Energy Lab Outline:Building Automation System

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Executive Summary

Objective

To outline the function, sensors, controls and integration of the HPA energy lab building automation system

Background

Hawaii Preparatory Academy is in the process of building a model facility using the latest in renewable and sustainable building and design practices. It is our hope to forge a new standard for LEED and Living Building Challenge facilities, using materials and systems presently available.

Goals

The HPA energy lab is a completely energy, water and waste self sufficient facility with several key goals:

1. To provide a safe, pleasant facility for study of renewable energy and sustainability
2. To utilize best practices as a test platform for sustainable building practices

In this light, the building automation system strives to monitor and control systems in a most efficient manner, that will hopefully become an example for future building practices.

Scope

Nine systems will be covered in this document:

1. Fresh water catchment and purification system (FCS)
2. Radiant cooling system (RCS)
3. Passive ventilation system (PVS)
4. Forced ventilation system (FVS)
5. HVAC system (HVAC)
6. Energy monitoring/control system (EMS)
7. Air quality monitoring system (AQS)

8. Meteorological monitoring system (MMS)

9. Solar thermal systems (STS)

System one: Freshwater catchment and purification system (FCS)

Function

The HPA energy lab strives to meet stringent goals for water self-sufficiency. The sole source for our non-potable water will be via rooftop water catchment/harvesting, feeding a system of gutters, to a holding tank of approximately 10,000 gal. (40,000 liters) capacity. Water is then pumped through a system of filters for use in the building.

Design

Four elements will be covered here:

1. Water catchment and storage

2. Water pump system

3. Water filtration system

4. Monitoring/alarm system

The energy lab has a roof area on the North side of approximately 6100 sq. ft. (564 sq. meters). Water will be gathered here by both precipitation and condensation, gathered into a lateral gutter system, then piped into the holding tank. Above the holding tank is an ultrasonic tank level sensor, which monitors tank level to 0.1 mm some 30 times each second. Data from this sensor is relayed via 0-5 Vdc levels to a translator module, which exports the data from the sensor to the energy lab brain system as XML data, for monitoring, recording, and integration over time.

Water is then pumped via an on-demand line pressurizing pump to outlet pressure, which automatically shuts off the pump when outlet pressure of ca. 30 psi is reached. A pressure and flow transducer follows this pump, measuring flow to the filter system. The pump has a pressure reservoir, to minimize pump activity with a threshold and dead-zone calibrated for minimal energy use.

The filter system utilizes particulate 5 micron and UV sterilization treatment to assure that the water meets all local standards for potable water, though the capacity of the facility precludes the use of catchment water for potable use, so the water will be for non-potable use only.

Data from these systems are integrated by the brain with external meteorological data such as rain catchment and EtO rates for further diagnosis and monitoring. An alarm system, integral to the brain system is configured to alert personnel in the case of fault.

Sequence of Operations

Data is collected on tank level, pump line pressure, and flow rate on the head end of the fresh water pump. The following data scenarios outline possible conditions and their indications.

In each of the following cases, data is recorded constantly by the brain system, and archived for future analysis. Alarms are sounded in abnormal conditions, and persist until the alarm is cleared and the system is repaired.

System failure will produce an alert to the operator, via email, iPhone app, and finally an email/phone tree of responders. An iPhone app has been developed which will enable the operator to set and respond to alerts, as well as control the systems.

Readings	Indication
Tank level rises, weather station senses rain gauge increase, no flow	Normal tank filling
Tank level does not rise, weather station senses rain gauge increase	Leak in gutter or catchment system, blocked or leaking first flush diverter
Tank level decreasing, flow rate proportional (integrated over time by brain)	Normal operation of system
Tank level decreasing, flow rate not proportional	Tank leak
Pump outlet pressure level decreases periodically, even in off-use hours	Pump leak
Pump outlet pressure level increases over time, and/or max flow rate decreases over time	Filtration system clogged
Tank level rises, weather station reads no rain collection (may be periodic or diurnal, e.g. in morning hours, as well as seasonal)	Condensation collection

System Two: Radiant Cooling System (RCS)

Function

This is first and foremost an experimental heat transfer system, with the goal of providing cooling and dehumidification for the building without resorting to traditional HVAC systems, which are much more energy intensive. The key elements are a thermally insulated storage tank of 3000 gal. (12,000 liters) capacity, a radiant cooling array, and heat exchangers in both the study spaces (air handler) and in the monitoring lab (desktop heat exchanger system). Heat is captured by heat exchange in an air handler above the rest rooms, cooling and dehumidifying the air in the project rooms. Heat is also captured by desktop heat exchangers which capture the heat generated by laptop computers in the monitoring lab. This warmer water is then circulated to the thermally insulated holding tank, which then radiates this heat out to space (radiation) and passive air flow in the airflow augmented by the building shape (conduction). There is some evaporative heat loss in the array as well, mainly in wind-blown mist conditions prevalent at night at the energy lab site.

The entire system is controlled and monitored at two levels: the first is by a modified Steca “Delta T” unit, the second is by the brain system. The first system is adaptive to heat exchange calculations, and responds with variable pump speeds to both conserve energy and to maximize heat transfer.

The second brain system is capable of the same operations, but includes an adaptive/predictive element, integrating information from the meteorological and room sensors to seek comfort in the project rooms and efficient heat collection in the desktop heat exchanger.

Design

Three heat exchange modes are covered here:

1. Air handler heat exchange for the project rooms

2. Desktop heat exchanger for laptops in the monitoring lab

3. Radiant array

Located above the rest rooms, an air handler utilizes a low pressure flow of water over fan aided radiator elements to capture heat in the North project rooms. This heat exchange also collects condensation (humidity at the site is often above 85%), leading to a decrease in humidity, aiding in the comfort of the building. A thermostatic module measures temperature and humidity and seeks the comfort parallelogram (see references below) which is a combination of temperature and humidity factors in the closed spaces.

In the monitoring lab, a dozen laptops running at 10-30 watts each produce heat which is normally dissipated via heatsinks in the base of each laptop. A copper covered table with copper coils beneath will carry cool water from the thermal reservoir tank to collect heat from these laptops, obviating the need for traditional HVAC systems, common in most IT installations. This heat collection will be augmented by passive ventilation, and in extreme cases traditional HVAC backup system.

At the peak of the roof, on the ends beyond the passive ventilation “wing” section of the building, an array of copper tubing is exposed to the passive ventilation, augmented by the wing shape of the North roof. Heat is exchanged by three methods here:

1. Radiation to space
2. Conduction with the air flow
3. Forced evaporation of wind-borne mist

The prevalent mode of heat transfer will probably be conduction, as the temperature differential in °K is not great enough to effect efficient heat transfer, assuming a temperature to the fourth power (T^4) radiation rate. Forced evaporation will likely be prevalent in the evenings. There will be some heat gathering by the array, as it will be exposed to the sun all day long, but backflow valves will prevent a thermal siphon effect from occurring.

Flow rates will be determined by a Steca TR0603MCu unit, a second generation solar “delta T” unit modified for this purpose, with an integral triac motor control. The unit is capable of sensing temperature at the hot and cold ends of each of the three critical points (tank, Air handler, radiant array) and responding with a variable pump speed to optimize heat exchange, while preserving energy expended. Flow rate is also measured and allows for setpoint and deadzone settings. Data from parallel sensors at each location, as well as the desktop heat exchanger are integrated into the brain system for logging and supplementary activation of pumps and/or fans.

The system includes two pumps: the first carries water from the thermal reservoir to the radiant array, the second carries water from the thermal reservoir to the air handler and desktop heat exchanger location.

Flow at the heat exchangers (air and desktop) are parallel, and can be valved for all/none operation. In cases where the project rooms do not need cooling, the air handler fan will not be activated, and there will be only minimal heat exchange at the air handler (it will reach stasis with the surrounding air) and heat exchange will continue for the desktop heat exchanger.

A digital thermal sensor located in the project rooms will integrate information from temperature and humidity sensors in the room, seeking the comfort curve.

A similar digital thermal sensor on the roof array will report data to the brain for system recording and optimization.

A third digital thermal sensor unit will report and record temperature and flow data for both pumps and the thermal reservoir.

Sequence of Operations

Data is collected on reservoir tank level, hot and cold temperature, flow rate on the head end of each recirculating pump, array hot and cold temperature, air handler hot and cold temperature, room temperature and humidity, and desktop heat exchanger hot and cold temperature. The following data scenarios outline possible conditions, and the response of the system.

In each of the following cases, data is recorded constantly by the brain system, and archived for future analysis. Alarms are sounded in abnormal conditions, and persist until the alarm is cleared and the system is repaired.

Extreme cases (weather or occupancy) may produce an alert to the operator for intervention. System failure will also produce an alert to the operator, via email, iPhone app, and finally an email/phone tree of responders. An iPhone app has been developed which will enable the operator to set and respond to alerts, as well as control the systems involved.

System input	System response
Tank hot temperature exceeds array cool temperature by >10° F (4°C)	Activate radiant cooling pump, optimize to effect maximum heat exchange with least pump energy
Desktop heat exchanger hot temp exceeds tank cool temp by >10°F (4°C)	Activate heat exchange pump, optimize to effect maximum heat exchange with least pump energy
Project room temperature exceeds tank cool temp by >10°F (4°C)	Activate heat exchange pump, optimize to effect maximum heat exchange with least pump energy, activate air handler fan with speed optimized to conserve energy and reduce noise.
Project room temperature exceeds tank cool temp by >10°F (4°C) and/or humidity/temperature calculus indicates outside comfort zone	Activate heat exchange pump, optimize to effect maximum heat exchange with least pump energy, activate air handler fan with speed optimized to conserve energy and reduce noise.
Temperature at head end of either pump is higher than cool temperature of tank	Pump overheating
Temperature at head end of either pump is cooler than cool tank temperature	Defective backflow valve, thermosiphon
Weather data indicates decreasing wind speed, increasing humidity	Activate heat exchange pump, optimize to effect maximum heat exchange with least pump energy, activate air handler fan with speed optimized to conserve energy and reduce noise.
Radiant cooling array temperature differential increases along with weather station precipitation increase	Rain augmented evaporative cooling, analysis by brain system to measure efficacy
Radiant cooling array temperature differential increases along with weather station decrease in dew point	Condensation cooling, analysis by brain system to measure efficacy

System input	System response
Radiant cooling array temperature differential increases along with weather station rapid air temperature decrease (cloudless nights)	Radiation cooling, analysis by brain system to measure efficacy
Decrease in tank level	Tank or system leak
Gradual increase in pump back pressure	System obstruction, defective valves
Differential in Steca unit temperature output vs. secondary temperature readings by brain	Defective thermistors
Decrease in Air handler temperature differential over time	Clogged air flow, defective fan

System three: Passive Ventilation System (PVS)

Function

The Energy Lab is situated in a location with average prevailing winds of 21 mph (10 m/s), and as such was designed to utilize this natural flow into the passive ventilation of the facility. The roof is in an arching wing shape, with convective spaces feeding a clerestory space, providing ventilation even on days with little or no wind. There are several control surfaces in this system:

1. Incoming air via North (windward) louvers mounted horizontally beneath the water catchment surface of the roof
2. Exhaust air via electrically controlled louvers at the top of the wing shaped roof
3. Exhaust air via electrically controlled windows on the south (leeward) facing walls

In all of our design processes, comfort and quiet were our two main concerns. This encompasses several factors:

1. Ambient temperature
2. Ambient humidity
3. Carbon Dioxide levels (also covered in section 7, air quality system)
4. Air flow

The effect of excessive ventilation was also a consideration, with indoor breezes not conducive to productive work inside.

Design

The wing shape of the windward roof also channels air admitted into the windward louvers along the internal ceiling and walls, minimizing this disruptive internal air flow, while maintaining sufficient air flow to enhance comfort factors listed above.

The Passive Ventilation System (PVS) is designed to preclude the need for the Forced Ventilation System (FVS) and HVAC systems (HVAC) to conserve energy.

Controls for these surfaces is first manual, in the case of the windward louvers/vents, this is direct manual. In the case of the leeward louvers and windows, this is done electrically (due to the high location in each room) with a manual wall switch for each bank of surfaces.

Air flow will be monitored in larger spaces by hot wire anemometers located high in the plenum spaces. In the smaller rooms, ventilation will be monitored by CO_2 levels in each closed space.

As mentioned before, we will seek the comfort zone determined by ASRAE as a combination of temperature and humidity, with ventilation controlled to maximize this as well.

In cooler conditions, the passive ventilation system will be used to control the loss of room heat, by opening windows rather than the higher louvers, where heat naturally convects. In the case of HVAC operation, windows and louvers will be closed automatically, to conserve energy.

In the case of rain, external meteorological sensors as well as simple contact closures will activate window and leeward surface closure.

In non-prevailing wind conditions, the source/sink profile is reversed, in which case convective flow will be reduced. In these cases, the upper South facing louvers will become the inlets, and will force exhaust air out the North facing louvers in the closed spaces. This will affect a more efficient CO_2 turnover, as the denser gas will be closer to the venting surfaces. In extreme cases, where passive ventilation is either disruptive or ineffective, all windows will be closed and the HVAC system will be engaged.

The passive ventilation system is controlled at three levels:

1. Manual control (either direct or via wall switch and bank of actuator motors)

2. Automatic thermostatic control

3. Brain system carbon dioxide, temperature, humidity and airflow calculus

The first of these systems retains human control over the surfaces: open or closed can still be controlled by users in the spaces.

The second system is direct and simple, based on thermostatic sensors in each closed space, activating the windows. This assumes that the manually operated louvers on the windward side of the building are opened to some extent.

The third system integrates input from environmental sensors inside each space as well as data from the meteorological sensors outside to maintain a target comfort zone. This has an adaptive/predictive aspect as well, e.g. the system can predict that weather is trending one direction or another, and control surfaces accordingly. This could be as simple as a wind change (speed or direction) or as complex as a falling barometer (cooler weather ahead). This integration will be complex and has a “training” aspect, so that the building should become more comfortable the more it is occupied.

Finally, all louvers have interlocks that shut off the HVAC system when opened to conserve energy.

Sequence of operations

Data is collected by sensors in each space, as well as external to the building by the meteorological monitoring system. Control surfaces include the North facing (windward) louvers, and South facing exhaust louvers and windows. Control of the leeward surfaces is via electrical window actuator motors, on the windward side by manual louvers. In each case below, it is assumed that the occupants will open the manual louvers to aid ventilation and close them when ventilation is excessive, or the room is chilled.

The activation of the louvers in each bank of 4-5 surfaces can be either binary (open or closed) or floating point (partially open or closed). This is determined by the brain system, and can be overridden by manual control at all times.

In all cases, data from each system input is logged by the brain system, for use in training the system as well as analysis by student/occupants and the system operator.

Extreme cases (weather or occupancy) may produce an alert to the operator for intervention. System failure will also produce an alert to the operator, via email, iPhone app, and finally an email/phone tree of responders. An iPhone app has been developed which will enable the operator to set and respond to alerts, as well as control the surfaces.

System input	System reponse
Temp, CO2, humidity within bounds, windows open	Normal situation, occupied mode
Temp, CO2, humidity above setpoints, air flow low	Open louvers first (convection aided) then windows
Air flow excessive, temp or CO2 below setpoint	Close windows first, then louvers
External meteorological data indicates increasing temp, normal wind direction	Open louvers first (convection aided) then windows, signal operator to make sure windward surfaces are open
External meteorological data indicates decreasing temp, normal wind direction	Close louvers to retain heat, decrease convection, monitor, if no change, then close windows as well.
External meteorological data indicates change in wind direction	Signal operator, open louvers first, then windows, adjust as needed to maintain comfort zone
External meteorological data indicates impending/current precipitation	Close or partially close louvers first, then windows, alert operator

System input	System reponse
System timers indicate night time, no occupancy	Close windows, close louvers to 10% open
System timer indicates night time, operator signals astronomy users in bldg (South facing deck)	Close all windows and louvers, vent warm building air via leeward shop-front doors to users on deck
CO2 level below setpoint, air flow normal	Alert operator, defective CO2 sensor
Air flow readings constant over time, despite variations	Alert operator, defective air flow sensor
Temp/humidity readings constant over time, despite variations	Alert operator, defective temp/ humidity sensor
Air flow high/low despite window/louvers closed/open	Alert operator, broken control or control surface
Inability to control system	Alert operator, possible intervention needed on manual vents, North side (windward)

System Four: Forced Ventilation System (FCS)

Function

The building has four variable speed, constant direction 1600 cubic feet per minute fans located at the ends of the hallways on both the east and west sides of the building. Prevailing winds are from the North East ("Trade" winds), and follow the contour of the building (see plan view) to maintain positive pressure on the East side of the building most of the time. Seasonal South West winds ("Kona" winds) reverse this flow.

Since the exhaust fans are constant direction and are located in the hallways, they influence air flow mainly in the larger spaces, unless the doors and windows on the South side of the closed rooms are opened, in which case they will produce a flow through these rooms of approximately 8 air changes per hour. This flow will usually be a draw (e.g. out the doors), aiding the trade wind flow.

Additional fans are located in the restrooms (600 cfm each), in the electrical inverter room (3000 cfm) and the janitor closet (120 cfm), but these are locally controlled (presence or thermostatic) and not part of the building automation system.

Design

The fans can be operated singly or in banked mode, either north bank (EF-3 and EF-4) and south bank (EF-5 and EF-6) or east bank (EF-4 and EF-6) and west bank (EF-3 and EF-5). Since the fans are set to exhaust only, they will be configured to augment natural external air flow, which is detected by the meteorological monitoring system.

The Forced Ventilation System (FVS) is designed to augment the Passive Ventilation System (PVS), and preclude the need for the HVAC system (HVAC) to conserve energy.

Internal sensors include temperature, humidity, CO2 and airflow sensors in all plenum spaces, along with the room air quality sensors mentioned above, and covered below in the air quality system section.

Three levels of control are enabled on the forced ventilation system:

1. Manual control, via wall switch, on/off mode
2. Local thermostatic control, on/off mode
3. Brain sytem, variable speed

The first enables users to activate the fans singly from a set of wall switches below each fan pair on the west end of each hallway.

The second is activated by thermal sensors located in the plenum spaces, where heat naturally flows via convection. It is assumed that the window system will activate first, as it receives data from these same temperature sensors.

The third system is more complex: integrating internal data (temperature, humidity, CO2 and air flow) with external meteorological data (e.g. wind speed and direction) the system brain activates banks of fans, usually in an east or west configuration (see above) to augment the north east trade winds or the south west Kona winds.

Sequence of operations

It is assumed that this Forced Ventilation System works in concert with the passive system, sharing data from similar or co-located sensors.

System input	System response
Temperature, humidity, CO2, air flow all within limits	Normal conditions, no fan operation
Temperature in plenum space beyond extreme setpoints	Local thermostatic control system activated adjacent to each fan
Temperature in plenum space beyond setpoints, over time	Brain system engages to override defective thermostatic activation
Temperature in plenum space beyond sensitive setpoints	Brain system engages with variable speed to maintain comfort zone, conserving energy, activates in banks, determined by meteorological data
Airflow in plenum spaces above setpoints	Brain system engages to close clerestory surfaces, then alarms operator, no fan operation
Airflow in plenum spaces low, despite activation	Alert operator, defective controls
Recurrent thermostatic activation	Alert operator, defective sensors or brain integration

System five: Heating, Ventilation and Air Conditioning System (HVAC)

Function

With the overall goal of reducing energy use and environmental impact while promoting a comfortable, quiet working space, the Building Automation System (BAS) is designed to optimize non HVAC methods for atmospheric control in the building first. In cases where these systems are inadequate, an extremely efficient, dual mode HVAC can be employed. This Sanyo ECO-i system is controlled by vendor specific control systems, with two interfaces to the BAS, the first through a BACnet converter interface, the second through physical interrupts in parallel to traditional thermostats. These are then controlled by the BAS via web and XML interface. Wall mounted controls for the HVAC system are clustered with BAS environmental monitors (temperature, humidity and CO2) for monitoring and system optimization.

Design

The system is designed to provide cooling, dehumidification and heating for the closed spaces on the north wing of the building. Interlocks in the doors and windows ensure that the HVAC system is not working in an open system. CO2 monitors as part of both the BAS system and the vendor specific sensor suite monitor CO2 levels, and activate outside air blowers (OSA) to forcibly ventilate the rooms when needed. Setpoints for these CO2 sensors is set to 800 ppm, above the threshold of the BAS sensor system (600 ppm) to provide an escalating alarm and monitoring system. All data is recorded by the BAS for further tuning of the system to maximize comfort while minimizing energy use.

Air handlers in each of the closed north wing rooms operate either as wall units or concealed units, with two, four ton AC compressors located north of the building. The design of the system included specifications for refrigerant leakage, control interface access, and use as a heat pump in winter conditions.

The system is also configured to heat and cool in zones, to minimize wasting HVAC resources on unoccupied rooms.

Sequence of operations

The HVAC system operates following vendor designed activation criteria including temperature, humidity and CO2 levels. These are monitored and augmented by the Building Automation System, to provide data on optimizing the use of the HVAC system while minimizing energy expenditures.

The brain will also monitor the overshoot of the HVAC system, to decrease hysteresis in the system, again with the goal of decreasing unneeded energy use.

System input	System response
Temperature, humidity, CO2, air flow all within limits	Normal conditions, no HVAC operation
Temperature in closed spaces beyond extreme setpoints, on individual thermostats	Local thermostatic control system activated, controlling each room/zone air handler

System input	System response
Temperature in room spaces beyond setpoints, over time	Brain system engages to override defective thermostatic activation
CO_2 in closed spaces beyond sensitive setpoints	Brain system engages outside air blowers, alerts users and operator
Carbon dioxide and/or temperature in closed spaces beyond sensitive setpoints over time	Brain system alerts user to system fault and/or design failure in HVAC system
Temperature control in closed spaces defective, despite activation (overshoot, undershoot, hysteresis)	Alert operator, defective controls
Recurrent thermostatic activation	Alert operator, defective sensors or brain integration

System Six: Energy Monitoring and Control System (EMS)

Function

Power for the building is provided by two renewable energy sources: wind power delivered by a 5 kW vertical axis helical wind turbine, and three discrete arrays of photovoltaic panels providing 23 kW of PV power. These systems are grid-tied, using the local power utility grid as a "battery" of sorts. These systems are augmented by a hybrid battery backup system, that is charged via the mains and/or renewable sources in situ, providing uninterrupted power to the monitoring and control systems, computers and data loggers installed in the building. The capacity of this backup system is designed to withstand at least 8 hours of continuous use unattended, with alarms and a phone tree activated in case of failure. A secondary UPS system is located adjacent to the central brain unit, the most critical logging and control device in the building, to provide data integrity and prevent loss or damage to the programs running the building.

The PV array is a hybrid system as well, with three discrete panel types:

1. North array: PV with inverters built-in
2. Central array: Standard 210 watt PV panels
3. South array: Sanyo bifacial PV panels, providing light below and absorbing light in both directions (up and down)

Each of these inverter systems is located in the inverter room, at the basement level on the West side of the building, under the workshop, with fire proof walls, doors, and a thermostatically activated ventilation system that closes in case of fire.

The control aspect of the EMS is designed to minimize energy loss due to vampire or passive loads, such as wall mounted charging units and instant-on video devices. Any device with volatile memory settings, such as channels on a TV or video teleconferencing settings will not be included in these control schemes.

The control system will have the ability to shut down certain circuits in the building at certain times, e.g. night time, with manual and scheduled overrides possible, for example if night astronomy users need to charge their laptops or other devices. Monitoring if each circuit will precede any shutdown, with alarms in cases where chronic vampire loads are detected, for intervention by the operator. Building Automation Systems, environmental controls and other systems included in this document will be on protected circuits, but will be monitored to isolate and diagnose system faults, or inefficient energy use by the building users.

There are three circuit designations in the building: critical (e.g. system brain, alarms, video monitoring, data gathering, sensors, and window/louver actuators), non-critical (e.g. fans, video presentation equipment, student workstations, HVAC system) and vampire loads (e.g. always on charging units, computer “brick” chargers, other passive loads.

Emergency exit lights are self contained units, requiring no power from the building.

In the event of a power utility outage, a phased alarm and shutdown process is activated: For short term outages, the battery system (which is always on) continues to run critical systems, and non-essential systems are shut down. For example, the windows and louvers would still operate, but the fans and HVAC system would not. In the event of a long term shutdown, some critical systems may be shutdown manually, and in the extreme case of a power failure and battery/inverter system failure, a local UPS unit and surge protector would provide power for the brain and data logging/backup systems, to ensure data integrity. These could be termed “super-critical” systems.

Design

Three sets of inverters are incorporated into the EMS profile:

1. 5 kW wind turbine: inverter located adjacent to the turbine, in the field
2. 23 kW PV array: either local to the source or in the inverter room.
3. Battery backup (UPS) system, located in the inverter room.

As heat is produced by any inverter system, the BAS will monitor temperature levels both ambient and attached to each inverter system for monitoring, alarm and diagnosis. Each system will incorporate vendor specific monitoring software and hardware, which is augmented by sensors for temperature, power in and power out by the BAS.

Long term trends will allow the operator to modify or tune the system for maximum efficiency, while minimizing damage to the systems.

The least reliable element in the system is the local power utility, with frequent outages, power spikes, frequency and voltage variations and in some cases, outages of over several hours’ duration. This may cause some shutdown of the renewable energy system inverters, as these must shutdown power if the local utility fails for safety reasons.

When operating at peak output (a sunny, windy day), the renewable energy system could provide up to 10% of the energy used by the campus, and should always offset the power used by the building, when averaged over a monthly or annual basis.

Energy use calculations for the building project a 37 kWh per day energy use, which should be offset by 23 kW of solar panels gathering light for an average of 5.5 hours per day (at this location) and 5 kW of wind power with an 80% Weibull distribution and average wind speed of 21.7 mph (10 meters per second).

Data from the meteorological monitoring system (MMS) will record solar radiation and wind speeds for comparison with power produced by each renewable energy system, for optimization and detection of system failure. In such a critical system, even a small percentage drop in efficiency (perhaps dirty PV panels) will have a large impact on the efficiency of the building.

Energy control system will include current transformer sensors on all circuits, with series control relays on controlled circuits, controlled via XML and web by the brain.

Sequence of operations

Three main energy production metrics will be measured by the energy monitoring system:

1. System power production

2. Available environmental energy (solar insolation, wind speed and direction)

3. Local environmental factors (inverter temperature, panel temperature, turbine temperature)

These will all be monitored and recorded by the BAS, as well as statistics on local power utility production, for fault diagnosis, preventive maintenance, and predictive optimization (e.g. low wind periods will force increased reliance on PV system, so panels should be cleaned more often, or high winds may increase PV panel dust, again requiring more frequent cleaning).

Smaller experimental systems in the field will be compared with both wind and PV systems to determine if relocation or repositioning is needed for either renewable energy system (e.g. tilting the PV panels to a new angle or relocating the wind turbine).

System input	System response
Inverter temperatures, power levels all within limits	Normal conditions, system data recorded and archived for later analysis and diagnosis
Inverter temperatures above setpoints	Local thermostatic fan control system activated, brain system alarms operator, manual inspection of units required to clear alarm, video recording activated
Inverter temperatures below setpoints, power below setpoints, acute case	Brain system engages to alarm operator, either defective inverters, energy systems or sensors
Inverter temperatures below setpoints, power below setpoints, (chronic case) or trend detected by brain	Energy system or inverter system maintenance required (e.g. turbine blade/bearing binding, PV panels dirty)
Vampire loads detected on branch circuit, or scheduled branch circuit shutdown	Brain system engages to shutoff branch circuit
Wind power system vs. meteorological monitoring system data collection factor decreases	Energy system or inverter system maintenance required (e.g. turbine blade/bearing binding)
PV power system vs. meteorological monitoring system data collection factor decreases	Energy system or inverter system maintenance required (e.g. dirty/defective PV panels)
Power utility failure, short term (e.g. less than 2 hours)	Inverters go offline per utility rules, alarm operator, phone tree activated, response required to silence alarm, battery bank runs inverter for critical systems for up to 6 hours
Power utility failure, long term (e.g. more than 2 hours)	Secondary operator alarm goes out, non-essential systems shutdown to preserve battery life, if daytime, PV array with inverters charges battery bank, if night, generator backup kicks in when battery life is less than 20%

Summary

References

System

Function

Design

Sequence of operations

templates:

System

Function

Design

Sequence of operations