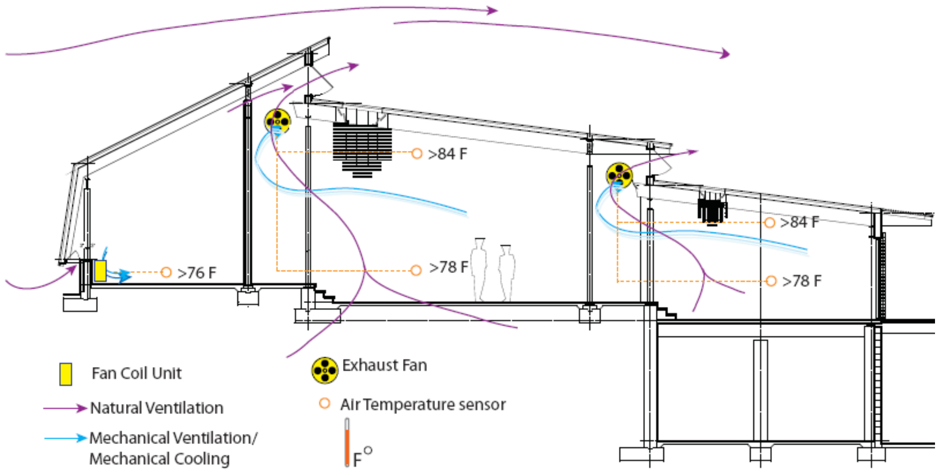
COSA SOLUTIONS



Hawaii Preparatory Academy

Natural Ventilation Study

Dynamic Thermal Modeling and CFD studies

Job No. 023578 July 2008

Revision 01

Revision	Description	Issued by	Date	Checked
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NOTE: This analysis work has been carried out to present data to inform the design and decision making process of appropriate authorities. The analysis work has been carried out with the level of skill and care expected of a consulting engineer. Due to the nature of this study, we can not accept liability arising from variations in actual climate, construction, and internal and external boundary conditions.

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1 Executive Summary

Buro Happold's Computational Simulation and Analysis (CoSA) group conducted a series of natural ventilation studies for the Hawaii Preparatory Academy Energy Lab building in conjunction with Flansburgh Architects to assess the effectiveness and energy consumption of the proposed architectural configuration. This study was carried out using dynamic thermal modeling software linked to an air flow network capable of modeling 8760 hours of operation based on hourly annual weather data. The following conclusions have been made and integrated into the architectural solution.

- The configuration as of July 24th, 2008, represents a successful natural ventilation strategy
- Solar shading is a critical component in the control of internal heat gains and must be integrated into the design
- High wind speeds can cause localized internal disruptions such as papers being blown off desks. This can force people to close windows thus reducing the capability of natural ventilation to maintain internal comfort conditions. To overcome this effect, it is recommended that the solar shading screens also be designed to act as a wind screen capable of reducing wind speed without forcing the window or door to be closed entirely.
- The current design maintains internal comfort conditions within five degrees of the external air temperature. This is accomplished by achieving a sufficient number of air exchanges per hour. The primary force driving the air exchange rate is the pressure differential between the internal and external environments created by the wind speed and direction.
- Humidity can not be controlled using natural ventilation. Humidity sensitive spaces will need air conditioning.
- The building would benefit from night cooling if security and rain issues can be addressed.
- It is recommended that exhaust fans be placed near the clear story windows for times of the day and year when there is insufficient number of air exchanges occurring due to natural ventilation. It is recommended that these fans be sized to provide a minimum of 8 air changes per hour. It is also recommended that the fans only operate when the clerestory windows are closed. For additional detail refer to the appendix 8.3 of this document.

The content of this report is intended to be a summary of the work to date. The contents of the report have been previously communicated to the design team during workshops, teleconferences and other fluid exchanges.

2 Introduction

2.1 Project Brief

The Hawaii Preparatory Academy is located on the Big Island of Hawaii. The site is located on the leeward side of the geological formation known as the Waimea saddle. The combination of the macro scale trade winds and the shape of the Waimea saddle with respect to the mauna kea create a microclimate that is dominated by strong winds blowing from NE to SW. This condition persists for the majority of hours in a year. Other locations on the island including Hilo are under the influence of opposing wind regimes, the trade winds and the land breeze also known as katabatic winds. Hence the net average wind velocity in locations such as Hilo compared to Kamuela is lower. Kamuela located over the Waimea saddle provides a clear unobstructed path for the trade winds. There are short periods of time each year when the wind blows from different directions. These wind events are referred to as Kona winds and are characterized by speeds averaging between 7 mph and 12 mph blowing from WSW to ENE. There are periods of calm when the air speed is below 5 mph.

Buro Happold was contracted to advise and analyze the effectiveness of the natural ventilation strategy proposed for the Energy Lab building. This building is intended to participate in the Living Building Challenge program. It is the intent of the design team to use the lessons learned during this study to apply to other buildings proposed as part of the HPA campus masterplan. The Energy Lab is approximately 4,500 square feet of educational space. It is intended to be a living laboratory providing students with examples of low energy design strategies utilizing passive environmental control strategies and renewable energy generation.

2.1.1 Design intent and Analysis goals

- Evaluate the impact and effectiveness of the building massing and configuration to maintain comfort conditions using natural ventilation
- Based on the results of this initial evaluation, propose possible design changes to be made to improve comfort conditions
- Evaluate typical and worse case conditions based on weather patterns
- Establish preliminary energy model as part of the design strategy to meet the Living Building Challenge goals
- Report annual energy consumption figures for renewable energy system sizing
- Review and evaluate available hourly weather data to be used in the simulation program meeting the requirements of ASHRAE 90.1 appendix G and ASHRAE 140. If necessary, make any changes to the weather data to improve accuracy and energy modeling results during later stages of design and LEED EA credit 1 documentation to the USGBC

3 Methodology

3.1 Environmental Performance Simulation Strategy

To accurately model the complex interaction of heat and mass transfer within a building requires thorough understanding of the mathematical representation of the physical phenomena known as thermodynamics. For purposes of this study a three part strategy was employed to model varying levels of detail describing the movement of air (mass) and energy (heat) through the HPA Energy Lab.

3.1.1 Dynamic Thermal Model (DTM)

- A dynamic thermal model of the proposed building was built to accurately represent the current architectural plans to match both geometry and resolution. This model was constructed using the IES Virtual Environment software. The IES VE software uses APACHE as the computational engine to predict the various energy flows in building during a Typical Meteorological Year (TMY2). The Typical Meteorological Year for Hilo and Honolulu were obtained from the National Renewable Energy Laboratory (NREL) TMY2 tapes. For detailed information refer to http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/State.html. NOTE: this weather file was later modified to more accurately represent the weather at the site. This process is described in more detail in section 7.2 of this report.
- The main analytical tool used in the analysis was the DTM. This software is used to generate a 3D model of the building with the internal space split into a number of control zones. The software then uses annual weather data to calculate the various energy flows into and out of each zone, including solar gains, people and equipment gains, the energy stored within the building fabric, and also the temperature diluting effect of natural ventilation. The DTM is capable of calculating variations of temperature in each control zone for every hour of the year and also bulk air movement between control zones. This modeling was carried using IES Virtual Environment. This software utilizes the APACHE dynamic thermal calculation engine to perform hourly calculations in conjunction with 8760 hours of weather data. This software meets the requirements of ASHRAE 140 as referenced by ASHRAE 90.1 2004 appendix G and referenced by LEED NC 2.2 Energy and Atmosphere Credit 1. ASHRAE standard 140 establish minimum software performance capability for executing dynamic thermal models. The requirements include the ability to simulate 8760 hours of operation using hourly weather data. For additional information regarding ASHRAE standard 140 please refer to the ASHRAE web site.
- The IES Virtual Environment software was selected for this study for two reasons. First this software has the capability to link a dynamic thermal model to an air flow network at each time step of the simulation. This will be described in more detail below. Second the software models both direct and diffused solar radiation using hourly calculated shading files in combination with hourly weather data.
    - <u>Air Flow Network</u> - An air flow network runs adjacent to a dynamic thermal model exchanging information at each time step to achieve a fully integrated simulation of air and thermal exchanges. The following issues may be addressed with

an air flow network; Infiltration, Single-sided ventilation, Cross-ventilation, Natural ventilation as a whole-building strategy, Temperature-controlled window opening, Mixed-mode solutions.

- An air flow network has the capability to simulate the flow of air through openings in the building envelope. Openings are associated with windows, doors and holes created in the geometry model and may take the form of cracks or larger apertures. Air flow is driven by pressures arising from wind and buoyancy forces (stack effect).

- The definition of an opening type in the model requires that pressure coefficients be considered based on the exposure level of the opening. The pressure coefficient is combined with external wind data (angle of attack, exposure factor, and wind speed) at each time step. This information combined with scheduled degree of opening, internal room temperature, pressure, and buoyancy calculation combine to determine the exchange of energy and mass between nodes.

- Hourly Solar Shading Calculations for Direct and Diffuse Radiation: IES has the capability to model solar shading geometry as discrete elements within the thermal model environment. Hourly shading data is generated for the 15th day of selected months using solar geometry for each hour relevant to the specified longitude and latitude. This shading data is used to modify the beam component of the solar radiation weather data for each hour of the respective month. The resulting data describes the exposure of both exterior and interior building surfaces to beam solar radiation. The shading data also contains diffuse shading factors indicating, for each exposed surface of the building, the degree of shading from the sky vault. For purposes of this analysis an anisotropic diffuse solar radiation model was used to designate a portion of the diffuse radiation as circumsolar, which it treats as that component as if it emanated from the sun position. The proportion of the diffuse radiation designated *circumsolar* varies with the intensity of the beam radiation.

- The shading data records a shading factor for each exterior building surface receiving beam solar radiation. In the case of glazed elements, the file also records which interior surfaces are irradiated by the beam after it has passed through the glazing, and to what extent (expressed in terms of sun-patch area projected perpendicular to the beam). If a receiving surface is itself glazed, the radiation is traced on through this element to other receiving surfaces beyond, and so on. This process is referred to as *solar tracking*. Solar tracking data is used by the APACHE calculation engine to distribute beam solar radiation at each time-step. The radiation intercepted by each exterior receiving surface is calculated from the incident beam solar flux, taking account of the surface geometry and any external shading factor. If the receiving surface is transparent, APACHE calculates the transmission and absorption of the beam. The attenuated transmitted beam is then tracked through successive interactions with building surfaces. Any radiation falling on an opaque element is partially absorbed and partially reflected, using an assumed solar absorptance of 0.55. Beam radiation falling on a transparent element is transmitted, absorbed and reflected in accordance with the element's properties as defined in the materials database. Radiation reflected from opaque or transparent surfaces is returned to the adjacent room for later distribution as diffuse radiation.

- Diffuse radiation incident on an exposed surface is the sum of components from the sky, the ground, and certain types of shading object. Shading objects block diffuse sky solar radiation to a degree determined by a *diffuse shading factor*. This type of shading applies to both glazed and opaque surfaces. Shading objects are assumed to scatter ambient radiation, as well as blocking diffuse radiation from the sky. This gives rise to an additional term in the diffuse incident flux. This level of detail is required to accurately asses the impact of the exterior solar shading elements.

- After performing a survey of available weather files it was determined that none of the existing TMY2 weather tapes were from geographic locations that could sufficiently represent the microclimatic conditions experienced on the site during a typical year. To over come this limitation a series of test days were selected from the available weather tapes that did contain conditions representative of the sites micro climate. These test days were used to perform the initial assessment of the energy labs natural ventilation strategy during a windy day with wind speeds over 15 mph blowing from the prevailing wind direction that is NNE to SSW day, a windy day with wind speeds of 15 mph blowing from the direction opposite to the prevailing wind direction that is from SSW to NNE day, and a low wind speed day with wind speed 7 mph or below.

- During the discussions and analysis of the existing weather tapes it was determined that Buro Happold would augment existing TMY 2 hourly weather data to more accurately describe the sites microclimate. This is necessary to accurately predict the building energy consumption for purposes of design and documentation for the USGBC LEED NC 2.2 Energy and Atmosphere Credit 1 submission as will as the Living Building Challenge. This is described in more detail in appendix 7.2.

3.1.2 Computational Fluid Dynamics (CFD)

- The DTM model has some limitations in the resolution of information that can be output. One limitation is the numerical output of the results as opposed to graphical. Another limitation is related to the limited density of the nodal network resulting in a single average temperature and a single magnitude of air movement provided per control zone/surface. To further study the details of temperature, velocity and pressure distribution, Computational Fluid Dynamic (CFD) is used. Unlike the transient hourly simulation representing an entire year in DTM, a CFD model provides a visual 'steady state' snapshot of the temperature and airflow distribution under a defined condition. The 3D calculation grid used by CFD is much finer than the DTM model’s nodal network and is therefore capable of showing air movement and temperature distribution within each control zone.

- The effect of natural ventilation is determined by multiple factors. The first one is the effect from the exterior environment. The terrain, the neighbouring buildings, and the climate data (especially wind data) are all considered as boundary conditions that define the external pressure and flow. The wind speeds and directions will influence wind driven pressure differentials between the internal building environmental and external environment. Second, the internal heat gains, solar gains and surface temperatures influence the internal air movement of the space due to natural buoyancy of air, also known as the stack effect.

- To establish a CFD model, a series of inputs must be made to define the boundary conditions of the study. Based on the external and internal factors described above, two scenarios were defined for study using CFD. The first was an external wind flow study using typical wind speeds and direction to aid the design team in the formation of the roof structure as it relates to natural ventilation. The second condition was that of a still condition, where internal heat gains and solar gains would be the primary force behind internal air movement due to the natural buoyancy of air.

4 Assumptions and Inputs

4.1 Dynamic Thermal Model Inputs

For purposes of this study a series of test days were used to study various climatic conditions. Using information provided by the design team and faculty members of the HPA, a series of daytime schedules were created to represent likely occupancy patterns for Energy Lab spaces. These schedules control the application of various thermal and energy loads to the building over a 24 hour period. These various schedules are assembled to create an hourly annual profile which various the intensity of the energy and thermal loads at each hourly time step of the simulation.

4.1.1 Dynamic Thermal Model Assumptions and Inputs

- Schedules – The entire building is assumed to be occupied from 9 AM to 7 PM on weekdays and the lab spaces are assumed to be partially (50%) occupied on Saturday. There is no occupancy on Sunday.
- Internal Heat Gains:

Space type	No. of People	Lights	Equipment	Weekend partial occupancy (y/n)
Labs + monitoring lab	11	1.4 W/sq ft	1.0 W/sq ft	y
Workstations	7	1.1 W/sq ft	1.0 W/sq ft	n
Conference room	5	1.3 w/sq ft	.5W/sq ft(over head projector only)	n
Private office	1	1.1 W/sq ft	1.0 W/sq ft	n

- Fan assisted natural ventilation control was modeled for some studies to determine resulting thermal comfort levels and energy consumption. Refer to appendix 8.3 of this document for additional information.

4.1.2 Air Flow Network Assumptions

- Windows open: Windows and the sliding doors are assumed to be open during occupied hours only. The upper level clerestory windows and the lower level vents are assumed to be open at all times.
- Windows closed: The site experiences extremely high wind speed events. Under these conditions it is assumed that the occupants would close the doors and windows within their reach. The sliding doors and windows are assumed to be closed at all times when the external wind speed exceeds 17 mph.
- Stacked zone description: The occupied zone of the building is assumed to extend 7 feet up from the finished floor elevation. A second thermal zone was modelled above the occupied zone extending up to the roof level. These zones were connected by a hole that allows heat and air to be exchanged between the zones as calculated by the air flow network using buoyancy and pressure differential equations.
- Fan assisted ventilation control: Fan assisted control strategy has been studied for the Lab space in the south and the work station area that would otherwise completely rely on natural ventilation only. The fans shall operate to support the natural ventilation under conditions of low wind speed or under conditions when the major openings, that is the doors and windows are closed due to rain or extremely windy conditions outside. The fans create a negative pressure inducing the air to flow from the low level vent to achieve around 8 ach per hour. Fans are controlled by temperature sensors located in the occupied zone and the zone above (as described in the preceding point). At any time when the temperature in the occupied zone exceeds 78F or the temperature exceeds 84 F in the zone above the occupied area the fans shall operate to provide supplemental ventilation. The clerestory windows however need to be controlled in conjunction with the fans for effective creation of pressure differential for additional ventilation. This described in greater detail in the design note entitled ”Natural Ventilation“ sent to Flansburgh Architects on June 22, 2008

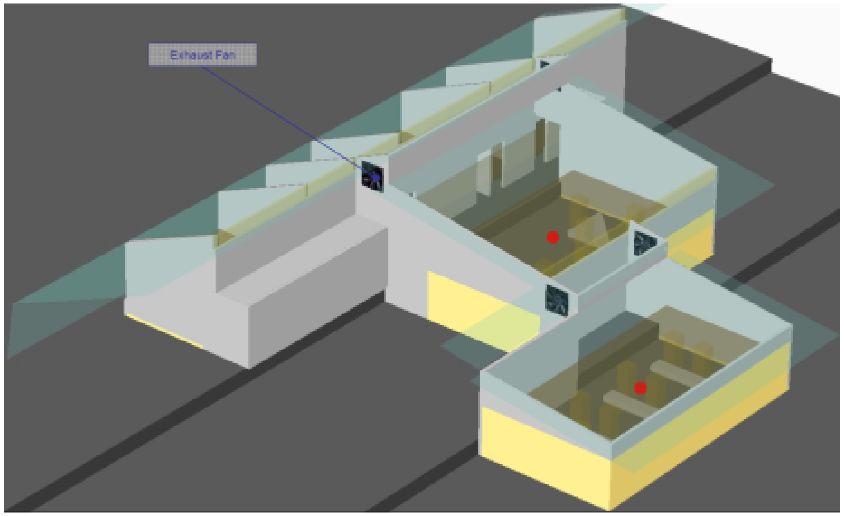
4.2 Computational Fluid Dynamic Inputs

In addition to the building geometry internal heat gains were explicitly modeled in the CFD environment. This included modeling the heat gain from people, lighting and computers in their relative geometric position in the building.

4.2.1 Computational Fluid Dynamic Assumptions and Inputs

- To account for thermal lag, solar gain, the surface temperatures for the various building elements have been calculated from the dynamic thermal model and applied as boundary conditions to the CFD models.
- Ambient Temperature:80 (°F)
- Ambient Wind speed: 0 for worse case, 15 – 20 mph for typical wind speed used to evaluate configuration 1 and 2, 0 wind speed used as worse case scenario for option 3 and fan size studies.
- People are modeled in the building distributed according to program and vary depending on the configuration plan. The heat out put is 300 Btu/h sensible heat 200 Btu/h latent.
- In some models, fans are modeled to allow for mechanically assisted venation. Refer to appendix 7.3 for additional information.

Figure 1 showing CFD model set up including location of opening, screens, people and fans.



5 Results and Observations

5.1 Dynamic Thermal Model Results and Observations

The dynamic thermal model with integrated air flow network was used to test the internal comfort conditions inside the various spaces of the energy lab during three test days representing a range of likely climatic conditions to be experienced at the site. The purpose of the dynamic thermal model is to understand the complex interaction of the various modes of heat transfer as they interact with the buildings fabric, material, internal thermal loads, and most importantly, through time. The dynamic thermal model allows designers to understand how the buildings internal environments change over time due to varying occupancy patterns, solar positions, operational strategies (operable windows and air conditioning), building materials capacity to store and release heat, and exterior weather patterns.

5.1.1 Configuration 1: the initial architectural configuration was much larger is floor area and volume than the current design. This the size created some issues with the effectiveness of the natural ventilation strategy as the center of the lab and staff spaces did not benefit as much from the perimeter openings. Additionally the wind shield along the ridge lines did not work well during periods of moderate to slow winds. Refer to appendix 8.1 Configuration 1 for more detail. Additional observations included:

- This configuration had a large area of skylight envisioned as horizontal bands. This increased the solar heat gain off setting the benefit of the natural light and corresponding reduced lighting energy and heat gain. Several sketches were discussed looking at the possible ways of organizing the skylights to have the spaces daylit but avoid direct solar radiation penetration into the occupied area.
- The south facing lanai did a reasonable job of shading the south glass, however there were large portions of the lower portions of the glass are left exposed resulting in solar gain through the windows and doors.
- The spaces in the northern bar did not receive sufficient air changes per hour to naturally ventilate the spaces effectively. Additionally some spaces in this bar were determined to need mechanical cooling for functional purposes to control humidity.

5.1.2 Configuration 2: A series of modifications were made to the ridge vents size and length of the low level air intake vents was increased. This resulted in an increased air exchange rate and slightly lower internal temperatures. Refer to appendix 8.1 Configuration 2 for more detail.

- The skylight area remained too large to be solely beneficial to the middle and south bar in terms of comfort vs energy saved. It was recommended that this be studied further to balance the daylight harvesting benefits with the solar heat gain drawback.
- Solar Gain from the vertical glass doors and windows remained a major influence to the internal air temperatures.

- The spaces in the northern bar did not receive sufficient air changes per hour to naturally ventilate the spaces effectively. Additionally some spaces in this bar.

5.1.3 Configuration 3: Based on the concern of wind driven rain from the north penetrating the north facing ridge vents, as well as a reduced floor plan due to budgetary constraints a revised ridge line was proposed placing the ridge vents along a vertical south facing clearstory. Refer to appendix 8.1 Configuration 3 for more detail.

- The skylight area was reduced to balance heat gain with natural light levels. It was determined that daylight dimming would still perform the majority of hours each day with the reduced skylight.
- A series of shading elements were added to the vertical glazing to control both solar gain, and wind speed. The solar shades were envisioned as a shutter like devices mounted on sliding tracks that could be pulled across the sliding glass doors to reduce solar gain and wind speed when external conditions warrant. These proved successful in addressing concerns regarding both solar gain and wind speed in the near vicinity of the window and door openings.

5.2 Computational Fluid Dynamics Results and Observations

Three architectural configurations were tested at various phases of the design process.

5.2.1 Configuration 1: the initial architectural response was to create a type of windshield structure threat would act as a wind and rain block to the north facing roof vents. Refer to appendix 8.1 Configuration 1 for more detail.

- This configuration did create a negative pressure zone along the ridge line and did induce some pressure driven air flow through the openings along the first and highest bar.
- The northern most windshield like structure created a substantial wind shadow in its wake reducing the wind speed and creating turbulence.
- As a result of this wind shadow the next two wind shield structures and coinciding ridge vents do not create a strong negative pressure zone at the opening reducing the air flow out of the middle and south bar which also experience higher solar load due to southern exposure.

5.2.2 Configuration 2: based on the results from configuration one a series of recommendations were made suggesting that the windshield like structure be reconfigured to maximize the ability to crate a negative pressure zone along each ridgeline regardless of wind speed or direction. A horizontal fin was proposed to be located at the top of each ridge line to create a localized negative pressure. This effect, known as the venture effect, creates a localized negative pressure zone by squeezing the air as it passes between the fin and the ridge.

This causes the air to accelerate thus creating a small localized negative pressure zone. Refer to appendix 8.1 Configuration 2 for more detail.

- The initial modelling indicated that the concept did indeed increase the effectiveness of the natural ventilation strategy.
- The horizontal wind allowed the natural ventilation scheme to work during times of the year when the winds were not coming from the N/NE.
- The horizontal fin increased pressure differential between the exterior and interior of the ridge line thus increasing the air flow through the ridge opening during time of slow winds (less than 10 mph) .
- The horizontal fin and related ventilation troughs did allow for water drainage on the exterior side of the buildings weather envelope but there was concern that wind driven ran would penetrate the proposed north facing ridge vents regardless of the sheltered.

5.2.3 Configuration 3: Based on the concern of wind driven rain from the north penetrating the north facing ridge vents, as well as a reduced floor plan due to budgetary constraints, a revised ridge line was proposed placing the ridge vents along a vertical south facing clearstory. Refer to appendix 8.1 Configuration 3 for more detail.

- This ridge line configuration with south facing clearstory windows works well during times of the year when the wind is from the north. As this wind direction is prevailing, it is deemed optimal within the constraints of the project
- During times of the year when the wind blows from the south, the effectiveness of natural venting will be reduced. This represents a smaller portion of the year than the time the winds will blow from the north.
- In general this configuration is a well formulated natural ventilation strategy. However there were some scenarios envisioned where this configuration would not perform as well as expected, therefore a fan assisted strategy was also put forward. See appendix 8.3 for additional detail regarding the fan assisted natural ventilation control strategy.

6 Future Study

6.1 Energy Consumption figures

This building is pursuing the Living Building Challenge. This program requires the building to be designed, constructed and operated in such a way that it does not consume any energy from the utility grid. To accomplish this design goal it is important to address two issues. First, the building thermal loads should be minimized as to reduce the demand for utility supplied electricity and fossil fuel delivery. Second annual energy consumption estimates must be made to aid in the sizing of onsite renewable energy production systems. Both are critical to the energy labs ability to demonstrate Net zero energy consumption during the Living Building Challenge post occupancy evaluation after the building is complete.

There are two primary energy reduction strategies. The primary issue is the natural ventilation strategy. The dynamic thermal models built by Buro Happold are linked with an air flow network to simulate natural ventilation as part of the overall building environmental control strategy. The energy conservation strategy is the use of natural light to reduce or eliminate the need for electrical lighting inside the energy lab during daytime hours. The natural ventilation strategy is heavily influenced by the local microclimate created by the terrain and topography area referred to as the Waimea saddle. The unique microclimate of the Waimea saddle is not accurately captured in the TMY2 Weather data files available from the United States Department of Energy. To overcome this limitation data was collected from the site, other near by climate stations, and relevant research papers (ref Chen and Wand, *Diurnal Variation of Surface Thermodynamic Fields of the Island of Hawaii*, American Meteorological Society, Sept 2004). This information was used to modify hourly annual data sets to accommodate the unique conditions at the site. See appendix 8.2 for additional information. This custom weather file has been used to simulate the annual hourly energy consumption of the energy lab. This modification of the hourly weather data will improves the accuracy of the energy consumption prediction and the in the hourly simulation.

6.1.1 Preliminary Energy Consumption Figures

- To be filled in after DD submission as part of the Energy Modeling Scope of Work. This modeling will include natural ventilation control strategy as well as daylight harvesting control and HVAC.

Energy Summary by End Use – Place holder

End Use	Regulated?	Energy Type	Proposed Building		Budget Building		Optimized Energy Performance
			Energy [10^3 Btu]	Peak [10^3 Btu/h]	Energy [10^3 Btu]	Peak [10^3 Btu/h]	[%]
Lighting - Conditioned		elec	-	-	-	-	-%
Space Heating		gas	-	-	-	-	-%
Space Cooling		elec	-	-	-	-	-%
Pumps		elec	-	-	-	-	-%
Fans - Interior Ventilation		elec	-	-	-	-	-%
Service Water Heating		Gas	-	-	-	-	-%
Office Equipment		Elec	-	-	-	-	-%
TOTAL BUILDING CONSUMPTION			**-**		**-**		**-%**
TOTAL REGULATED BUILDING CONSUMPTION			**-**		**-**		**-%**

Note: Energy Consumption is listed in units of site energy

10^3 Btu = kWh x 3.413 10^3 Btu = kWh x 3.413

Elec Rate **-** **/kWh**

Gas Rate **-** **/kBTU**

Energy and Cost Summary by Fuel Type – Place holder

Type	DEC Use [10^3 Btu]	DEC Cost [$]	ECB Use [10^3 Btu]	ECB Cost [$]	DEC / ECB Energy %	DEC / ECB Cost %
NONRENEWABLE (REGULATED + UNREGULATED)						
Electricity (Total)	-	$ -	-	$ -	-%	-%
Natural Gas (Total)	-	$ -	-	$ -	-%	-%
Total Nonrenewable (Regulated + Unregulated)	-	$ -	-	$ -	-%	-%

Type	DEC' Use [10^3 Btu]	DEC' Cost [$]	ECB' Use [10^3 Btu]	ECB' Cost [$]	DEC' / ECB' Energy %	DEC' / ECB' Cost %
NONRENEWABLE (REGULATED + UNREGULATED)						
Electricity (Total)	-	$ -	-	$ -	-%	-%
Natural Gas (Total)	-	$ -	-	$ -	-%	-%
Total Nonrenewable (Regulated Only)	-	-	-	-	-%	-%

Type	DEC'' Use [10^3 Btu]	DEC'' Cost [$]			DEC'' / ECB'' Energy %	DEC'' / ECB'' Cost %
Renewable (REC)		$ -		$ -		
Total including Renewable	-	$ -	-	$ -	-%	-%

Percent Savings = (ECB' $ -DEC'' $)/ECB' $ = -%

Percent Renewable = REC $/DEC' $ = -%

6.2 LEED

When the final design of the air conditioning system, lighting, and renewable energy systems are complete, the most recent dynamic thermal models will be updated to represent the latest design. These models will be constructed and simulated according to the methodology required by LEED NC 2.2 which references ASHRAE 90.1 2004 appendix G. This modeling methodology defines the base case model that the proposed design will be compared against to determine the energy savings. This modeling methodology will include hourly annual air flow modeling to account for the energy savings from natural ventilation.

The majority of the modeling required for LEED Energy and Atmosphere will occur during the later half of design development and earlier part of Construction documentation. This is due to the development schedule and refinement of the mechanical systems design. Once the mechanical design is compete, the inputs will be added to the energy model and simulated within the dynamic thermal software using the modified weather data described above to estimate the annual energy savings of the Energy Lab as compared to a base case building defined by ASHRAE 90.1 2004 Appendix G.

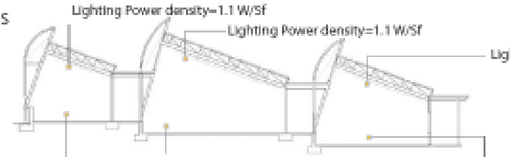
If necessary exceptional calculation methodologies will be developed to account for the additional energy saving features such as radiant night time cooling, photovoltaics and wind power. This work will be documented and reported to the USGBC using the online LEED Letter Template as part of the design phase submission.

7 Appendix

7.1 Natural Ventilation Results

Configuration 1 – presented to the design team December 13, 2007 showing dynamic thermal modelling and CFD results

BASE ASSUMPTIONS



People: 2 people per room at peak occupancy
Equipment gains: 1.5 W/sf

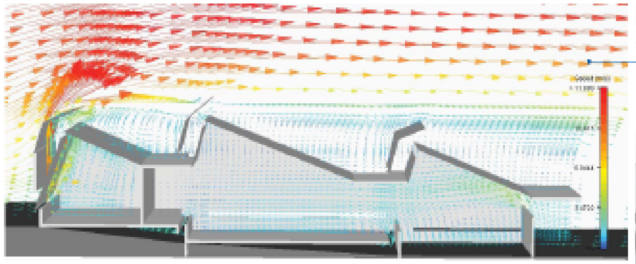
People: 34 people at peak occupancy @ 70sq.ft per person
Equipment gains: 3.0 W/sf (computers only)

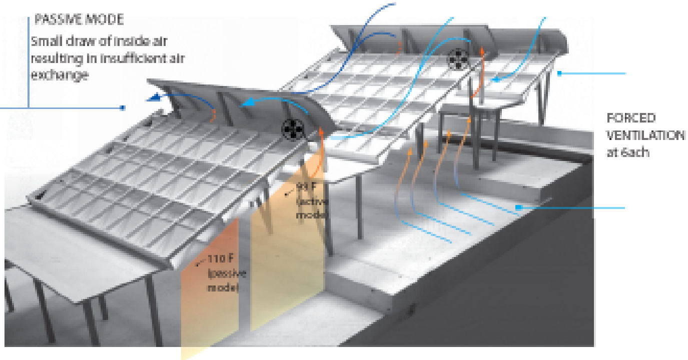
People: 30 people at peak occupancy
Equipment gains: 4.0 W/sf (assuming 30 computers plus other equipment

CASES STUDIED

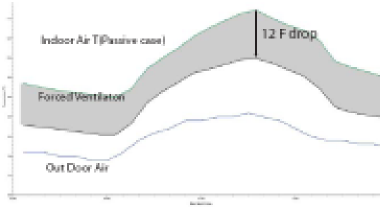
Passive Mode: The building is naturally ventilated 24 hours with the occupied hours being 7:30 AM to 7:00 PM on weekdays

Forced ventilation: The air is mechanically extrated at the roof level, out into the the sheltеded area formed by the wind shield. The model was tested for air change rates of 6,8 and 12 ach

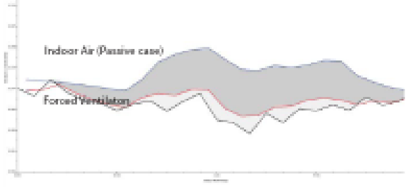




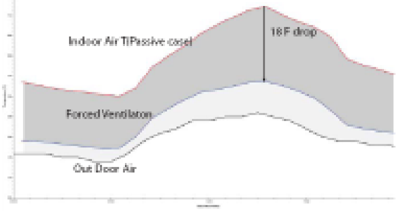
Temprature difference between completely passive and forced ventilation at 6 ach



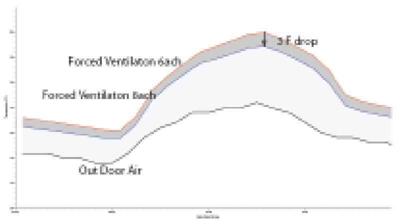
Difference between moisture content of indoor air in completely passive and forced ventilation at 12 ach case



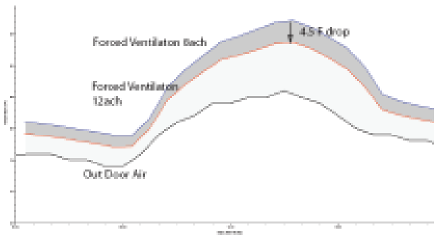
Temprature difference between completely passive and forced ventilation at 12 ach



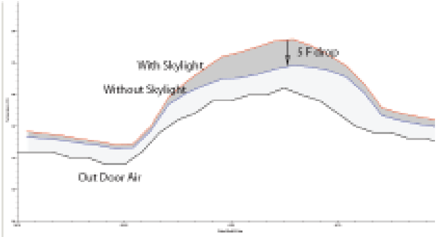
PERFORMANCE AT HIGHER AIR EXCHANGE RATES



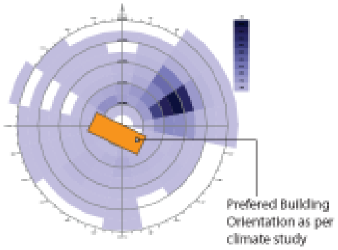
Temprature difference between forced ventilation at 6 ach and 8ach



Temprature difference between forced ventilation at 8 ach and 12ach

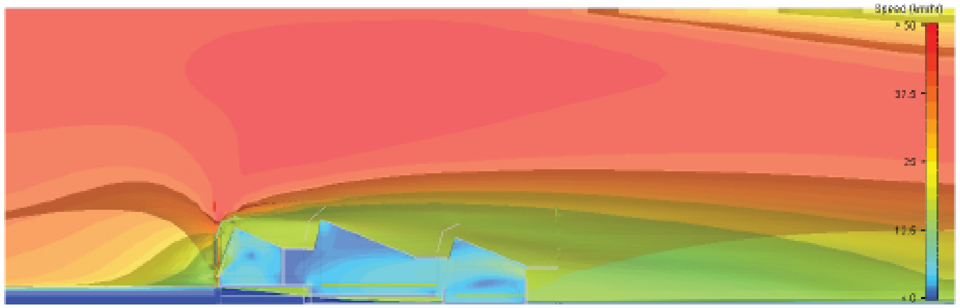


Temprature difference between forced ventilation at 12ach with and without skylights

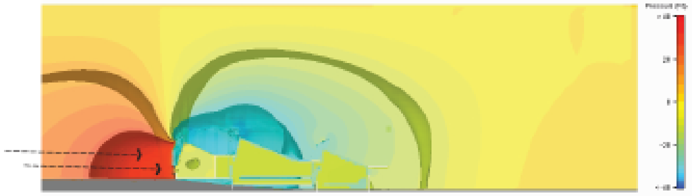


Prefered Building Orientation as per climate study

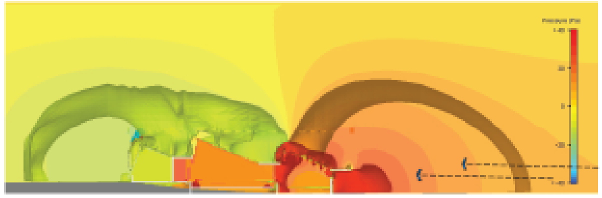
Wind Rose (Honolulu weather file)



Wind speed distidution under prevailing wind conditions



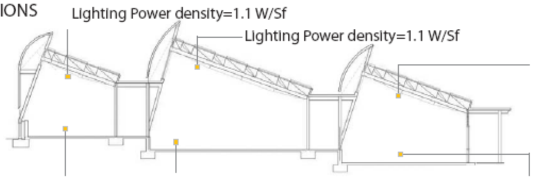
Pressure Variation under prevailing wind conditions



Pressure Variation under wind in the opposite direction

Configuration 2 – presented to the design team December 20th, 2007 showing modifications to ridge vent.

Revised BASE ASSUMPTIONS



Lighting Power density=1.1 W/Sf

Lighting Power density=1.1 W/Sf

Lighting Power density=1.1 W/Sf

People: 2 people per room at peak occupancy
Equipment gains: 1.5 W/sf

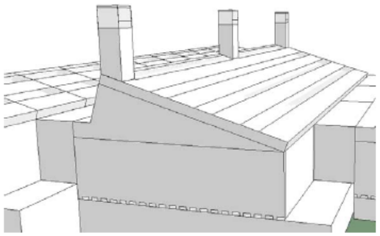
People: 34 people at peak occupancy @ 70sq.ft per person
Equipment gains: 2.0 W/sf (computers only)

People: 30 people at peak occupancy
Equipment gains: 2.0 W/sf (assuming 30 computers plus other equipment

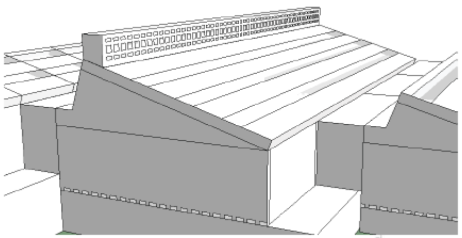
CASES STUDIED

Case 1 Chimeney Towers: The building is naturally ventilated 24 hours with the occupied hours being 7:30 AM to 7:00 PM on weekdays. Three towers 10 ft high are modelled to draw air using the venturi effect.
Case 2 Continous Chimney Towers: The building is naturally ventilated with a chimney extract running on the ridge. The chimney height is 3.5 ft.
Case 3: Base design with forced mechanical ventilation at 6 ach.

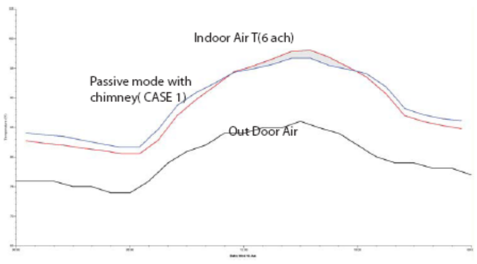
CASE 1



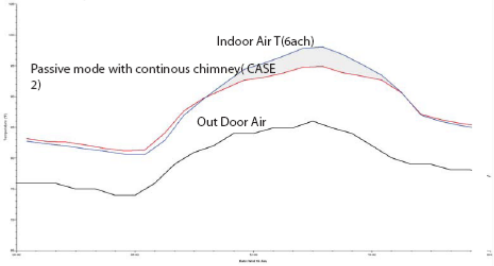
CASE 2

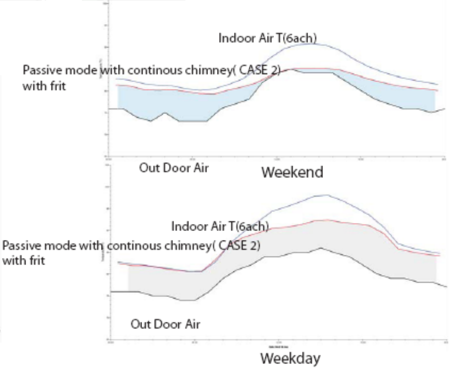


Temprature difference between base design forced ventilation at 6 ach(CASE 3) and CASE 1

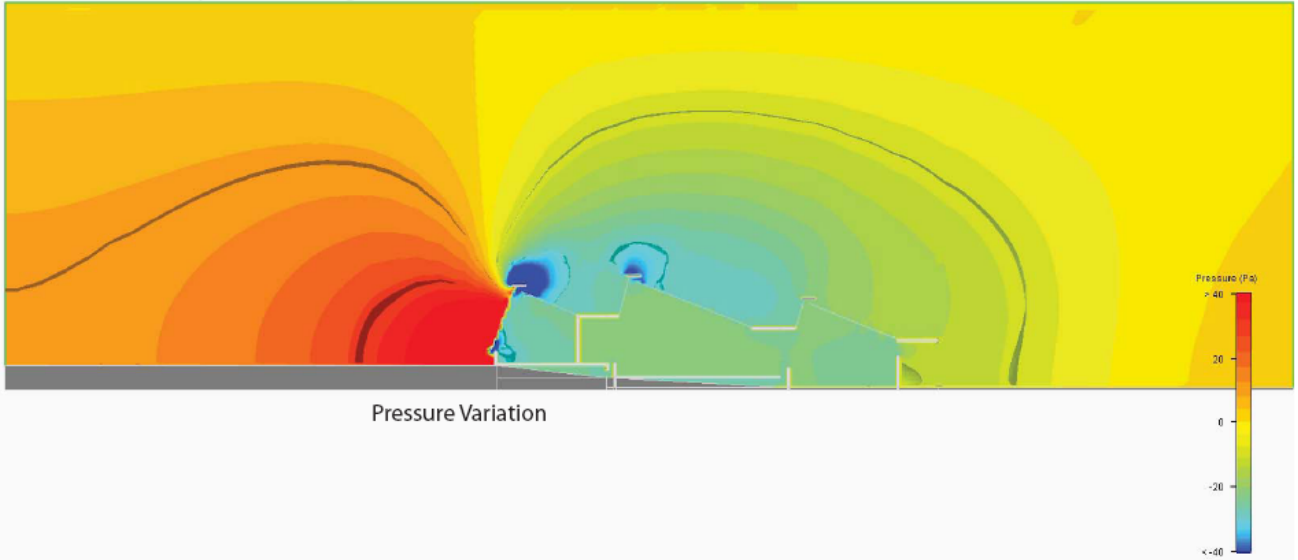


Temprature difference between base design with forced ventilation at 6ach(CASE 3) and continous chimney (CASE 2)

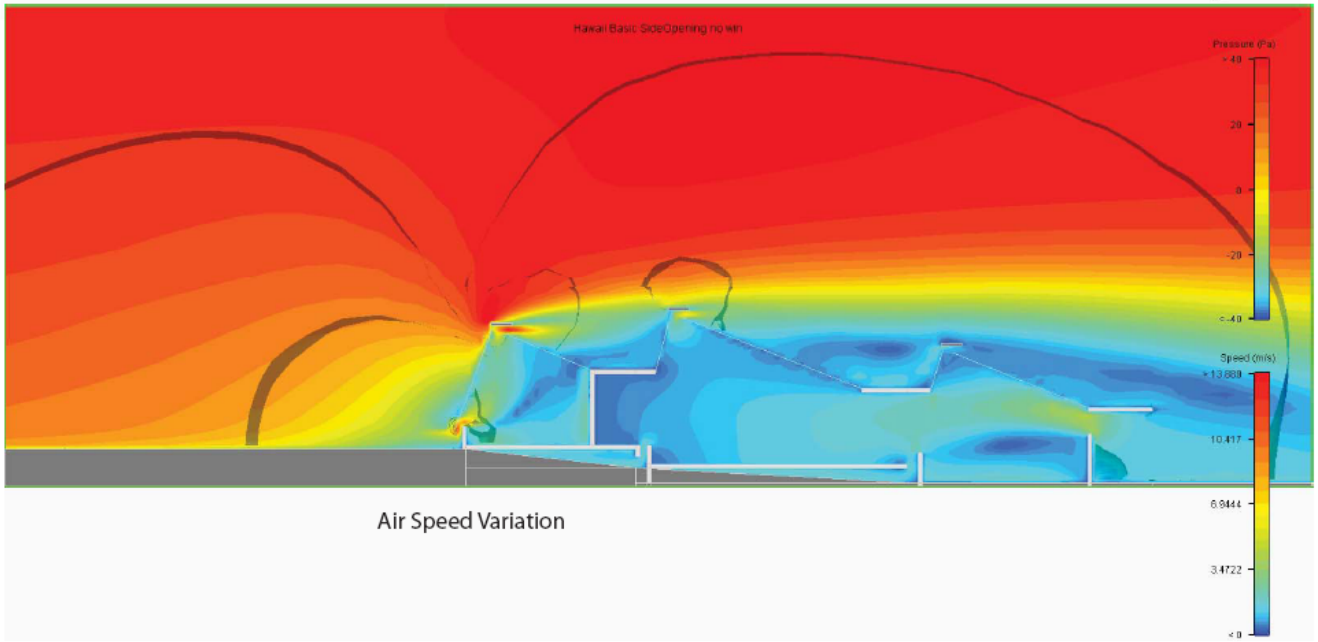




CFD Results with chimney on the ridge line

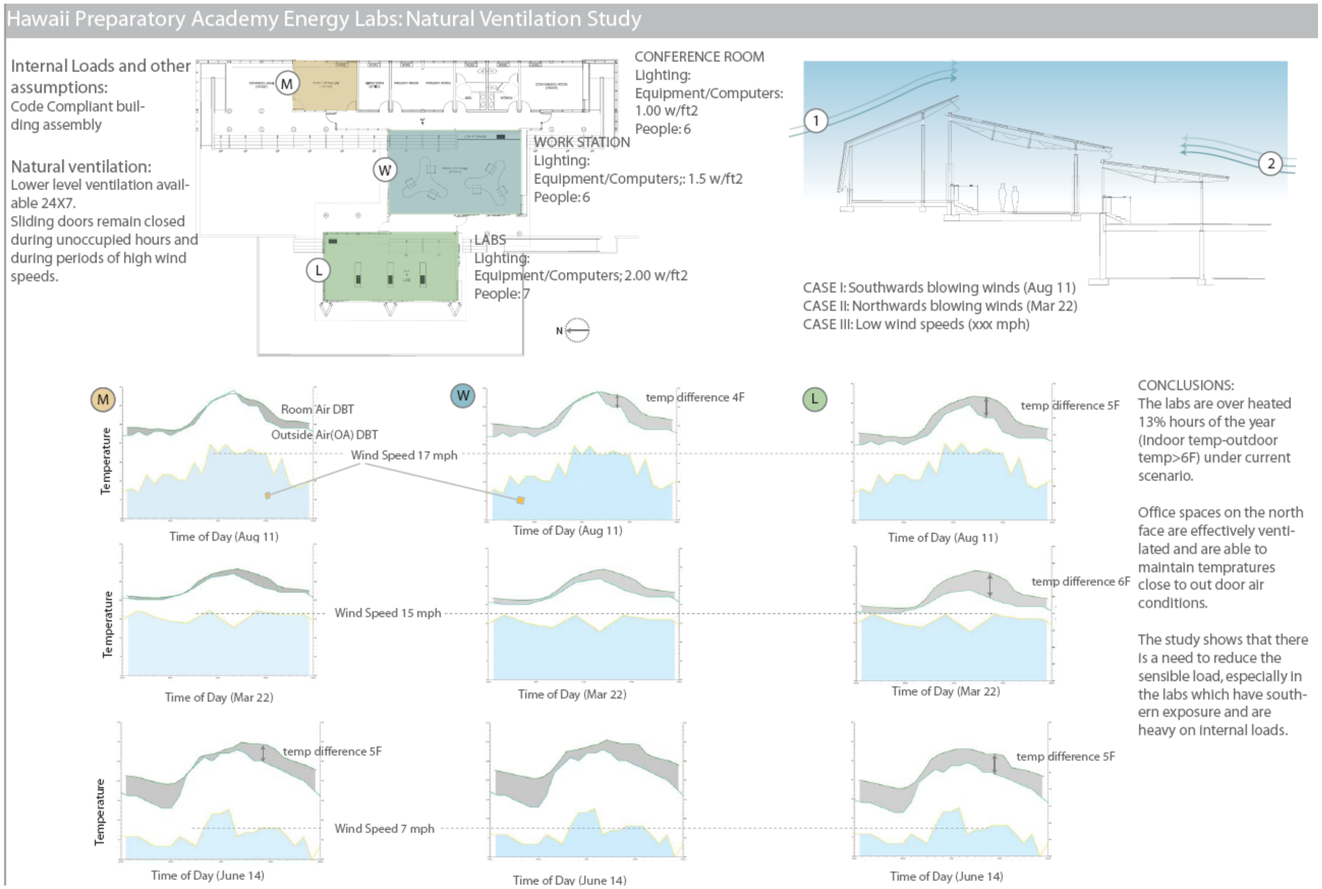


Pressure Variation



Air Speed Variation

Configuration 3 – presented May 6th, 2007 showing revise plan and section



Hawaii Preparatory Academy Energy Labs: Natural Ventilation Study

Internal Loads and other assumptions:
Code Compliant building assembly

Natural ventilation:
Lower level ventilation available 24X7.
Sliding doors remain closed during unoccupied hours and during periods of high wind speeds.

CONFERENCE ROOM
Lighting:
Equipment/Computers: 1.00 w/ft2
People: 6

WORK STATION
Lighting:
Equipment/Computers;: 1.5 w/ft2
People: 6

LABS
Lighting:
Equipment/Computers; 2.00 w/ft2
People: 7

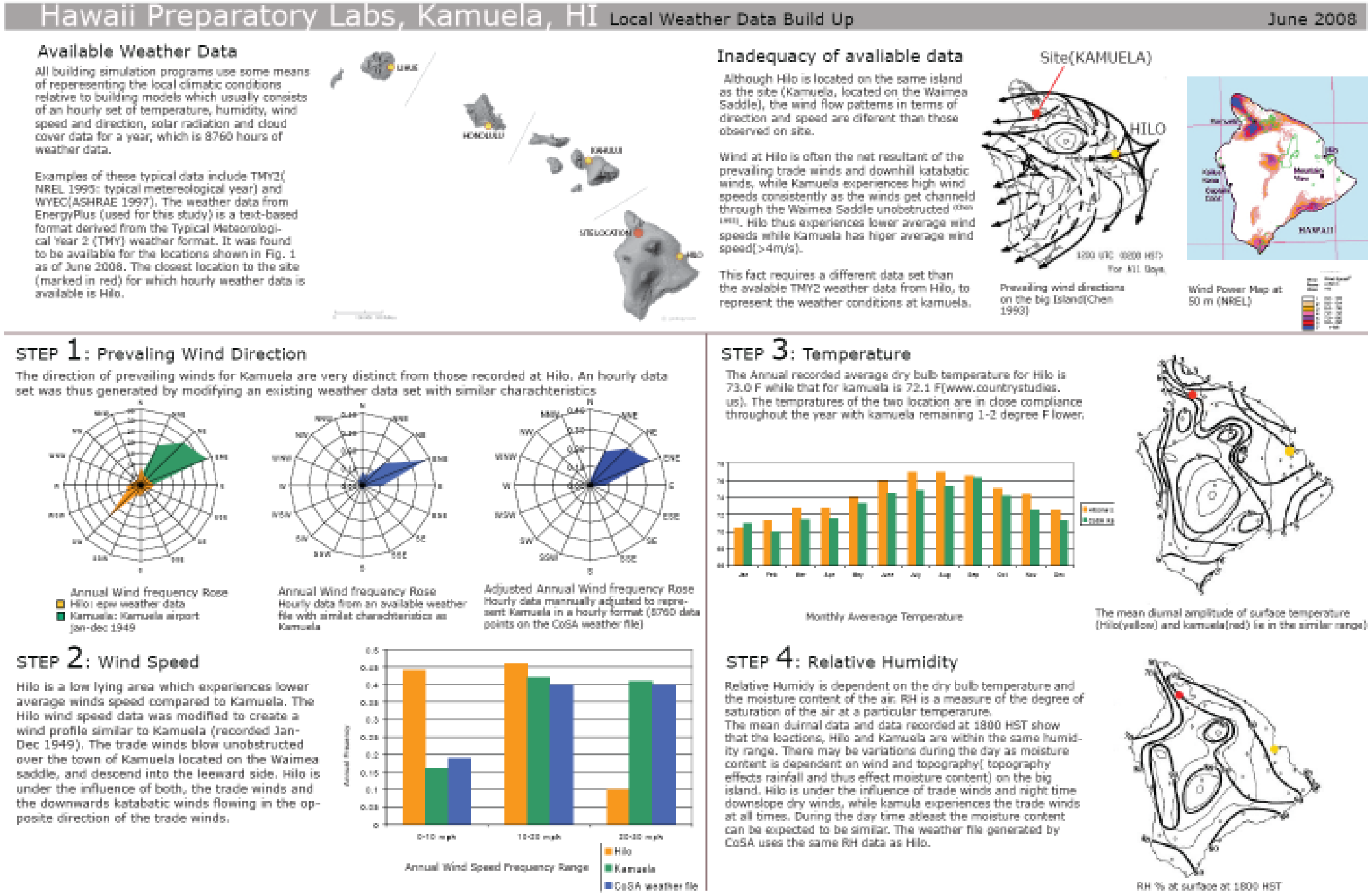
CASE I: Southwards blowing winds (Aug 11)
CASE II: Northwards blowing winds (Mar 22)
CASE III: Low wind speeds (xxx mph)

CONCLUSIONS:
The labs are over heated 13% hours of the year (Indoor temp-outdoor temp>6F) under current scenario.

Office spaces on the north face are effectively ventilated and are able to maintain tempratures close to out door air conditions.

The study shows that there is a need to reduce the sensible load, especially in the labs which have southern exposure and are heavy on internal loads.

7.2 TMY2 Weather File Modifications to Account for Site Microclimate



Hawaii Preparatory Labs, Kamuela, HI Local Weather Data Build Up June 2008

Available Weather Data

All building simulation programs use some means of reperesenting the local climatic conditions relative to building models which usually consists of an hourly set of temperature, humidity, wind speed and direction, solar radiation and cloud cover data for a year, which is 8760 hours of weather data.

Examples of these typical data include TMY2(NREL 1995: typical metereological year) and WYEC(ASHRAE 1997). The weather data from EnergyPlus (used for this study) is a text-based format derived from the Typical Meteorological Year 2 (TMY) weather format. It was found to be available for the locations shown in Fig. 1 as of June 2008. The closest location to the site (marked in red) for which hourly weather data is available is Hilo.

Inadequacy of avaliable data

Although Hilo is located on the same island as the site (Kamuela, located on the Waimea Saddle), the wind flow patterns in terms of direction and speed are diferent than those observed on site.

Wind at Hilo is often the net resultant of the prevailing trade winds and downhill katabatic winds, while Kamuela experiences high wind speeds consistently as the winds get channeld through the Waimea Saddle unobstructed (Chen 1993). Hilo thus experiences lower average wind speeds while Kamuela has higer average wind speed(>4m/s).

This fact requires a different data set than the avalable TMY2 weather data from Hilo, to represent the weather conditions at kamuela.

Prevailing wind directions on the big Island(Chen 1993)

Wind Power Map at 50 m (NREL)

STEP 1: Prevaling Wind Direction

The direction of prevailing winds for Kamuela are very distinct from those recorded at Hilo. An hourly data set was thus generated by modifying an existing weather data set with similar charachteristics

Annual Wind frequency Rose
🟨 Hilo: epw weather data
🟩 Kamuela: Kamuela airport jan-dec 1949

Annual Wind frequency Rose
Hourly data from an available weather file with similat charachteristics as Kamuela

Adjusted Annual Wind frequency Rose
Hourly data mannually adjusted to represent Kamuela in a hourly format (8760 data points on the CoSA weather file)

STEP 2: Wind Speed

Hilo is a low lying area which experiences lower average winds speed compared to Kamuela. The Hilo wind speed data was modified to create a wind profile similar to Kamuela (recorded Jan-Dec 1949). The trade winds blow unobstructed over the town of Kamuela located on the Waimea saddle, and descend into the leeward side. Hilo is under the influence of both, the trade winds and the downwards katabatic winds flowing in the opposite direction of the trade winds.

Annual Wind Speed Frequency Range

STEP 3: Temperature

The Annual recorded average dry bulb temperature for Hilo is 73.0 F while that for kamuela is 72.1 F(www.countrystudies.us). The tempratures of the two location are in close compliance throughout the year with kamuela remaining 1-2 degree F lower.

Monthly Avearage Temperature

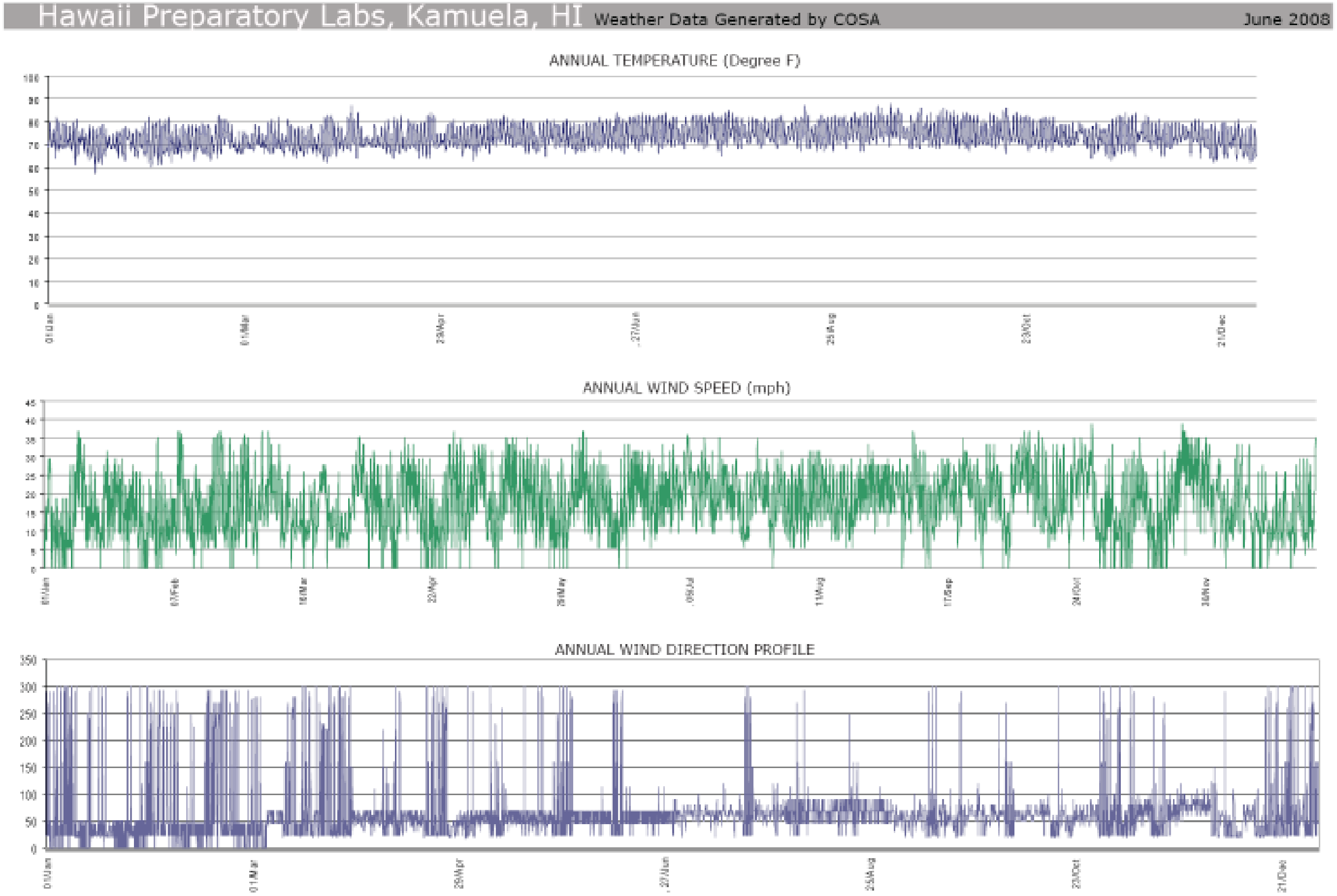
The mean diurnal amplitude of surface temperature (Hilo(yellow) and kamuela(red) lie in the similar range)

STEP 4: Relative Humidity

Relative Humidy is dependent on the dry bulb temperature and the moisture content of the air. RH is a measure of the degree of saturation of the air at a particular temperarure.
The mean duirnal data and data recorded at 1800 HST show that the loactions, Hilo and Kamuela are within the same humidity range. There may be variations during the day as moisture content is dependent on wind and topography(topography effects rainfall and thus effect moisture content) on the big island. Hilo is under the influence of trade winds and night time downslope dry winds, while kamula experiences the trade winds at all times. During the day time atleast the moisture content can be expected to be similar. The weather file generated by CoSA uses the same RH data as Hilo.

RH % at surface at 1800 HST

Appendix Figure 1. This board was presented to the design team on June 13 2008 to review and discuss adjustments made to customize the available hourly annual weather data for the likely conditions at the site.



Appendix Figure 2. The graphs above show the adjusted hourly annual weather data created by Buro Happold's CoSA team to account to the site's microclimate. This hourly data will be used in the energy modeling methodology required for LEED NC 2.2 Energy and Atmosphere Credit 1.

7.3 Fan Assisted Natural Ventilation Control Strategy

The attached design note was issued and discussed with the design team on June 13th.

COSA SOLUTIONS

Buro Happold Consulting Engineers

DESIGN NOTE

Project **Hawaii Preparatory Academy Energy Labs**

Subject **Natural Ventilation**

Author MA, MH To: Flansburgh Architects

Date: June 13, 2008 Project#:

Introduction

The purpose of this design note is to provide further clarification about the concept, design and control of fan assisted natural ventilation. Two system types shall be discussed, one with automatic control fan with motorised control of clerestory windows and second with manual operation of clerestory windows and fans.

A fan assisted ventilation strategy increases the number of hours during which comfort conditions are met when it is not possible to do so with natural ventilation under the following conditions:

1. During conditions of low external wind speeds (0-7 mph) the air change rate achieved due to cross ventilation or pressure differential (stack effect) may not be sufficient to maintain comfort conditions indoors.
2. Rainfall: During periods of heavy rainfall the clerestory windows may need to be closed to avoid water damage. This will lower the air change rate significantly inside the building and result in conditions outside of the thermal comfort range. Fan assisted ventilation will help avoid this condition.
3. Extremely high wind speeds can disturb activities indoors, raise dust and papers. Under these circumstances it is assumed the building occupants would shut the sliding glass doors and windows to restore desirable low air speed indoors. During this time a fan assisted strategy ventilation will draw air from the low level vents at moderate speed to ensure thermal comfort.
4. Night time purge: The doors and windows of the building shall be closed at night for security reasons. Fan assisted ventilation can be applied to take advantage of the relatively lower temperatures at night for night time cooling again drawing outside air at moderate speeds from the low level vents. This strategy can assist with providing thermal comfort during the early hours of occupancy the following day.

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Fan Assisted Ventilation

During the periods of fan assisted ventilation, exhaust fans draw hot air from the upper levels of the spaces (>7ft) and exhaust air at a volume capable of achieving 8 ach per hour. To make up the exhaust air, fresh air is drawn in from the out side at the lower level of the spaces (<7ft).

To ensure that fresh air is brought into the building at the occupied level (<7ft) it is necessary to close the high level clerestory windows at the time of the fan operation. The following options discuss the method of achieving the integration of the fan operation and the clerestory window openings.

SYSTEM OPTION 1: Motorised control of clerestory windows with sensor controlled fans

The operational integration of clerestory windows with indoor and outdoor weather sensors shall involve monitoring of indoor air temperature and outdoor weather conditions such as temperature, rain and wind speed. The indoor air temperature is measure both in the occupied zone (<7ft) and in the upper unoccupied zone (>7ft). The intent is to maintain the temperature in the lower zone within the comfort range and to avoid excessive heat build up in the upper zone. The fans would start up when the indoor and outdoor air temperature differential is greater that a pre determined tolerance limit (Fig 1). The control unit would also shut the fans down when the conditions are suitable for natural ventilation. Following are the cases when the control unit would turn on the fan and close the clerestory windows.

CASE 1: When the indoor temperature, as measured by the temperature sensors located in the upper area of the space, rises above the threshold of thermal comfort the clerestory windows close and the exhaust fans turn on.

CASE 2: When the wind speed is greater than 10mph and rain is detected the clerestory windows close. Following that, in case the temperature indoors rises above the threshold, the fans turn on.

CASE 3: Occupant control: In case the occupants experience thermal discomfort a manual switch can be used to turn on the fans to drive ventilation. The clerestory windows are closed via a signal from the control unit. The occupants only control the fan operation.

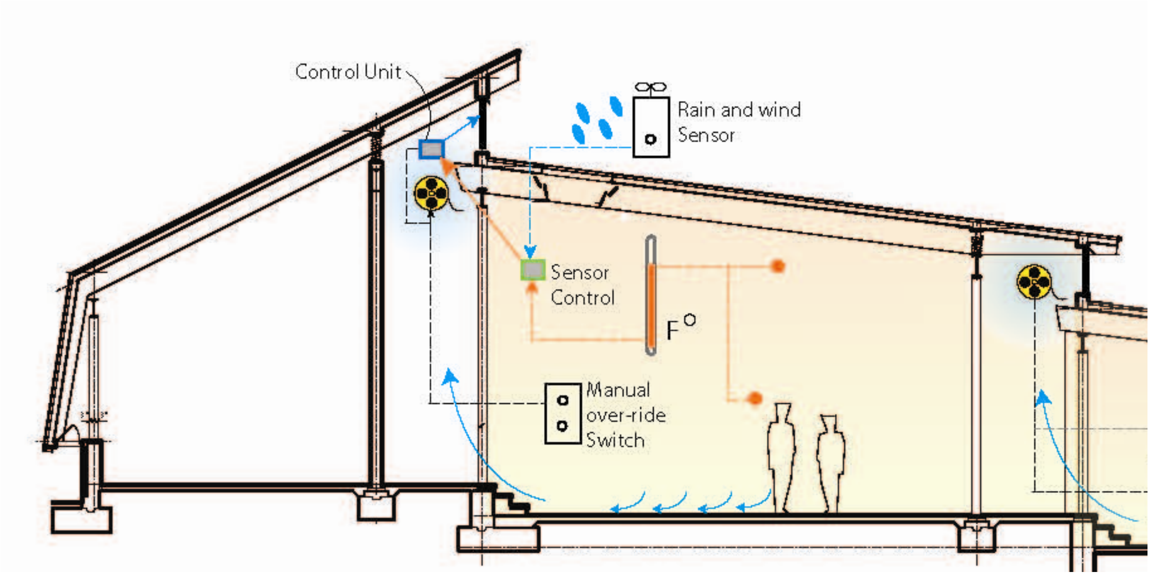

Figure 1: System set up for automated fan and clerestory window control

Components involved

1. Sensors: Indoor and outdoor temperature sensors and rain sensors supply weather condition data to the sensor control
2. Control Unit: Collects the readings from the different sensors and send the control signal to the window actuators for opening and closing the windows. It can control multiple windows at a time.
3. Window actuator: It controls the opening and closing of the windows.
4. Manual over-ride switch: The manual switch controls the fans and sends an over-ride signal to the control unit to close clerestory windows.

SYSTEM OTION 2: Manually operated clerestory window with indicators

The manually operated system consists of operable clerestory windows (Fig 4) with a manual crank at the lower level for the occupants to operate the windows. Indicators lights connected to an indoor and outdoor temperature sensor indicate when the conditions require occupants to turn on fans and close/open clerestory windows (Fig 3).

Option 1: Simple system with hand crack controlled clerestory windows and switch to manually operate fans based on occupant thermal comfort levels or noticing rain penetration into the interior.

Option 2: Additional Indicator lights linked to temperature sensors indicate conditions favourable for natural ventilation. A red light indicates when the users should close the windows and turn on the fans. A green light indicates when the users should turn off the fans and may open windows.

Option 3: In addition to option 2, a window switch can be installed at the clerestory windows with another indicator light to the users to warn the windows being open while the fans are on.

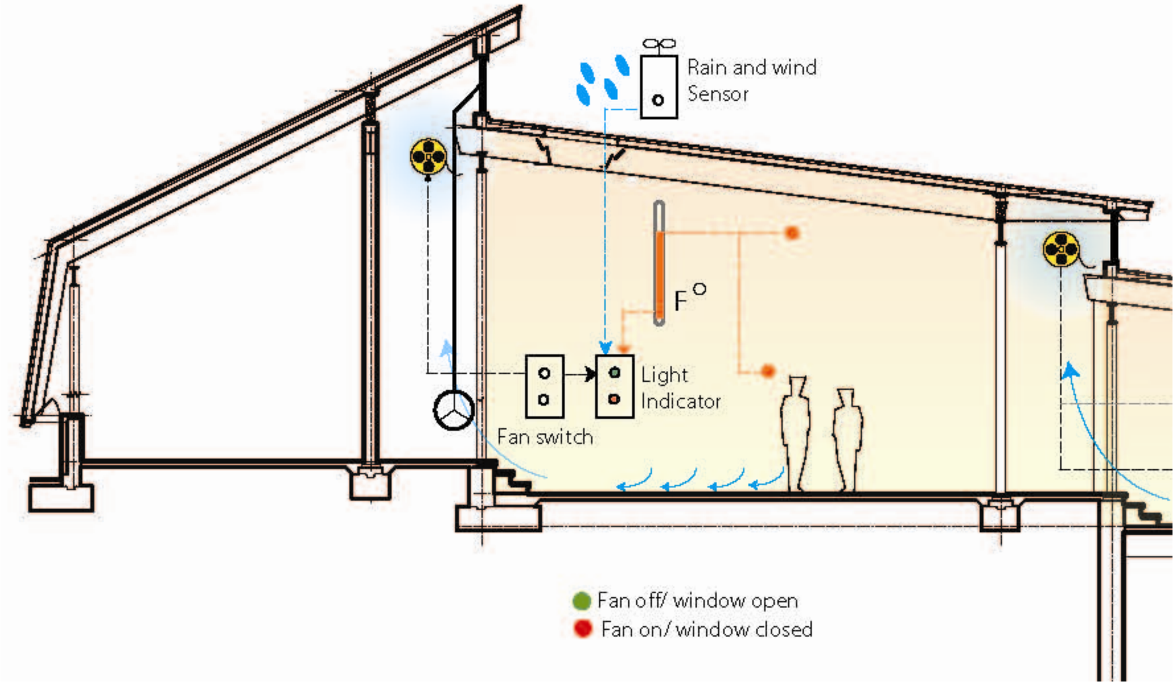

Figure 2: System diagram showing manually operated scheme

Figure 3: Indoor Wave Pool, Tempe, Arizona
www.daytonmetaproducts.com

Figure 4: Indicator lights for building occupants
AIA 2006 national convention and design exposition

System Comparison

AUTOMATIC SYSTEM

Pros:

- Ensures maximum occupant comfort under prevailing conditions
- Ensures economy in fan operation (energy conservation)
- Minimizes chances of rain damage
- Built in system intelligence

Cons:

- Higher first cost (equipment, installation, commissioning is essential)
- Life of actuators (typically 15 years)

MANUAL SYSTEM

Pros:

Simple system with low maintenance
Low first cost

Cons:

- High reliance on occupants to control indoor environment. The occupants are required to close the windows each time fans are required to be turned on.
- No assurance for protection from rain damage. Occupants must close the windows when it rains and also before leaving the building each day.
- Night time cooling not possible as the windows will have to be closed at night prevent possible rain damage