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

Ten 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)

10. Lighting control system (LCS)

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 several times each second. Data from this sensor is relayed via 4-20 mA then 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 caused by leak, low pressure or low tank level.

A visual indicator of tank level will be located in the water pump area, with three color indicators: green for >50% water level, yellow for >20% level, and red for levels below 20%. The tank is filled with municipal water upon commissioning, and thereafter from the water harvesting system.

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

Readings	Indication
Tank level is extreme low, dry conditions exempt from sustainability requirements	Requires manual fill from municipal water supply

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 2500 gal. (10,000 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 and copper sheeting 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 and a night time space radiation temperature of 4°K. Forced evaporation will likely be prevalent in the evenings, when local wind blown mist is prevalent in tradewind conditions. 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. An integral temperature/pressure valve on the array will allow for steam blow off, should the panel boil the coolant in the daytime.

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 (storage tank, air handler unit, 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 set-point and dead-zone 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 STECA unit includes a serial RS-232 interface that is routed by way of a Lantronix EDS8PR serial to ethernet interface to a monitor/control computer in the monitoring lab.

This system is augmented for redundancy by a parallel sensor and control system with both web (html and XML) and brain interfaces. Digital thermal sensors located at the dissipation array, storage tank and heat collection fan coil unit (AHU) collect data on RCS array temperature (in and out), tank temperature (top/warm and bottom/cool) and AHU (in and out water temp, in/out air temp). Each location has an integral DAQ unit to collect these data, which is relayed to the brain system by cat5 cable. Each DAQ unit is capable of relay action, coupled with SSR relays to control the circulation pumps (GF-2 and GF-3) as well as the fan coil unit (FCU) in the air handler unit (AHU) above the bathrooms. The FCU is actuated when either ambient temperature exceeds a setpoint above coolant temperature, or the brain system calculates there is a sufficient temperature differential to produce effective cooling in the closed spaces.

A second low flow system will be used to cool the monitoring lab computers, by way of copper heat exchangers. This will be a low pressure, low flow system actuated by similar DAQ units (X-300) with included digital temperature sensors and an internal thermostat, which is also integrated into the brain system.

It is possible that the roof array circulation pumps could be activated in daytime, should the heat collected by the AHU and low pressure computer coolant system bring the tank temperature to above the ambient temperature of the array. This would likely happen in cloudy conditions, as the array will be exposed to ambient light, acting as a solar collector instead of a radiator as intended.

Each evening when the ambient temperature drops, array thermometers will assure that the coolant temperature in the roof array is below tank temperature before actuating the array circulation pumps, as there may be residual hot water in the array which should be dissipated before effective cooling can begin.

A visual indicator of tank level will be located in the water pump area, with three color indicators: green for >50% water level, yellow for >20% level, and red for levels below 20%. The tank is filled with municipal water upon commissioning, and thereafter from the water harvesting system as needed to retain tank level.

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, array high temperature blow-off
Gradual increase in pump back pressure, or pump on with no flow recorded	System obstruction, defective valves, coolant leak
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
Visual indicator for tank level yellow or red	Fill tank, via FCS water system (hose bib to fill port)

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, and in reverse (e.g. South west, “Kona”) wind conditions via windows and louvers mounted under the eaves above each corridor.

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 at lines C and E.

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.

All window intakes will be screened, and in the monitoring lab, these screens will be augmented with a filtering system, to prevent dust damage to the monitoring lab systems.

Design

The wing shape of the windward roof also channels air admitted into the horizontal 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 minimize 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, enabling either full open or full closed operation.

There are two relay actuated modes possible by the brain system: full open/closed mode, or floating point mode, where the system can open or close the surfaces partially by executing a pulsed signal. Since the opening time of the actuators is known (170 seconds), pulses can be delivered at any fraction of the total to effect partial opening or closing of the 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 horizontal louvers in the closed spaces. This will affect a more efficient CO_2 turnover, as the denser gas will be closer to the lower 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

System input	System reponse
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 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

System input	System response
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.

The system is designed to run in two modes: heat pump and air conditioner for heating or cooling, and can be activated in separate zones, to minimize the cooling of unoccupied rooms.

The system brain will monitor three metrics external to the BAC interface included with the Sanyo ECO-i unit: air temperature, coolant temperature (in and out) and electrical use (via current transformers). These data will be integrated to optimize system efficiency, and allow for predictive/adaptive control beyond the scope of the vendor supplied BAC unit.

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
Temperature in room spaces beyond setpoints, over time	Brain system engages to override defective thermostatic activation
CO2 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: 10 kW PV with built-in inverters, 48 volt bus
2. Central array: 12.6 kW PV, standard 220 watt PV panels, feeding 2 x 6 kW SMA inverters
3. South array: 4 kW by 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.

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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, 3.6 kW 48 Volts

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 (e.g. 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, wind turbine charges battery bank. If/when battery bank fails, external generator backup kicks in when battery life is less than 20%. Upon severe failure, staged computer shutdowns via local UPS USB control interfaces to preserve data integrity.

System Seven: Air Quality Monitoring System (AQS)

Function

The goal of the AQS system is to monitor and control air quality in all closed spaces. The building is divided into three zones, following an educational workflow as follows: collaboration, design and construction. For this reason, the North collaboration zone is made up of smaller rooms that can be closed off, have access to the HVAC system resources and also have the best access to the augmented airflow created by the wing design of the North roof of the building.

The middle (central) zone of the building is a large plenum space with operable sliding glass doors as well as louvers and windows in the clerestory areas, to promote convective air exchange.

The South zone is a construction zone, again open at ground level with operable sliding glass doors as well as windows and louvers.

There is a storage space/garage below this zone, in the basement level, which may have occupancy on a transient basis.

The main function of the AQS is to monitor and control air quality in all occupied spaces. Measured metrics include CO2, airflow, temperature and humidity. Established criteria are provided by ASHRAE et. al. regarding minimum air changes per hour in all closed spaces. The minimum air change per hour value in each space should be above 8 ACH, estimated by measurement of CO2 levels at 4 ft. AFF (above floor level) in all occupied spaces. Sensor clusters of CO2, temperature and humidity will be located in all occupied spaces, and data from these clusters will be recorded and logged by the system brain every 5 minutes, 24 hours each day, 7 days per week. This will enable adaptive/predictive optimization of the BAS system, to minimize energy expenditure while ensuring optimal comfort and safety for the occupants. Atmospheric monitoring will be augmented by occupancy sensors, via either infrared motion detectors in the closed spaces or video monitoring with visual field motion detection in the larger spaces and garage (AXIS camera control system). The system operator will use the BAS to seek a parametric relationship between occupancy, CO2 levels and meteorological data, again to optimize comfort and to develop predictive schemes, e.g. opening windows when occupants arrive, closing a certain period after they vacate the spaces. These will necessarily include factors such as room size and location in the building, and should enable future building scenarios to use this optimization information as well.

Each room will have a visual indicator of CO2 level in the monitoring lab, for one-look status checks of CO2 levels. These indicators will move from green (under 600 ppm CO2) to yellow (600-800 ppm CO2) and red (above 800 ppm CO2). These levels are lower than the previous ASHRAE levels, as recent research has indicated links between CO2 level and learning, as well as recent GBC data suggesting that the present standard is applicable to adults, not K-12 students as our building is designed to accommodate.

A web interface for each room will enable local monitoring via wall monitors in some spaces, as well as remote monitoring parallel to the brain system. External CO2 sensors will record ambient levels for comparison, and to establish relative and absolute levels for system optimization.

The second function of the AQS will be to optimize the temperature/humidity conditions to seek the “comfort zone” near 10% absolute humidity (AH) and 72° F (25°C). This may involve a combination of dehumidification and warming/cooling, as ambient conditions usually hover around 40% AH and 65-85°F (18-30°C). Two means will be used to effect these changes, the first is the radiant cooling system mentioned above, which will offer some cooling and dehumidification. The second is the much more energy intensive HVAC system. Hybrid Calcium Chloride dehumidification systems may be tested by the occupants, but the main comfort control systems will necessarily be active, energy consuming devices.

CO2 detection and purge is accomplished by dual, redundant systems: The first is the brain system, gathering data from local environmental sensor clusters (CO2, temperature and humidity). These have low set-points around 600 ppm CO2 (ambient at the energy lab location is about 420 ppm CO2), with local alarm and operator notification. The system response will be to open louvers first, as their airflow is augmented by the building airfoil design. The second system response will be to open windows in the spaces. In each case, it will be assumed that a local alarm will engage the local room occupants to open the manual air inlets: louvers at the North end of the North zone, or doors at the East and west of the middle zone, south edge of the South zone.

If the CO2 level exceeds 600 ppm, and action by the system is ineffective, a second tier of action by the BAS includes a secondary alarm by the BAS, indicating system failure or over capacity occupancy.

As the level reaches 800 ppm CO2, a forced ventilation system in the North wing is activated, bringing in outside air (OSA) to clear the spaces. Since these are direct and pressure driven, even if all surfaces are closed, it is hoped that enough leakage will occur to effect air changes and drop the ambient CO2 levels to within acceptable limits.

Design

Sensor clusters composed of CO2, temperature and humidity sensors will report every few seconds to the brain unit, which will log these data every 5 minutes to the system log archive for later analysis and system optimization.

Control actuators are capable of opening or closing the operable louvers at the highest point in each space, and above the clerestory, as well as operable windows below these louvers. A forced air system including four fans at the ends of each hallway are capable of forcibly evacuating air, should passive means be inadequate. A secondary forced air system is part of the HVAC system, pushing outside air (OSA) into the building, to be vented by the systems above.

Sequence of operations

When the system detects CO2 levels above limits, a phased alarm is activated:

1. 600 ppm CO2 detected: local room alarm, alarm operator, open louvers
2. 700 ppm CO2 detected: secondary alarm to operator, open windows
3. 800 ppm CO2 detected: forced ventilation of outside air (OSA) via HVAC system elements.

The first two actions involve the brain system, with the second set of sensors and actuators completely separate from the first system for redundancy.

System input	System response
CO2 levels all within limits	Normal conditions, system data recorded and archived for later analysis and diagnosis
600 ppm CO2 detected	Local room alarm, alarm operator, open louvers
700 ppm CO2 detected	Secondary alarm to operator, open windows
800 ppm CO2 detected	Forced exhaust ventilation of outside air (OSA) via hallway fans, activated to augment natural wind as measured by meteorological monitoring system
1000 ppm CO2 detected	Forced inlet of air via OSA fans as part of HVAC system
>1000 ppm CO2 detected	Alarm system operator, system failure, occupancy issues
Low CO2 levels, combined with high meterological monitoring data on wind speed	Louvers and/or windows adjusted to close, BAS sends message to close North facing louvers (inlets), monitoring lab louvers first.
Low CO2 levels, combined with low ambient room temperatures, below comfort curve.	Louvers closed, windows adjusted to provide adequate ventilation while reducing convective heat loss from rooms, BAS will notify users to close windward windows.
Smoke detected, alarms integrated into lighting control system (LCS)	Alarm system operator, authorities, enable remote ventilation closure as soon as occupants are evacuated.

System Eight: Meteorological Monitoring System (MMS)

Function

The primary role of the MMS is to measure external meteorological data to aid in the ventilation of the building. The secondary function is as a metering component of the Freshwater Catchment System (FCS). The tertiary function is to monitor wind and solar energy available for collection by the various energy systems, including the dissipation of heat by the radiant cooling system (RCS). Finally, the system aids in the prediction and adaptation of the building internal environmental systems, enabling modeling to achieve maximum comfort for occupants with the smallest expenditures of energy.

Design

The main element of the MMS is the weather station, a Weatherhawk unit with no moving parts, capable of accurate measurement of wind speed, direction, and precipitation, as well as barometric pressure, solar radiation, ETo, dew point and humidity.

The first tier of these measurements is used by the air quality system to determine optimum ventilation for the building by passive and augmented methods. It is also used to close the window and louver surfaces in case of rain. Once the system operates for several months, predictive functions of the barometric pressure sensors will enable the system to be proactive instead of reactive to changes in the weather. This will be done by a combination of trend analysis by the system in conjunction with standard weather prediction software.

Wind and solar radiation data will be used to determine system operating efficiency for the Energy Monitoring and Control System (EMS), as described earlier.

Solar radiation and temperature values will be combined with sensors on the Radiant Cooling System to activate the RCS flow pumps, and will provide a more granular data analysis and prediction of flow pump speed, to optimize heat transfer.

Ambient humidity will be combined with internal room sensors to monitor trends in RH, in order to proactively activate systems such as the ventilation and RCS to decrease humidity. With the external environment as a baseline, system efficiency can be determined, and then compared with energy expended to maintain internal comfort conditions, for further optimization of the system.

Rain data will be compared with tank levels and flow rates in the Freshwater Collection System (FCS) to monitor and determine system water harvesting efficiency, as well as detecting system faults.

Since the Weatherhawk rain gauge detects rain using an acoustic sensor, it will be compared with a standard bucket tipping gauge (Davis Vantage Pro2 weather station) for mist collection data, which is not usually detected by acoustical sensors.

A redundant wind and solar detection suite will also be part of the Vantage system, for comparison of the two systems, and to provide system robustness in the case of unit failure.

Data from both systems will be monitored and recorded by the system brain, as well as exported as SQL data for future analysis and realtime system response.

A VOG (volcanic fog) detection system is capable of monitoring ambient VOG levels. In closed spaces the effects of VOG can be mitigated to some extent by condensation of the aerosols (mainly volcanic ash and sulfuric acid). This condensation can be effected by either the HVAC system, the RCS system, or by portable dehumidifier units in the closed spaces.

Sequence of operations

System input	System response
MMS system detects rain	Augmenting rain sensors on louver surfaces, louvers and windows are closed.
MMS system detects rain in Kona conditions (southwest winds, counter to normal tradewind flow)	System alarms operator, secondary closures may be necessary
Rain detected, freshwater catchment system level static	Alarm operator, water harvesting system leak (e.g. gutter leak)
Mist detected, no rain detected by acoustic sensor, tank level increases	Evening/wind blown mist conditions, normal. Record for prediction of water gathering capacity vs. water use
Solar radiation levels low, external temperatures low	Night operation: activate radiant cooling system
Solar radiation levels high, wind levels low	Open louvers in unoccupied rooms to pre-ventilate for possible use. Coordinate with room sensors for temp control. (CO2 may be at ambient levels)
Solar radiation levels high, wind levels low, Tradewind direction (northeast)	Augment passive ventilation with exhaust fans EF-3 and EF-5
Solar radiation levels high, wind levels low, Kona direction (southwest)	Augment passive ventilation with exhaust fans EF-4 and EF-6
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 or current precipitation	Close or partially close louvers first, then windows, alert operator
Solar radiation levels high, Energy Monitoring Control System (EMS) detects low/no energy collection	Alert operator, system failure or system down for maintenance. If power is still delivered by panels with integrated inverters, then larger inverters may be failing. If low value, then integrated inverters may be in failure mode.

System input	System response
Wind levels high, EMS detects low energy collection from wind turbine.	Alert Operator, system failure or system down for maintenance. If power is still delivered by field turbines, then turbine failure. If visual inspection shows no turbine failure, then inverter failure.
VOG monitoring system detects high VOG levels	Alert operator, reduce external ventilation in closed spaces, activate HVAC system and/or manual dehumidifiers to condense VOG particles

System Nine: Solar Thermal Systems

Function

Two solar thermal collection arrays are part of the energy lab. The first is a passive Solahart collection unit with integral storage tank located on the middle roof, towards the East side of the roof. The second system is an array of passive and active panels South of the building used mainly for research and development.

The role of the first Solahart collector is to collect and store hot water for lab and bathroom use. Since it is passive, it requires no additional circulation power from the lab, as water circulation to and from the pump is provided by the Freshwater Catchment System (FCS). This unit has a dual role of research and building infrastructure, and will be integrated into the BAS brain unit for monitoring and evaluation of system efficiency.

The second array is a passive/active system, and serves a dual role of infrastructure for the campus, exporting thermal energy much in the same way that the Energy Monitoring and Control System (EMS) exports electrical power. This array will also enable students to evaluate passive and active solar thermal panels constructed as part of the educational mission of the lab, for evaluation by the BAS brain system.

Design

The Solahart passive rooftop array will be fed by pressurized water from the FCS freshwater system, with a pressure storage reservoir located upstream from the water filter assembly. Local water circulation is by convection, as the tank is located at the top of the small 4 x 8 foot array. The array size is capable of collecting 2 kW of solar thermal energy at noon on a typical day, which should keep the 20 gallon tank at peak temperature, depending on infrastructure use.

The external array will be composed of 30-60 solar thermal panels 100 ft. south of the building, with local convective heat transfer, as well as local integrated tank storage. A well insulated pipe well will carry the hot water on demand to the dorms, some 150 ft. to the southwest. An external connection will enable students to quantify energy collection efficiency in panels of their own design and creation, and compare these data with commercial units such as the Solahart.

Sequence of operations

System input	System response
Passive array temperature at nominal setpoint levels	Normal conditions, system data recorded and archived for later analysis and diagnosis
High heat values detected at array, out of set-point range.	Possible system leak, over-temp, alert system operator
Passive array above setpoint temperatures, acute condition	Alert System operator, possible overheating scenario
Passive array above setpoint temperatures, chronic condition	Alert system operator, possible system fault
Passive array below setpoint temperatures, MMS system detects ambient sunlight, acute condition, timer near noon	Alert system operator, possible system fault, design under capacity.
Calendar function predicts chronic low occupancy (e.g. vacation)	No action, passive system halts when system reaches max temp.
Water flow meters detect flow, temperature sensors on array detect warm water	Defective backflow valve to solar thermal array
Diffferential values between water in/out of array dropping below set-points	Alert system operator, possible system fault

System Ten: Lighting Automation System

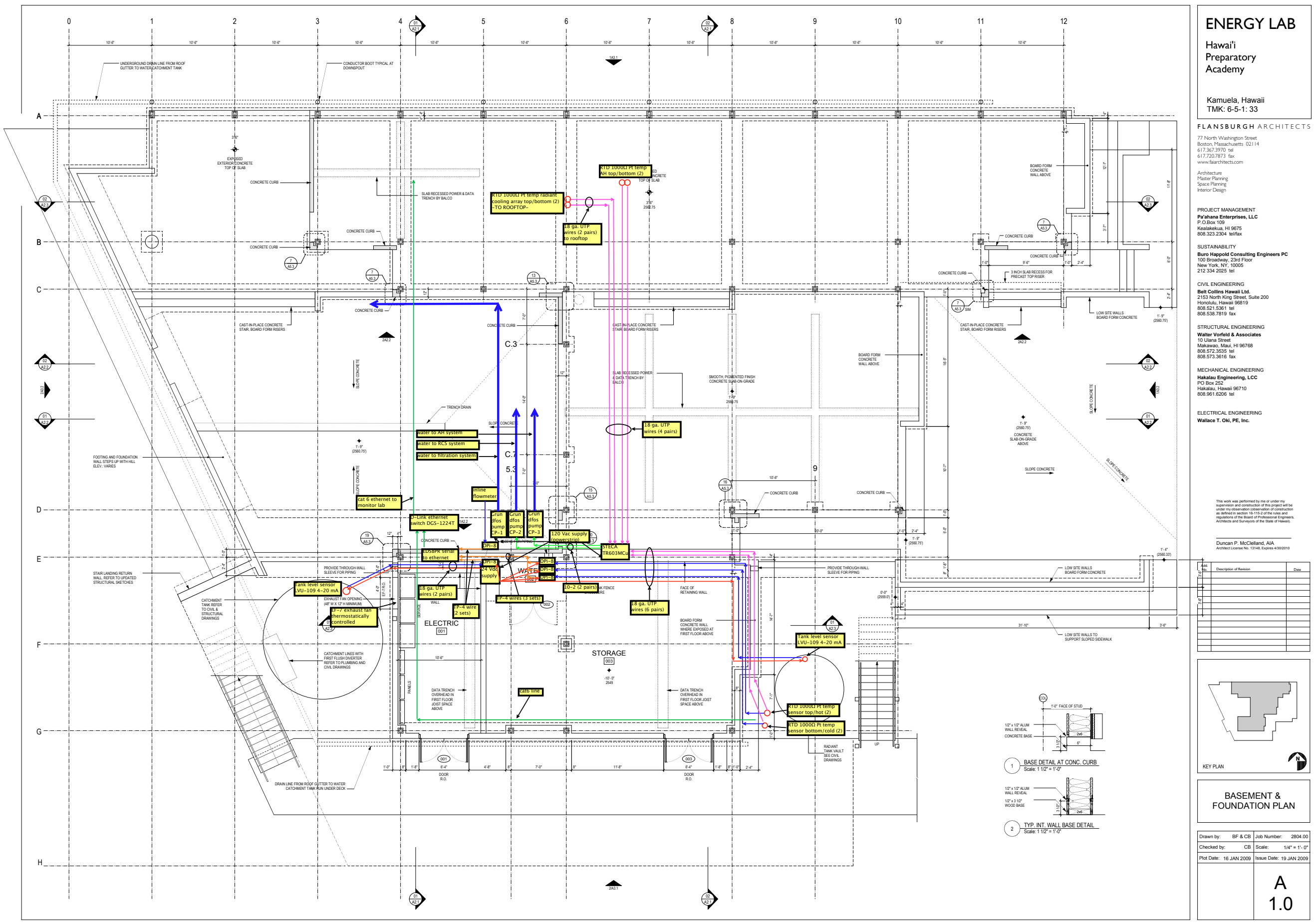
Function

The primary role of the LAS is to provide adequate space lighting in rooms, walkways and covered spaces. Since this system incorporates many vendor specific lighting devices which could also be potentially a great energy drain, this system is very plastic, allowing for great adaptation to various conditions of light and occupancy.

The Lutron lighting system was chosen for these reasons, and is integrated completely into the BAS brain system via computer interface.

Design

The Lutron system uses occupancy and ambient light sensors to activate lights in the various spaces, but also provides the BAS brain with occupancy information that is integrated into the other occupancy determined systems such as Air Quality Monitoring System and the HVAC system.



Lighting devices include Compact Fluorescent (CFL) and LED bulbs to conserve energy, with desk mounted task lighting at each of the workstations.

Each closed space has at least one skylight to provide ambient light, except the bathrooms, which are illuminated by powered CFL bulbs with occupancy sensors.

Lighting in the larger central room is activated by zones, determined by an array of ambient light sensors. The goal of this zone illumination is to only illuminate areas that are dark, without wasting energy illuminating those that have adequate ambient light from either the windows or the skylight.

A phasing system can activate the ambient light gradually, using dimmers, to smooth the transition from natural light to augmented light. For example, a reader in the large main room would therefore not notice a change in light as clouds obscured the light from the skylight, as the ambient light sensors would activate just enough light in just the right locations to maintain optimum reading conditions.

Control of the system will be manual, via low voltage controllers on the walls, to automatic mode determined by the Lutron system, based on ambient light sensors, occupancy sensors, time of day and calendar data, all incorporated into the Lutron HomeWorks computer system.

The Lutron HomeWorks system will interface with the BAS brain in both monitor and control mode. In monitor mode, the BAS brain will record occupancy and ambient light conditions in each room, as well as light activation data initiated by the Lutron system. This will enable the system operator to fine tune the system over time to optimize the system energy use. One example might be timed lighting schemes that do not have occupancy data. In such cases, the system could be adjusted to reduce the energy waste. Another might be to optimize the on/off cycles of the CFL devices, which require a startup current that is only amortized over several minutes of operation. Rapid on/off cycles therefore waste energy, or could be signs of system fault or occupant abuse.

As much as possible, the LAS system should accommodate the needs of the occupants, while detecting waste, either malicious or benign.

Remote activation and control of the system can be achieved either through the Lutron remote control system or the Lutron iPhone application. A second tier of control can be initiated via the BAS brain system, as a result of trend analysis as mentioned above, or via direct control of the system by computer interface or the BAS brain iPhone application.

Several other layers of complexity are possible with the Lutron HomeWorks system, including video surveillance and motion detection, smoke and security alarms to name a few.

Video surveillance will be done using the Axis system of wired and wireless network cameras, located in all closed spaces and surrounding the building, which feed into an Axis video server for security and occupancy data. This system has motion detection capacity that is then tied into the BAS brain for integration into the LAS, AQS and HVAC systems. They also serve to alert the system operator of presence in non-supervised areas, such as the basement garage.

Energy use by the lighting system will be measured using current transformers attached to each leg of the lighting system, as a direct, passive method augmenting the Lutron data. This should detect the use of task lighting and other manual only energy draws that could present malicious or benign energy waste.

Sequence of operations

System input	System response
Night time use, no astronomy sessions, occupancy sensors read zero	Normal night conditions, security/safety lights only, system data recorded and archived for later analysis and diagnosis
Daytime use, ambient light sensors read light, occupancy zero	Vacation or day off mode, no light activation, all lights off

System input	System response
Daytime use, ambient light sensors read light, occupancy nonzero	Lutron system activates lights in occupied spaces to meet criteria for adequate lighting
Daytime or nighttime use, rooms dark for presentations, ambient light sensors read light, occupancy nonzero	Manual control, via Lutron remote or iPhone app to dim lights. After 24 hours, resume normal control cycle.
Daytime use, ambient light sensors read light, occupancy nonzero, ambient light levels decrease	Lutron system engages to augment ambient light
Axis video server detects motion in closed spaces	Signal Lutron system to activate lights, alert system operator
Current transformers detect vampire loads on lighting circuits-task lighting after hours	Alert operator, task lights left on/in use by occupants after hours
Manual control needed for functions, manual on override, manual off override	Controls Lutron system, reset alarms by Axis system, silence alarms to system operator
Power utility failure	Lutron system activates low light command for safety only

Freshwater Catchment System (FCS) Diagram

templates:

System

Function

Design

Sequence of operations