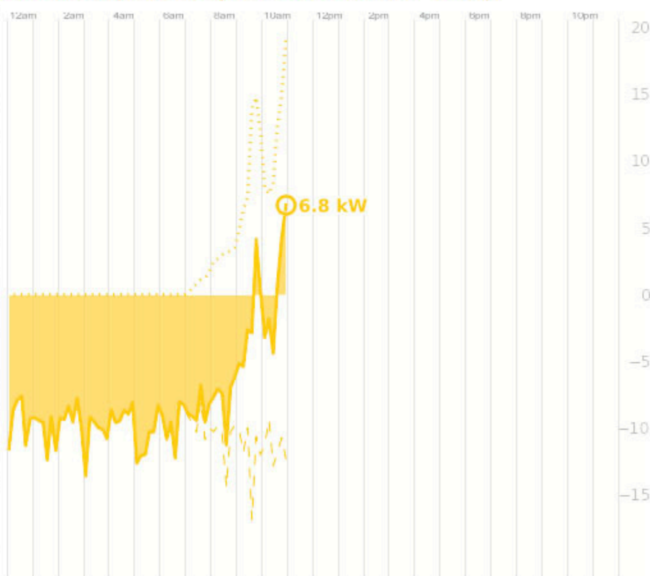
comfort

water

weather

electricity use vs production so far today

what is a kW ?



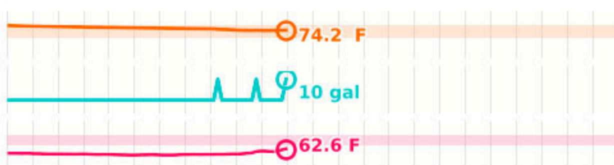
typical energy performance for this buiding (kW)

net energy performance (produced - used) (kW)

total energy produced (+) (kW)

total energy used (-) (kW)

current energy performance (kW)



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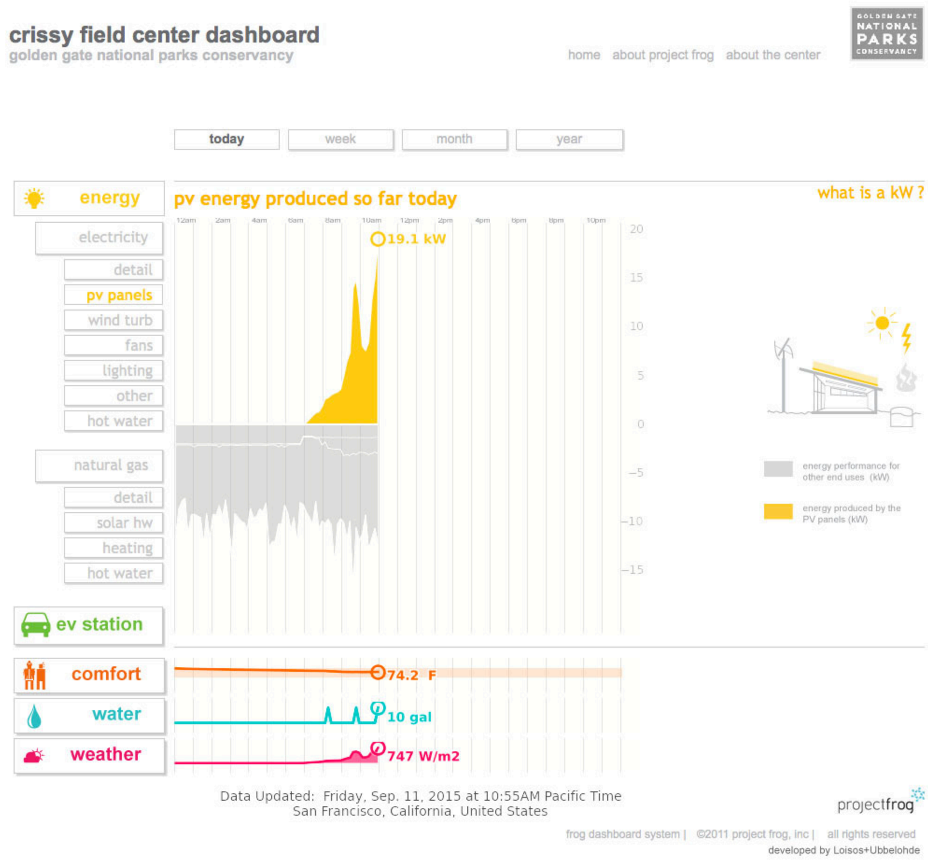
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ev station
19.1 kW
20
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−5
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energy performance for other end uses (kW)
energy produced by the PV panels (kW)
comfort
74.2 F
water
10 gal
weather
747 W/m2
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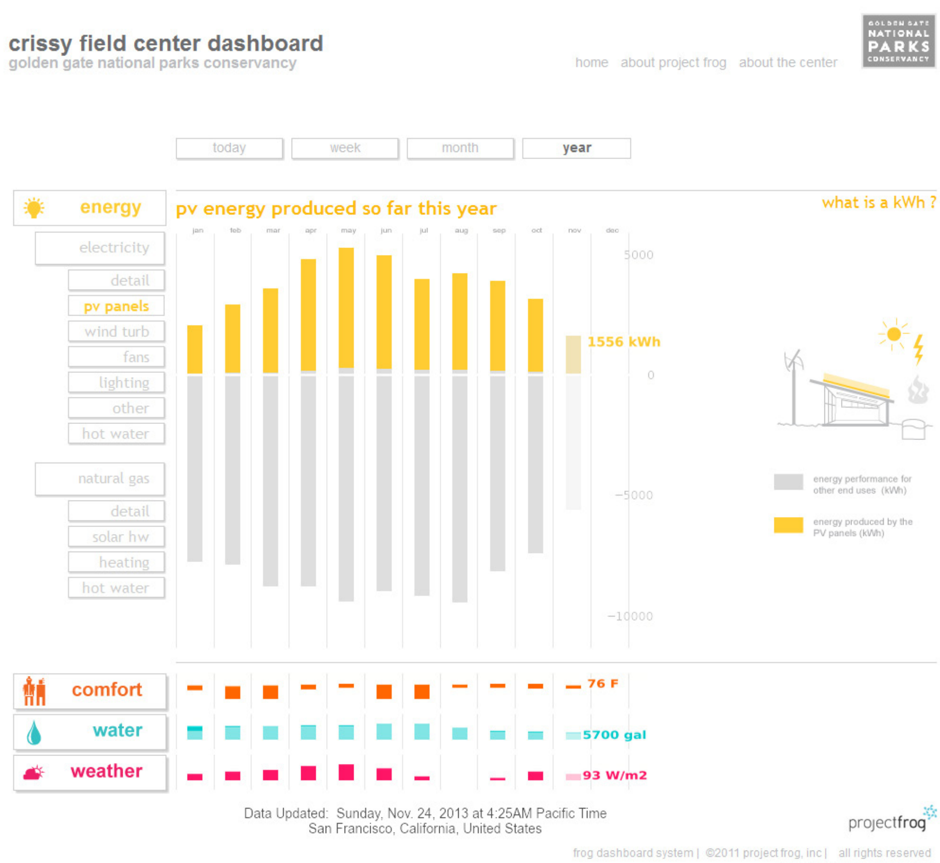
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energy performance for other end uses (kWh)
energy produced by the PV panels (kWh)
comfort
76 F
water
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93 W/m2
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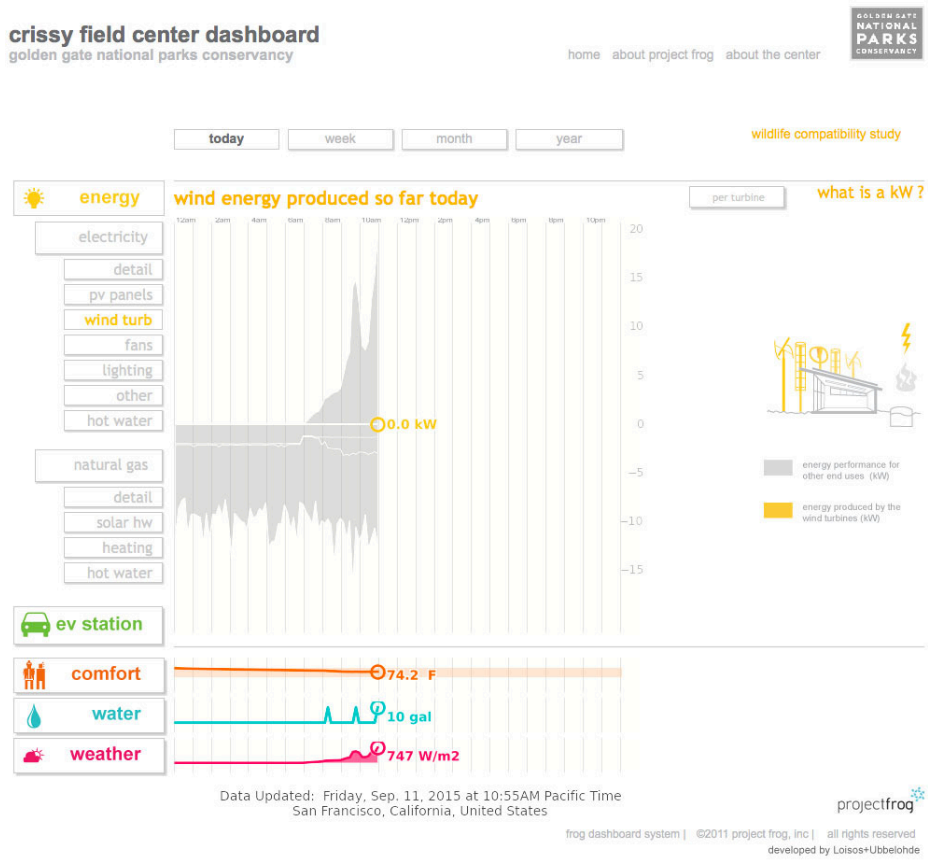
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home about project frog about the center
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wind energy produced so far today
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energy performance for other end uses (kW)
energy produced by the wind turbines (kW)
comfort
74.2 F
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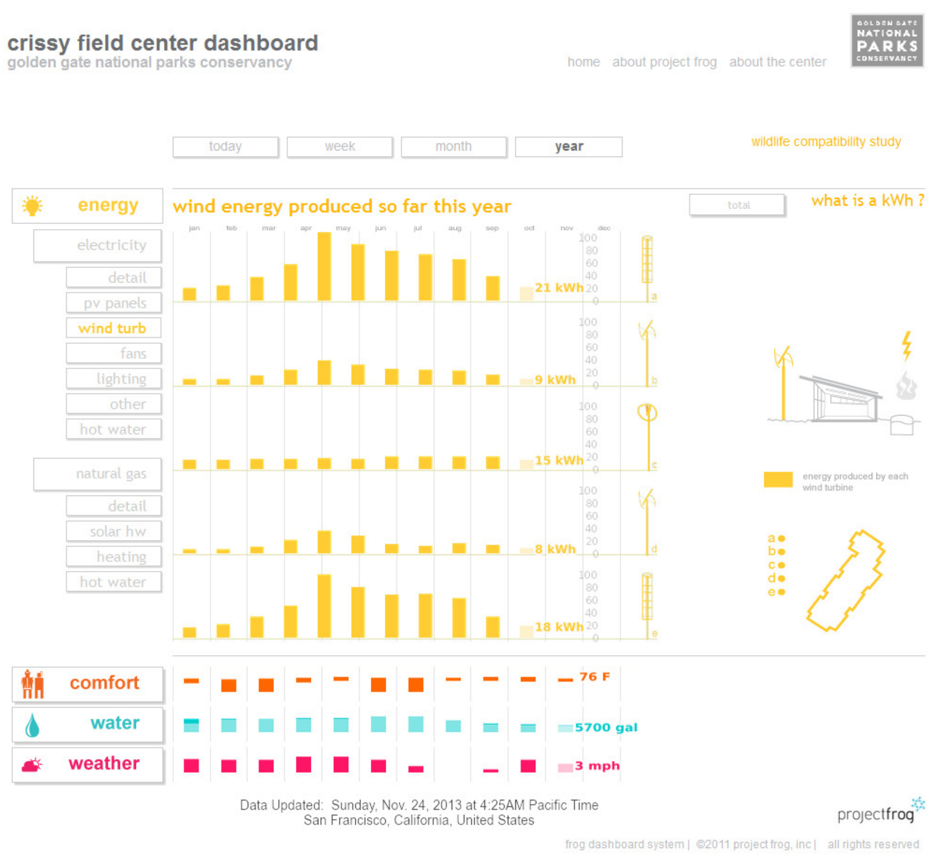
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21 kWh
9 kWh
15 kWh
8 kWh
18 kWh
energy produced by each wind turbine
a b c d e
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76 F
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5700 gal
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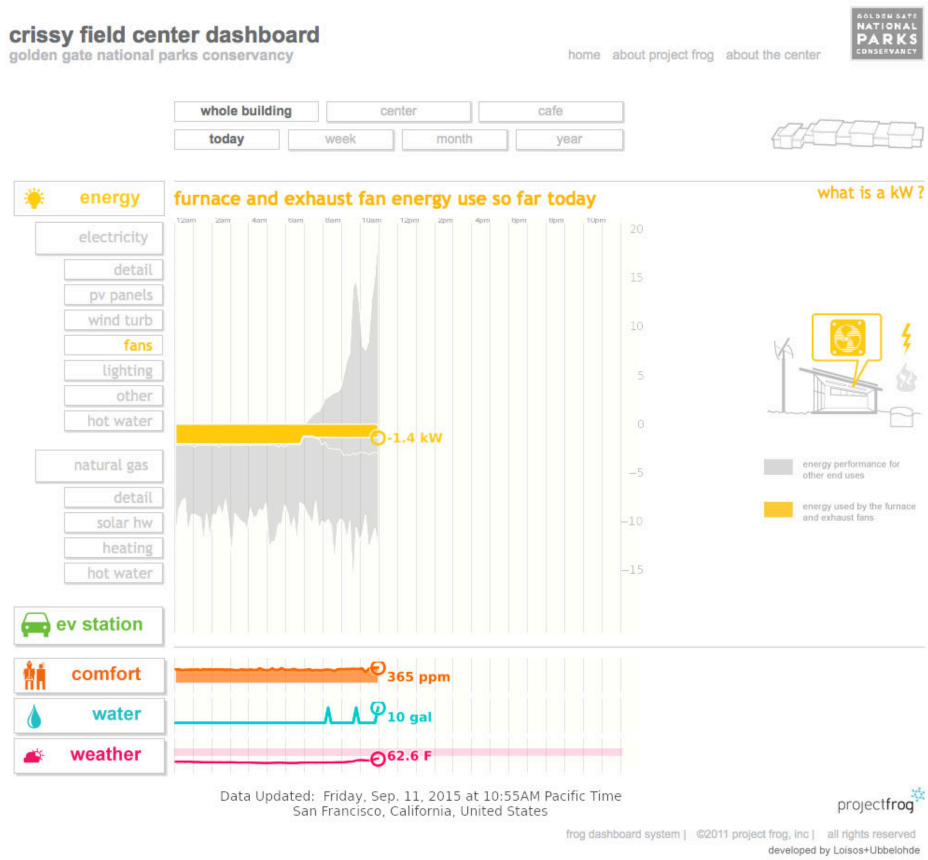
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whole building center cafe
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natural gas
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energy performance for other end uses
energy used by the furnace and exhaust fans
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comfort
365 ppm
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62.6 F
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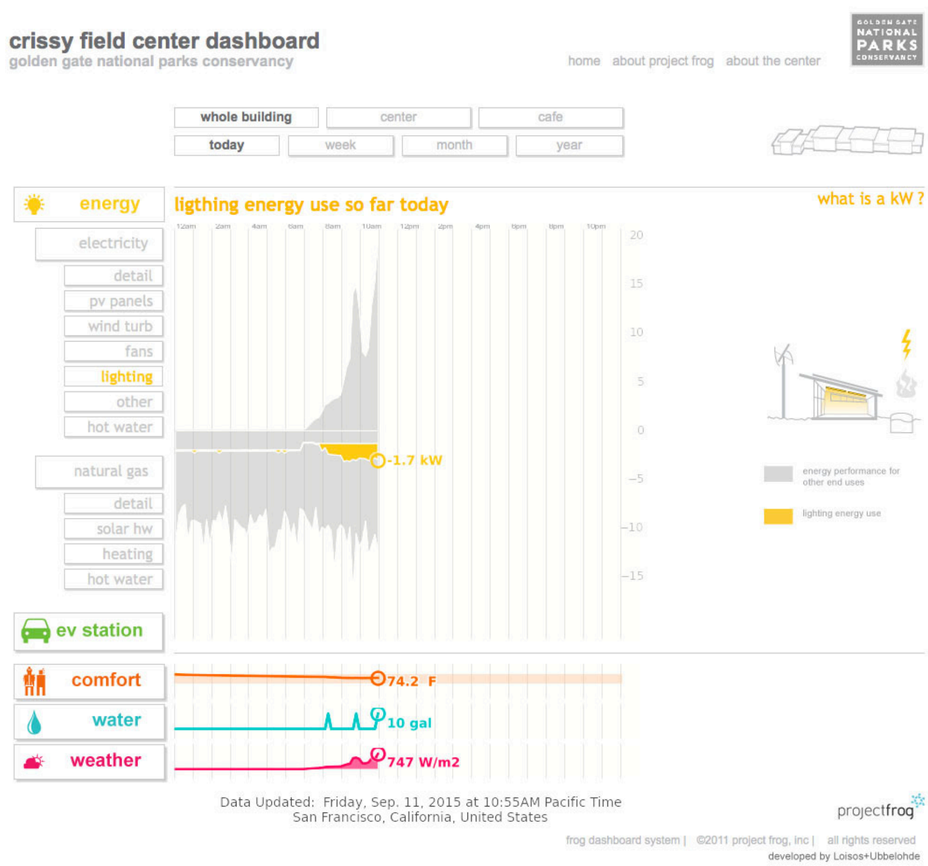
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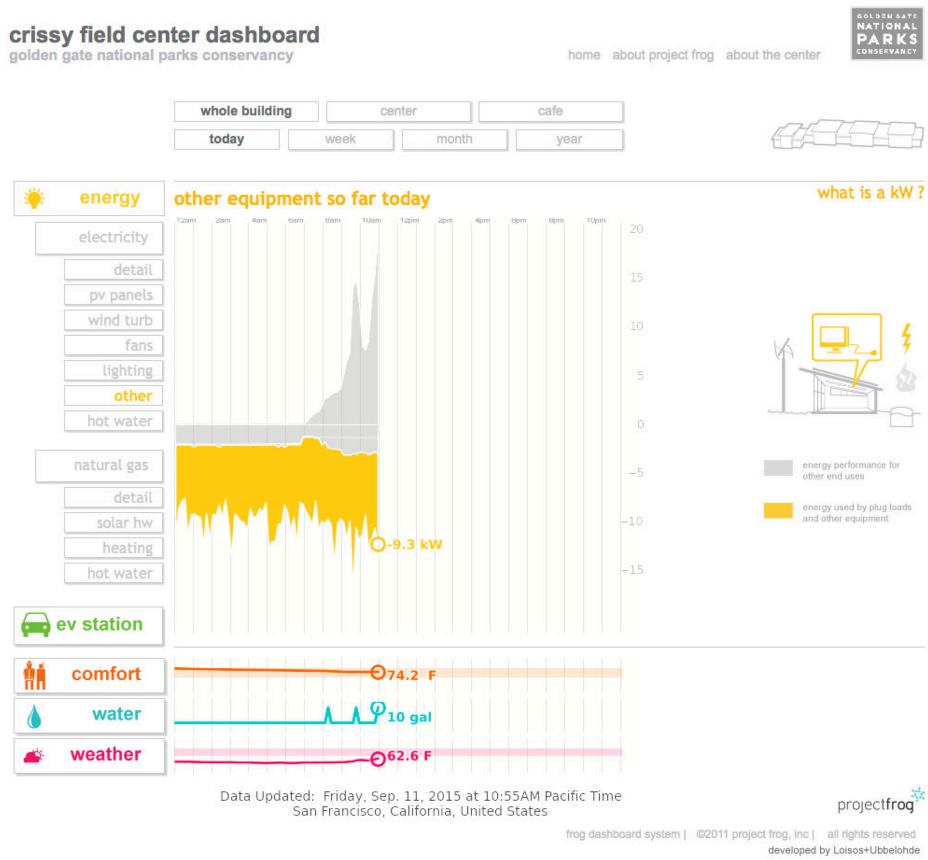
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energy performance for other end uses
energy used by plug loads and other equipment
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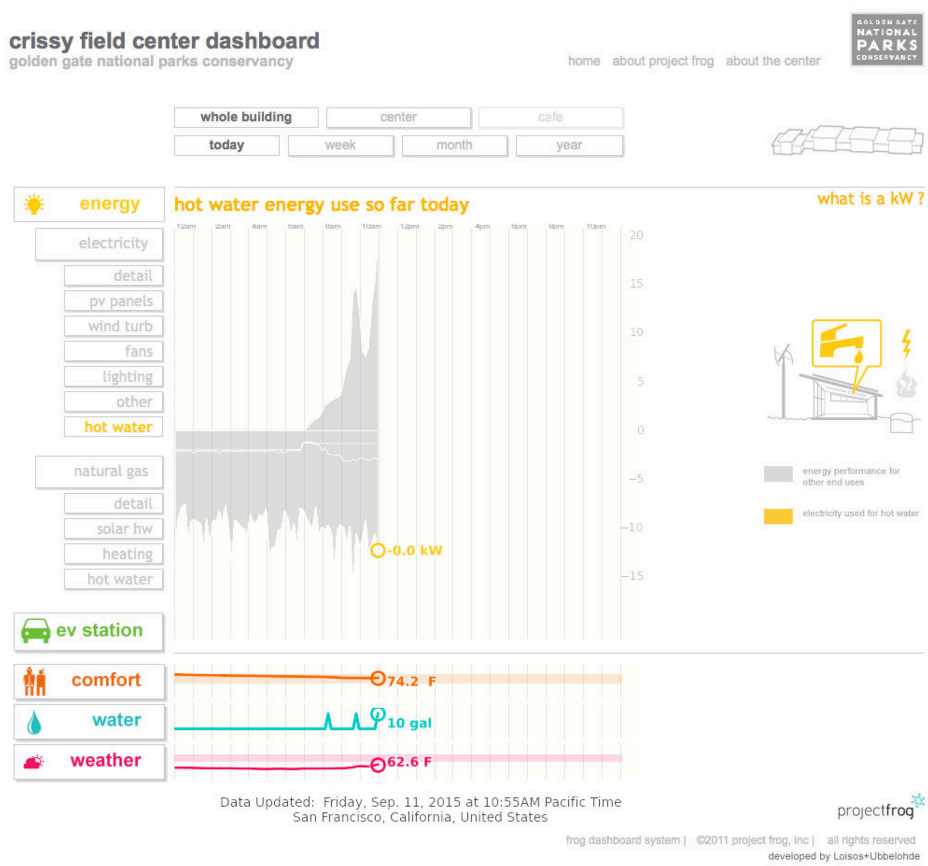
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electricity used for hot water
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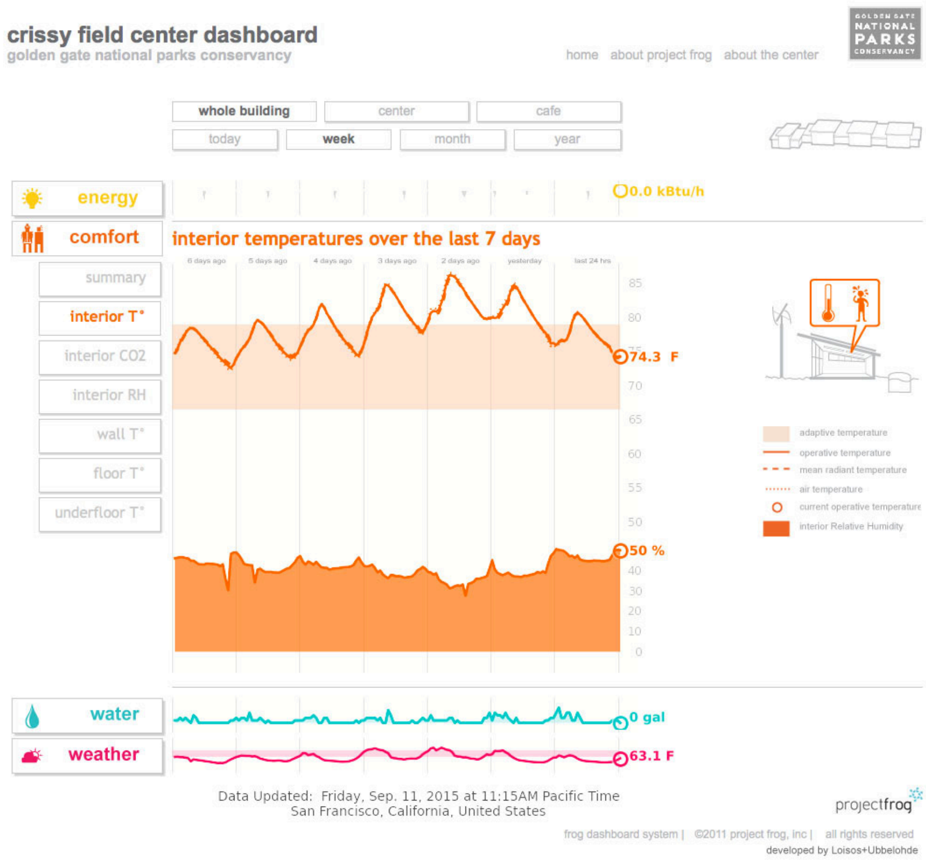
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home about project frog about the center
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whole building
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today
week
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year
energy
0.0 kBtu/h
comfort
interior temperatures over the last 7 days
summary
interior T°
interior CO2
interior RH
wall T°
floor T°
underfloor T°
74.3 F
50 %
adaptive temperature
operative temperature
mean radiant temperature
air temperature
current operative temperature
interior Relative Humidity
water
0 gal
weather
63.1 F
Data Updated: Friday, Sep. 11, 2015 at 11:15AM Pacific Time
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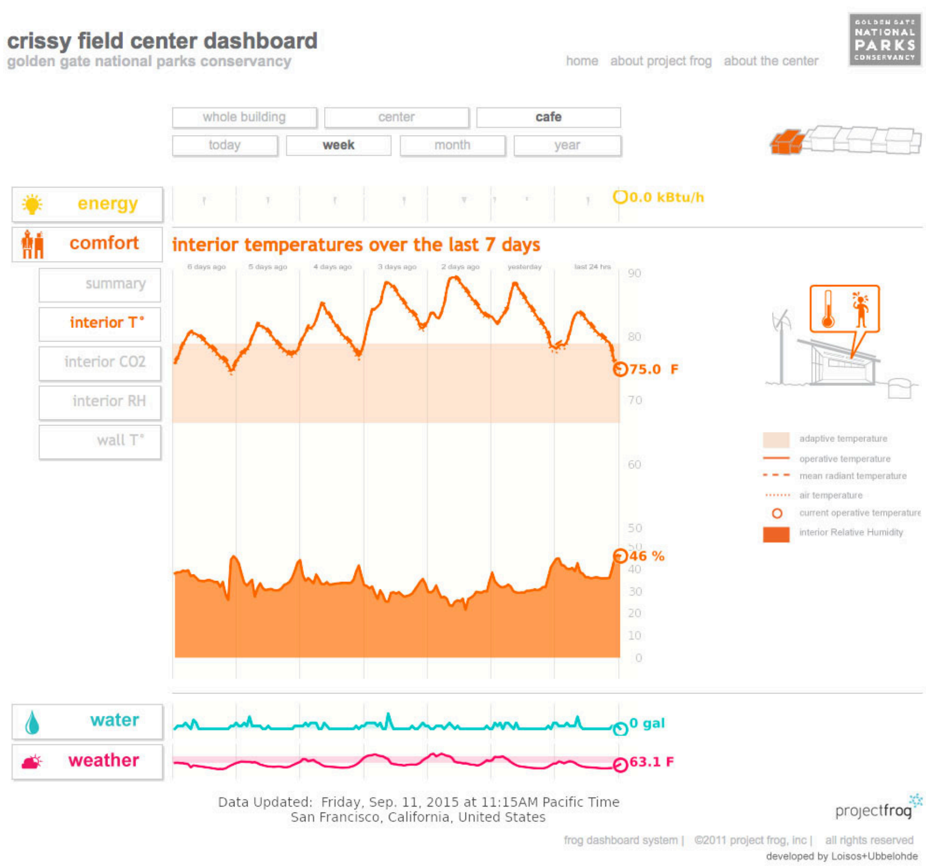
crissy field center dashboard
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interior T°
interior CO2
interior RH
wall T°
75.0 F
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operative temperature
mean radiant temperature
air temperature
current operative temperature
interior Relative Humidity
water
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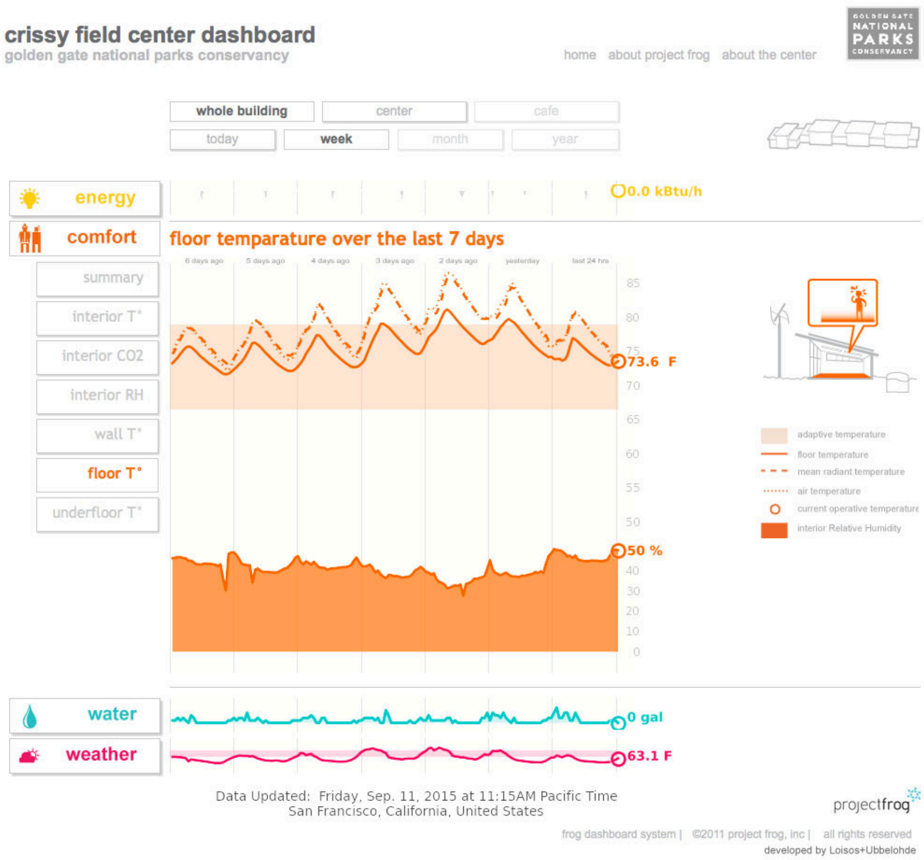
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interior RH
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underfloor T°
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mean radiant temperature
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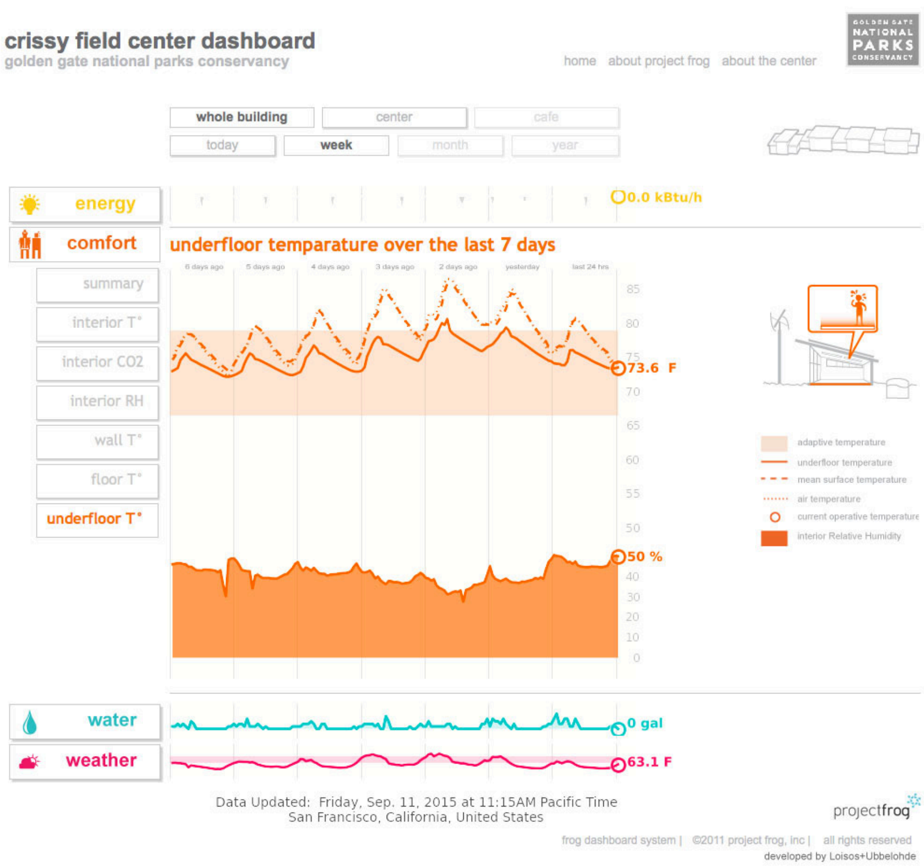
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interior RH
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floor T°
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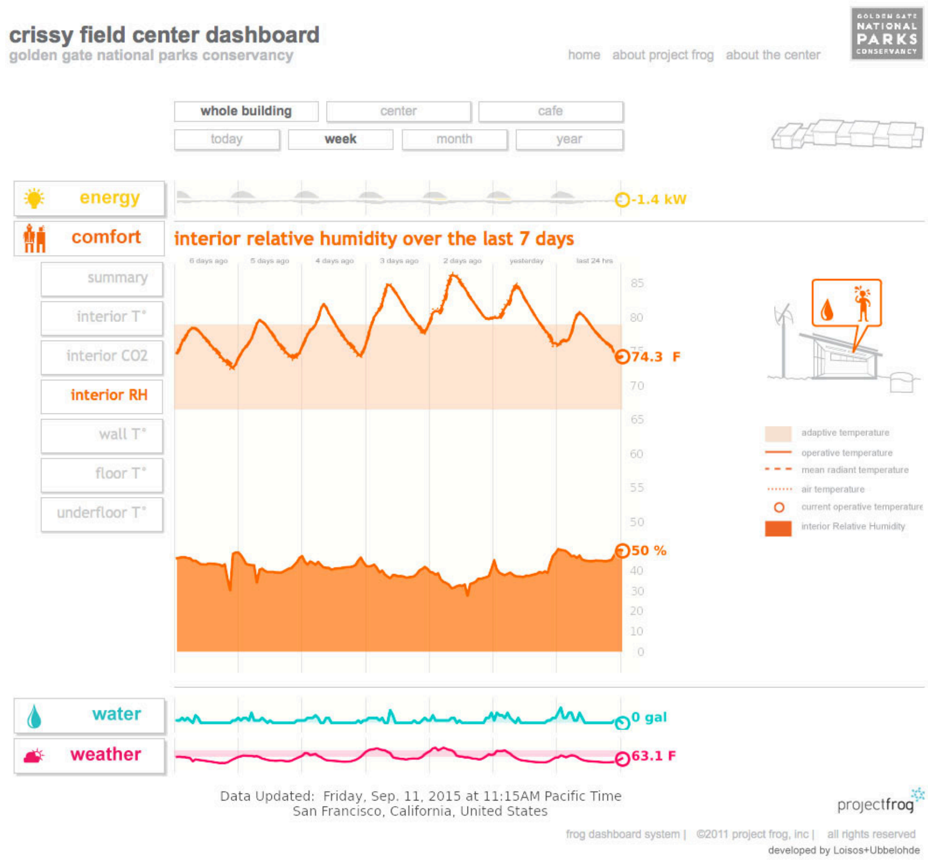
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interior CO2
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wall T°
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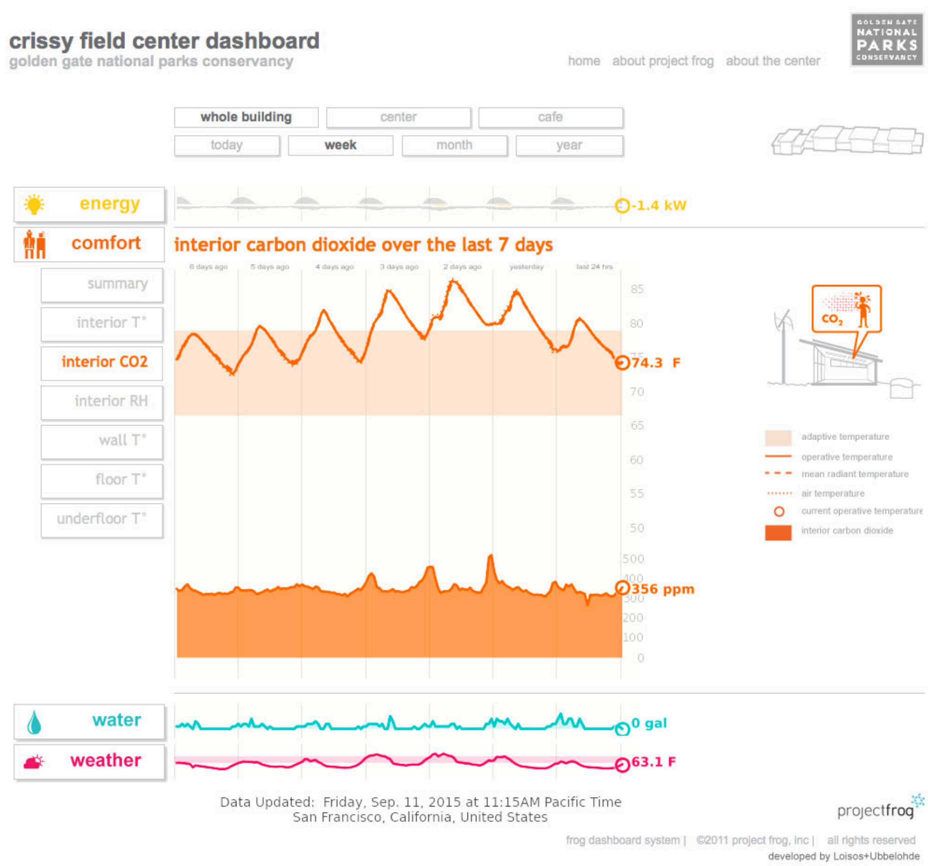
crissy field center dashboard
golden gate national parks conservancy
home
about project frog
about the center
GOLDEN GATE NATIONAL PARKS CONSERVANCY
whole building
center
cafe
today
week
month
year
energy
-1.4 kW
comfort
interior carbon dioxide over the last 7 days
summary
interior T°
interior CO2
interior RH
wall T°
floor T°
underfloor T°
74.3 F
356 ppm
adaptive temperature
operative temperature
mean radiant temperature
air temperature
current operative temperature
interior carbon dioxide
water
0 gal
weather
63.1 F
Data Updated: Friday, Sep. 11, 2015 at 11:15AM Pacific Time
San Francisco, California, United States
projectfrog
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crissy field center dashboard
golden gate national parks conservancy

home about project frog about the center

GOLDEN GATE NATIONAL PARKS CONSERVANCY

whole building | center | cafe

today | week | month | year

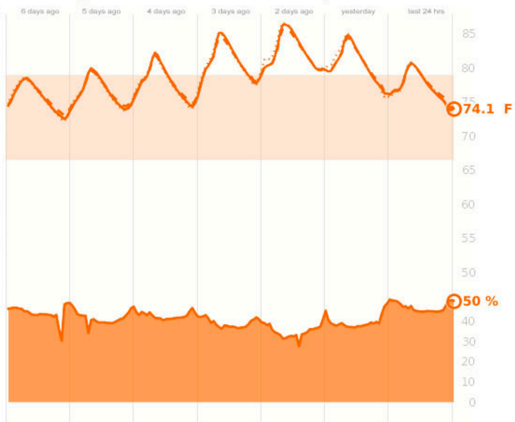
energy

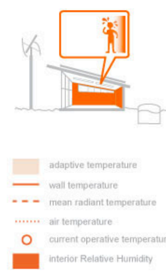
0.0 kBtu/h

comfort

wall temperatures over the last 7 days

summary
interior T°
interior CO2
interior RH
wall T°
floor T°
underfloor T°





water

weather

Data Updated: Friday, Sep. 11, 2015 at 11:15AM Pacific Time
San Francisco, California, United States

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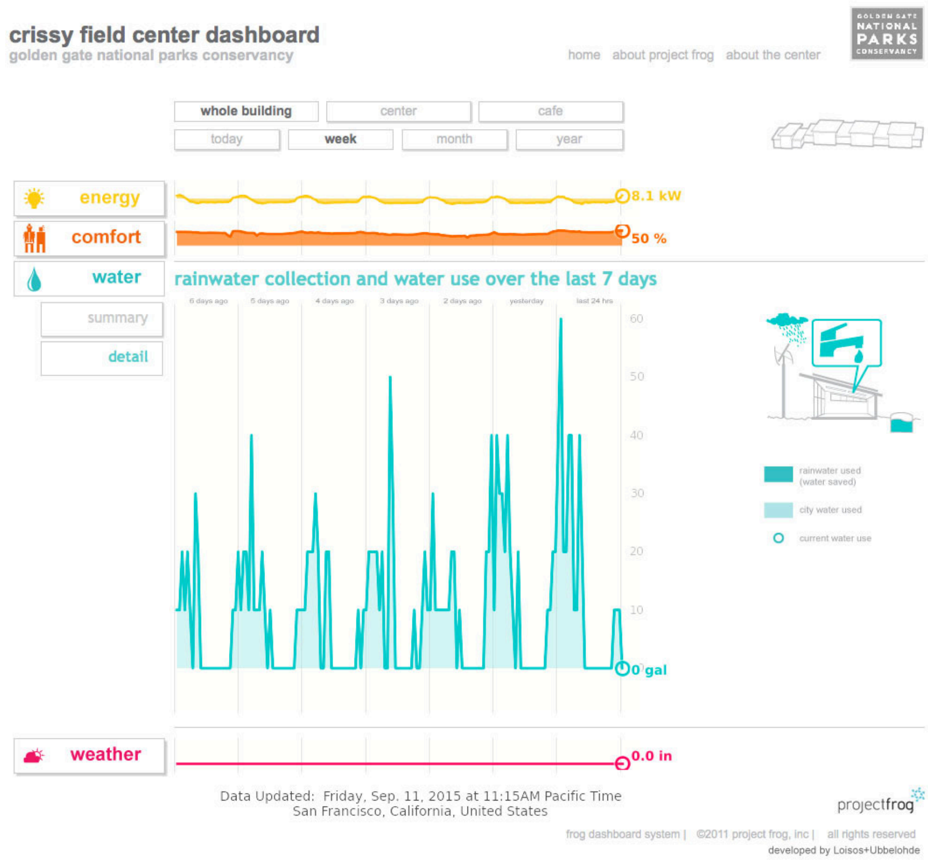
crissy field center dashboard
golden gate national parks conservancy
home about project frog about the center
GOLDEN GATE NATIONAL PARKS CONSERVANCY
whole building
center
cafe
today
week
month
year
energy
8.1 kW
comfort
50 %
water
summary
detail
rainwater collection and water use over the last 7 days
6 days ago
5 days ago
4 days ago
3 days ago
2 days ago
yesterday
last 24 hrs
60
50
40
30
20
10
0 gal
rainwater used (water saved)
city water used
current water use
weather
0.0 in
Data Updated: Friday, Sep. 11, 2015 at 11:15AM Pacific Time
San Francisco, California, United States
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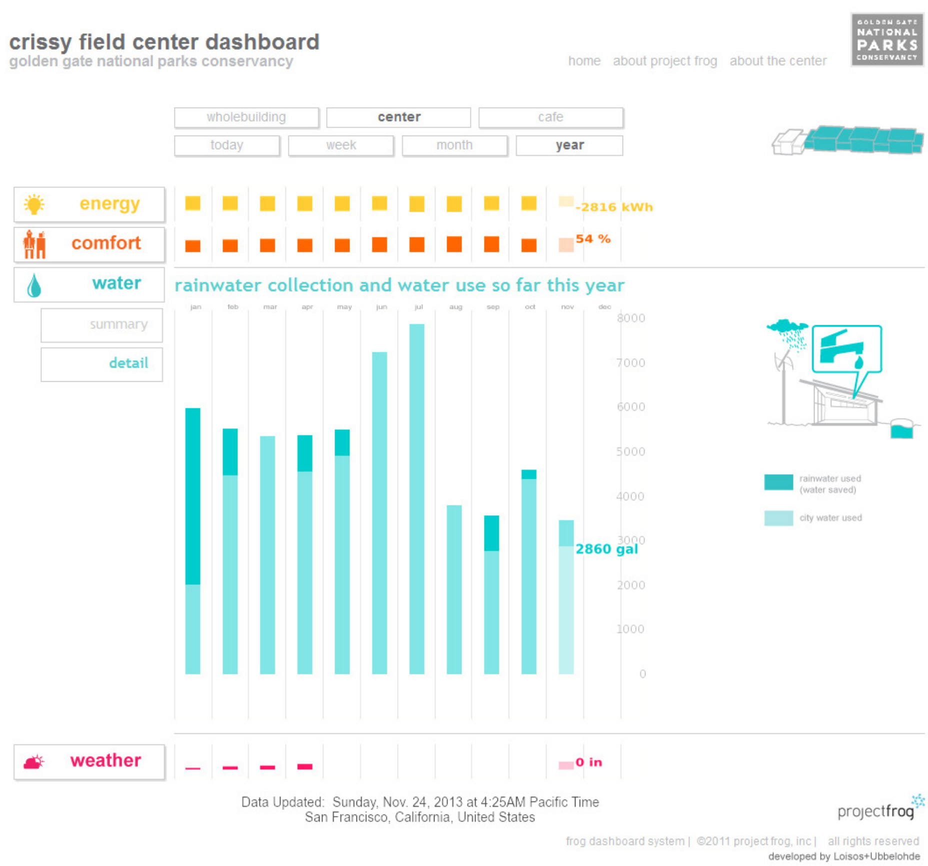
crissy field center dashboard
golden gate national parks conservancy
home about project frog about the center
GOLDEN GATE NATIONAL PARKS CONSERVANCY
wholebuilding
center
cafe
today
week
month
year
energy
-2816 kWh
comfort
54 %
water
summary
detail
rainwater collection and water use so far this year
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
8000
7000
6000
5000
4000
3000
2860 gal
2000
1000
0
rainwater used (water saved)
city water used
weather
0 in
Data Updated: Sunday, Nov. 24, 2013 at 4:25AM Pacific Time
San Francisco, California, United States
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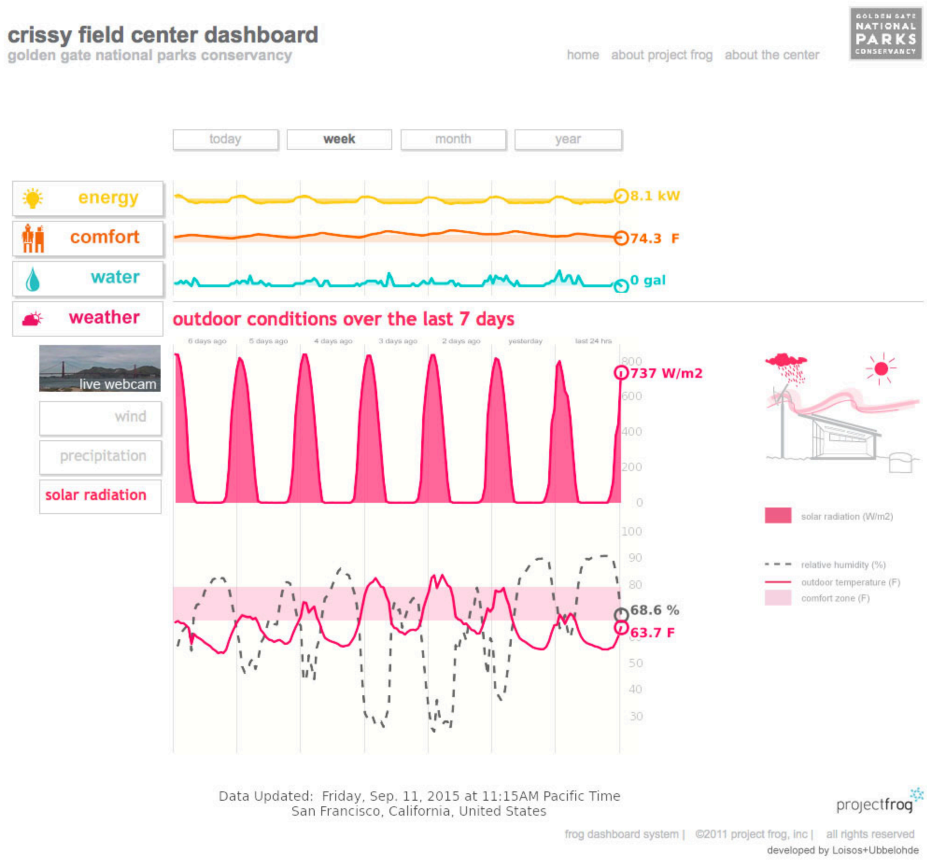
crissy field center dashboard
golden gate national parks conservancy
home about project frog about the center
GOLDEN GATE NATIONAL PARKS CONSERVANCY
today
week
month
year
energy
comfort
water
weather
8.1 kW
74.3 F
0 gal
outdoor conditions over the last 7 days
6 days ago
5 days ago
4 days ago
3 days ago
2 days ago
yesterday
last 24 hrs
live webcam
wind
precipitation
solar radiation
737 W/m2
800
600
400
200
0
100
90
80
50
40
30
68.6 %
63.7 F
solar radiation (W/m2)
relative humidity (%)
outdoor temperature (F)
comfort zone (F)
Data Updated: Friday, Sep. 11, 2015 at 11:15AM Pacific Time
San Francisco, California, United States
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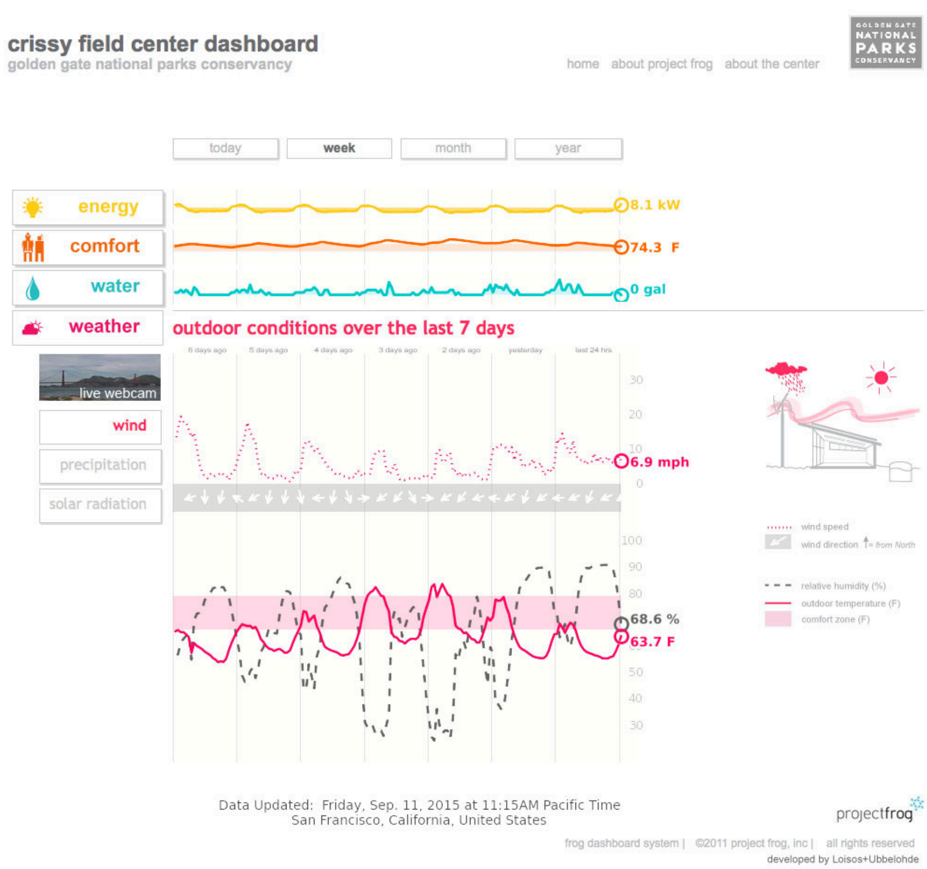
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home about project frog about the center
GOLDEN GATE NATIONAL PARKS CONSERVANCY
today
week
month
year
energy
comfort
water
weather
8.1 kW
74.3 F
0 gal
outdoor conditions over the last 7 days
6 days ago
5 days ago
4 days ago
3 days ago
2 days ago
yesterday
last 24 hrs
live webcam
wind
precipitation
solar radiation
30
20
10
0
6.9 mph
100
90
80
50
40
30
68.6 %
63.7 F
wind speed
wind direction ↑= from North
relative humidity (%)
outdoor temperature (F)
comfort zone (F)
Data Updated: Friday, Sep. 11, 2015 at 11:15AM Pacific Time
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Appendix C: Anemometer Wind Correction Factor Memo

LOISOS + UBBELOHDE
ARCHITECTURE . ENERGY

1917 Clement Ave Building 10A • Alameda, CA 94501-1315
510 521 3800 PHONE • 510 521 3820 FAX

MEMORANDUM

DATE	10 October, 2014
TO	**Tom Odgers,** Project Manager Golden Gate National Parks Conservancy **Jim Maskrey** Hawaii Natural Energy Institute, University of Hawaii at Manoa
FROM	George Loisos and Susan Ubbelohde, Principals Nathan Brown, Associate

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RE	Anemometer correction factor

SUMMARY

Loisos + Ubbelohde recently upgraded the weather station at Crissy Field Center and found that the new anemometer tended to report wind speeds that were higher than the old anemometer. The anemometer and peripheral mounted on the wind turbines were the same as the old weather station. We believe the new weather station calibration is the most accurate since it is a calibrated standalone product. The purpose of this memo is to estimate the correction coefficient that could be used to convert from the measured wind speed by the old weather station to that measured by the new weather station. Since the two original weather anemometers were the same, the same correction coefficient would be expected to correct the wind turbine anemometer readings.

The study found that the correction coefficient of 1.53 should be used to convert wind speed measurements taken using the old anemometer.

METHOD

The estimation of the correction coefficient involved two steps. First, using data gathered before the weather station replacement, a model was created to predict the wind speed reading of the old weather station anemometer given the wind speed measured by the wind turbine anemometer and the wind direction. Second, for the period of time after the replacement, the model was used to predict the wind speed readings of the old weather station anemometer. These predicted readings of the old anemometer and the measured readings by the new anemometer were then used to create a model to find the correction coefficient to convert from the old weather station anemometer wind speed to the new weather station anemometer wind speed.

Model 1: Predicting old weather station wind speed

The compass was divided into 72 segments. Data were taken from 2014 prior to the replacement of the weather station (January 1 to July 23). For each segment, an ordinary least squares (OLS) model was created to predict the wind speed at the weather station location given the wind speed measured at the wind turbines. Figure 1 shows an example of the results of this model: at 260 degrees, the model predicts the wind speeds measured at the weather station will be lower by a factor of 0.802, with an R-squared value of 0.847.

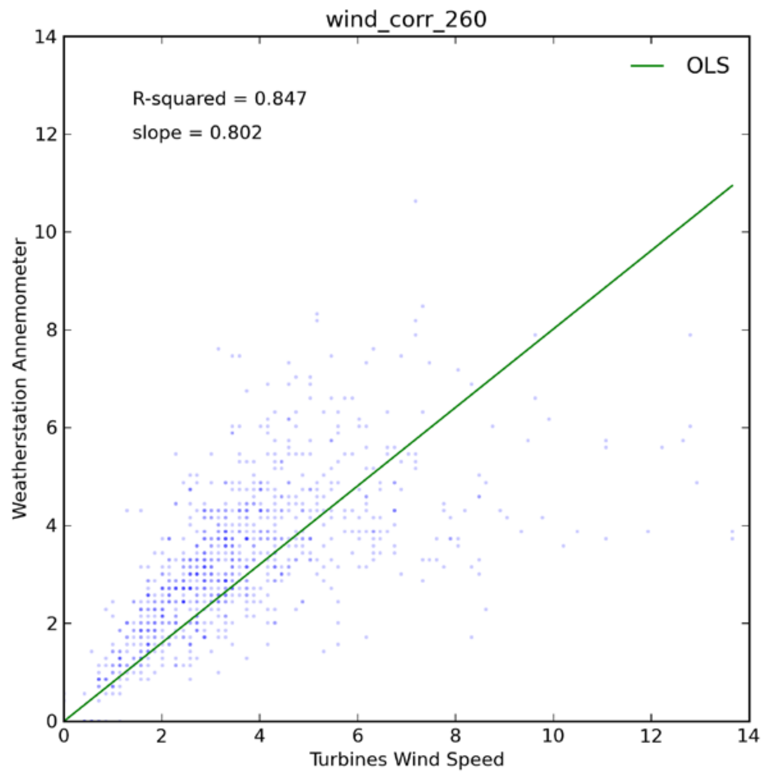

Figure 1. Model 1 results for wind directions of 260 +/- 2.5

Figure 2 shows the overall results for models for each wind direction, along with the frequency distribution of wind directions in the data set. Note that the results become more consistent when the wind comes generally from the west. This is likely due to the larger sample size and also to the presence of fewer obstructions when wind flows from that direction.

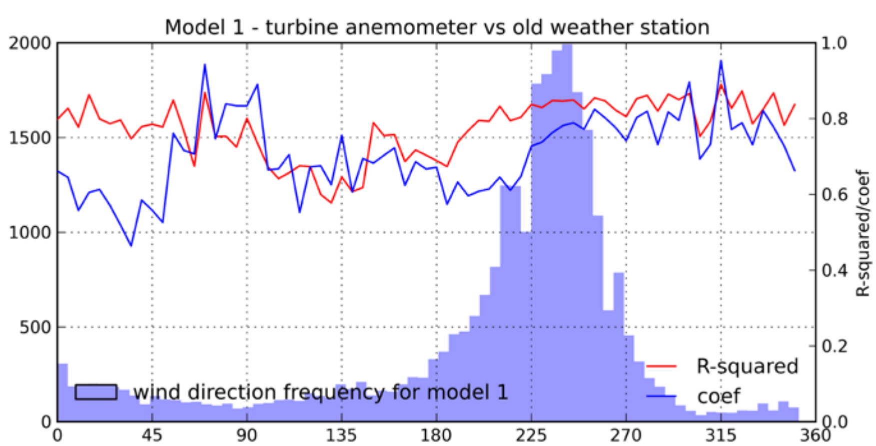

Figure 2. Model 1 results for all directions

Model 2: Predicting new weather station wind speed

The second model utilized data from after the weather station replacement (July 23 to September 30), along with predicted values for what the old weather station would have read using Model 1. We created Model 2 using an OLS model to the predicted the wind speed of the new weather station given the predicted old weather station wind speed. Figure 3 shows an example of the results of this model: at 260 degrees, Model 2 predicts the wind speeds measured at the weather station will be higher by a factor of 1.571, with an R-squared value of 0.862.

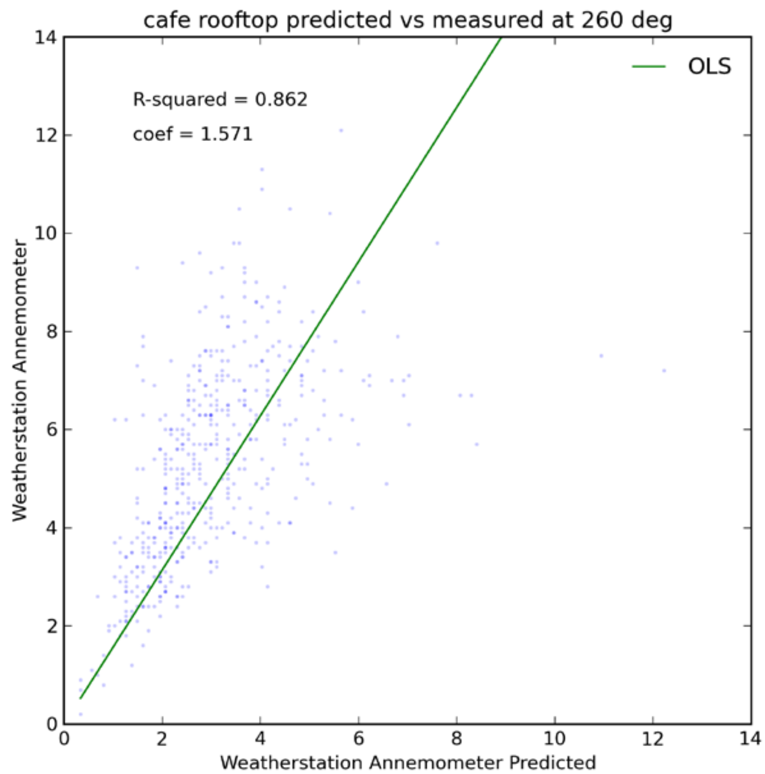

Figure 3. Model 2 results for wind directions of 260 +/- 2.5

Figure 4 shows the overall results for Model 2 for each wind direction, along with the frequency distribution of wind directions in the data set. Once again, the results become more consistent when the wind comes generally from the west, with the correction coefficient for each model averaging a bit more than 1.5. Note also that the R-squared values in this range are very similar for Model 1 and Model 2. This is expected assuming near-perfect correlation between measurements read by the old anemometer and the new.

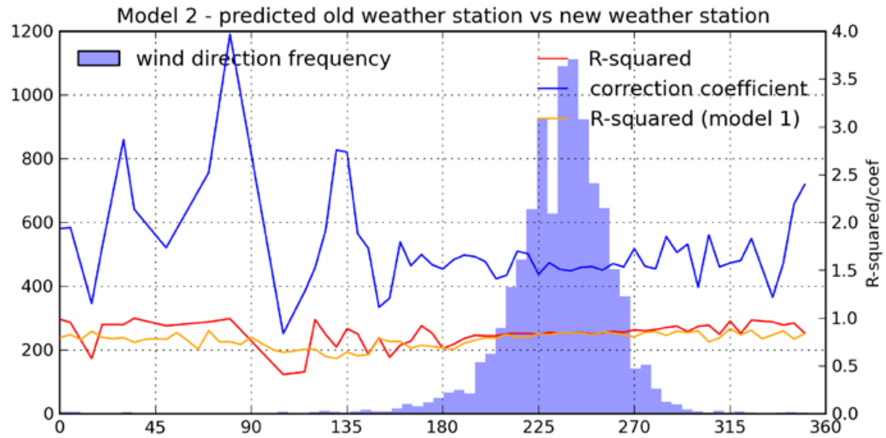

Figure 4. Model 2 results for all directions

In order to determine the recommended correction factor, we limited the data set to those directions we know to be less obstructed and that had consistent R-squared values. Using Figure 4 and an aerial photograph, we decided to limit the data to wind directions between 225 and 315 degrees (see Figure 5). We then took an average of the coefficients for each direction, weighted by the number of samples. This average was determined to be 1.53.

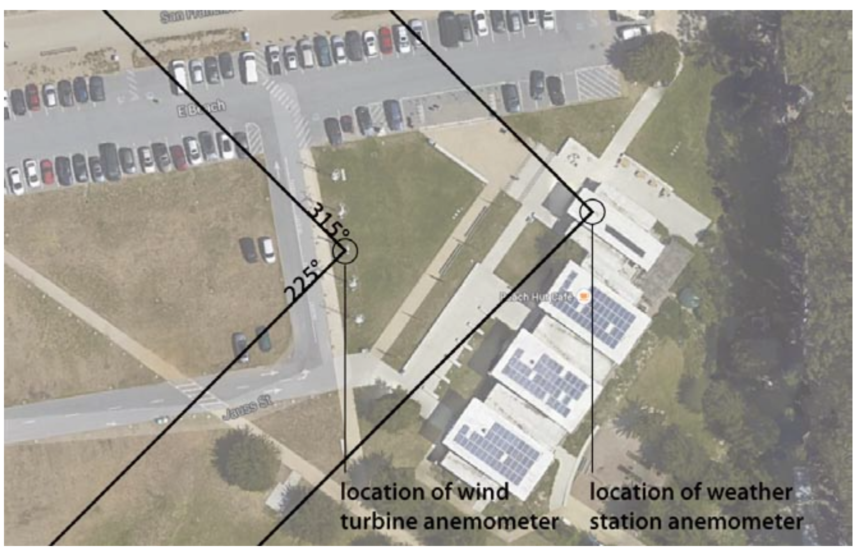

Figure 5. Anemometer locations and wind directions used to determine the recommended correction coefficient

Appendix D: Power Production of North Windspire and Tangerie Turbines, November 1–17, 2012

Power Production of North Windspire and Tangerie Turbines, November 1-17, 2012