OPPORTUNITIES AND CHALLENGES IN EMPLOYING ENERGY ANALYSIS EARLY IN THE INTEGRATED DESIGN PROCESS

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ABSTRACT

This paper takes a case study approach to outlining the pursuit of early design energy analysis on two National Park Service (NPS) projects. 'Early design energy analysis' here refers to analysis during programming and schematic design with inputs based on reasonable assumptions to obtain results that guide the rest of the design process.

Case Study 1: The proposed 17,000 gross square feet visitor center at Castillo de San Marcos National Monument (CASA) in St. Augustine, FL, is required by federal regulations to achieve energy performance that is 30% better than an ASHRAE 90.1-2004 baseline (a codified version of the Architecture 2030 challenge).

Case Study 2: The proposed 60,000 gross square feet Marine Research and Education Center in St. Croix, US Virgin Islands, is being designed to achieve net-zero energy performance and Living Building Challenge certification. Adaptive comfort based design aids in integrating passive survivability, cooling-load avoidance, natural ventilation, and onsite renewable energy generation.

1. CASE STUDY 1 - INTRODUCTION

The proposed visitor center near the Castillo de San Marcos National Monument, roughly 17,000 ft² in program, is intended to:

- Connect the visitor to the rich and unique military and civilian history of St. Augustine, FL.
- Connect the monument and the Spanish quarter living history museum
- Build context for both the monument and the Spanish quarter
- Function as a visitor gateway.
- Provide interpretation of archaeologically rich site
- Enhance the visitor experience with rotating exhibits

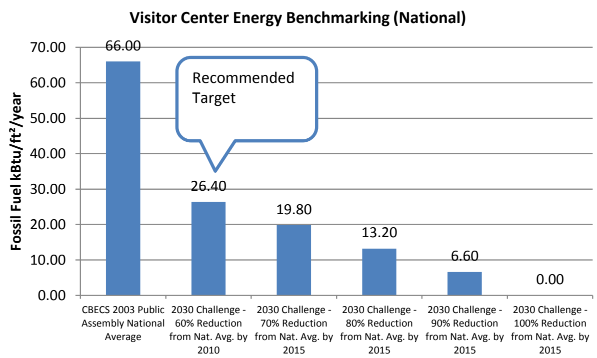
FIGURE 1. PROJECT SITE AND CONTEXT

In terms of sustainable design, challenging high performance goals have been set in the areas of site, water, energy, etc. The project hopes to achieve Gold level certification under the LEED NC 2009 rating system.

2. CASE STUDY 1 - METHODOLOGY

Federal mandate requires the building to exceed an ASHRAE 90.1-2004 baseline by at least 30%. Analysis however was carried out using the latest 2007 version, due to its relevance to LEED, energy code etc. An attempt to set a more absolute numerical target using the 'public assembly' building type from the CBECS 2003 database (1) yielded 26.4 kBtu/ft²/year, see Figure 2 below. Both these targets were considered simultaneously. The author was conscious of the uncertainty inherent to analysis at such early stages of the design process.

FIGURE 2. ENERGY BENCHMARKING AND TARGET SETTING



Climate analysis helped identify passive strategies based on their effectiveness for St. Augustine's climate. ASHRAE Handbook of Fundamentals Comfort Model 2005 and occupiable hours between 7 AM to 7 PM formed the basis for climate analysis.

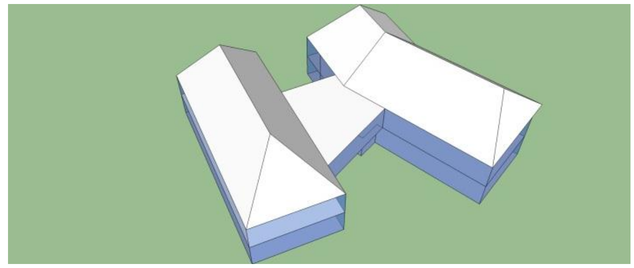
TABLE 1. PASSIVE STRATEGIES AND THEIR EFFECTIVENESS

Strategy	% of annual time comfort achieved
Already in comfort	14.7%
Sun Shading of Windows	38.4%
Natural Ventilation Cooling	19.1 %
Fan-Forced Ventilation Cooling	20.9%
Passive Solar Direct Gain with Low Mass	13%

We were an early adopter of the energy analysis program Sefaira Concept (2), (the 'analysis program'). This visitor center project was chosen as a test case for early design energy analysis using this analysis program purely based on timing. The authors understanding of this program's pre-release version was that it was a cloud-based iterative tool that could help compare different massing options and also effectiveness of design strategies within a massing option. Strategies could also be lumped into bundles and tested together for relative effectiveness.

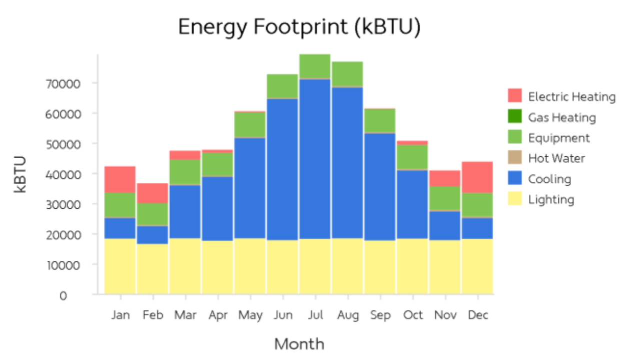
While three different design schemes were under development as options, the in-depth iterative analysis was performed on one of the schemes.

FIGURE 3. SKETCHUP GEOMETRY OF SCHEME A UTILIZIED BY THE ENERGY ANALYSIS PROGRAM



Geometry was created using the software SketchUp specifically for the purpose of exporting to the analysis program. Windows were not defined in detail because the window-to-wall ratio could be independently altered by orientation using a slider bar within the analysis program. The baseline case window-to-wall ratio was held at 50%. Space use type percentages were captured from the program and ASHRAE 90.1-2007's prescriptive requirements were assigned to envelope properties, lighting power densities, and HVAC system efficiencies to create the baseline case. Weather file of Jacksonville, FL, the closest available to the project site, was picked by the analysis program.

FIGURE 4. BASELINE ENERGY USE DISTRIBUTION



From Figure 4, it can be observed that cooling and lighting are the high impact areas for this project.

FIGURE 5. SCREENSHOT OF THE ANALYSIS PROGRAM INTERFACE SHOWING SAVINGS FROM INDIVIDUAL STRATEGIES OVER THE ASHRAE 90.1 2007 BASELINE

Run Analysis / New Strategy	Annual Energy Consumption kBTU		Annual Energy Use per Gross Internal Area kBTU/ft2	
Baseline + Measures	749,515		42	
shading_4'	730,245	↓3%	41	↓2%
shading_3'	733,218	↓2%	41	↓2%
shading_2'	737,214	↓2%	41	↓2%
shading_1'	742,449	↓<1%	42	0%
Wall_Rvalue20	744,086	↓<1%	42	0%
Wall Type (Stud)				
Wall Thermal Resistance (20.(				
Wall_Rvalue15	746,351	↓<1%	42	0%
Wall Type (Stud)				
Wall Thermal Resistance (15.0				
Wall_Rvalue10	745,481	↓<1%	42	0%
Wall Type (Concrete Block)				
Wall Thermal Resistance (10.0				
Glazing_SeriousSG5	734,722	↓2%	41	↓2%
Glazing U-Factor (0.30 BTU/h·1				
Glazing SHGC (0.23)				
Glazing_ViraconVUE1-40	731,223	↓2%	41	↓2%
Glazing U-Factor (0.40 BTU/h·				
Glazing SHGC (0.2)				
Glazing_Solarban70XL	741,817	↓1%	42	0%
Glazing U-Factor (0.40 BTU/h·				
Glazing SHGC (0.25)				
WWR25	715,793	↓4%	40	↓5%
WWR30	722,465	↓4%	40	↓5%
WWR35	729,183	↓3%	41	↓2%
WWR40	735,928	↓2%	41	↓2%

The analysis program's 'response curve' feature wasn't yet available at the time of this analysis, so incremental options from each envelope measure were modeled to approximate the point of diminishing returns. Based on the energy savings illustrated in Figure 5, from the bottom to the top, the following options were chosen:

- A building wide window-to-wall ratio of 25 to 30% (4-5% savings over baseline)
- Glazing SHGC of 0.2 to 0.23 (2% savings over baseline)
- Window overhang of 2' (2% savings over baseline)

Improving the wall's thermal resistance over the baseline did not yield significant savings.

The analysis program had the capability of modeling the following HVAC system types explicitly:

- Split Air Conditioning and Boiler or Heat Pump
- Central Plant and Air Distribution

The baseline HVAC system, System 4 PSZ-HP per Appendix G of ASHRAE 90.1-2007, was modeled using the Split Air Conditioning/Heat Pump option.

In the HVAC area, savings from improved efficiency and fan energy were calculated for the following options using the listed assumptions:

TABLE 2. HVAC IMPROVEMENT ASSUMPTIONS

	Efficiency (COP)	Fan Energy (CFM/HP)	Other
Baseline Cooling	3.28	658	None
Baseline Heating	3.25		
Ground Source Heat Pump (GSHP) Cooling	4.75*	1700	None
GSHP Heating	3.6*		
Variable Refrigerant Flow (VRF) Cooling	4.75**	2000	None
VRF Heating	3.6**		
High. Eff. Rooftop VAV Cooling	3.43	1200	VAV Box Minimum Flow set to 18%, airside economizer enabled
High Eff. Rooftop VAV Heating	3.55		

(*) While there was no direct way of modeling GSHP system types, we felt that applying improved efficiencies (per ASHRAE 90.1-2007 Table 6.8.1B) and improved fan energy performance (per mechanical engineer's preliminary calculations) to the split system was a conservative way to estimate the GSHP system performance.

(**) Based on industry/manufacturer studies (3) (4) reporting savings from VRF compared with more conventional counterparts, we felt it was reasonable to assume for early design stages that its performance would be in the same vicinity as the GSHP.

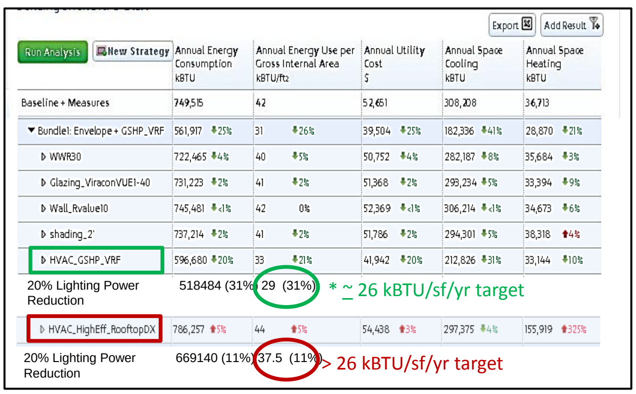
The 'Central Plant and Air Distribution' system type modeled by the analysis program represented a chilled water system utilizing a water chiller and a cooling tower. The high efficiency rooftop VAV system we were trying to test was just a packaged VAV rooftop system with no chilled water. We tried to model the Rooftop VAV system using the Central Plant option but could not derive meaningful results. Despite our best efforts to accommodate economizer and natural ventilation, the proposed design showed negative savings compared to the baseline case. This was an insurmountable shortcoming for us to make an apples-to-apples comparison. The results are presented as is in the Figure 6 and Table 3.

Improvements to lighting power density (LPD) could not be directly tested as a parametric run using the analysis program. A conservative workaround to testing 20% improvement was to subtract 20% from the lighting energy consumption results (this did not account for cooling energy savings and heating energy penalty).

3. CASE STUDY 1 – RESULTS

The chosen envelope strategies were bundled with HVAC improvements and LPD improvement to assess their overall impact on the baseline model.

FIGURE 6. MODIFIED ANALYSIS PROGRAM SCREENSHOT SHOWING RESULTS FROM APPLYING BUNDLES OF STRATEGIES



Run Analysis / New Strategy	Annual Energy Consumption kBTU	Annual Energy Use per Gross Internal Area kBTU/ft2	Annual Utility Cost $	Annual Space Cooling kBTU	Annual Space Heating kBTU
Baseline + Measures	749,515	42	52,651	308,208	36,713
Bundle1: Envelope + GSHP_VRF	561,917 ↓25%	31 ↓26%	39,504 ↓25%	182,336 ↓41%	28,870 ↓21%
WWR30	722,465 ↓4%	40 ↓5%	50,752 ↓4%	282,187 ↓8%	35,684 ↓3%
Glazing_ViraconVUE1-40	731,223 ↓2%	41 ↓2%	51,368 ↓2%	293,234 ↓5%	33,394 ↓9%
Wall_Rvalue10	745,481 ↓<1%	42 0%	52,369 ↓<1%	306,214 ↓<1%	34,673 ↓6%
shading_2'	737,214 ↓2%	41 ↓2%	51,786 ↓2%	294,301 ↓5%	38,318 ↑4%
HVAC_GSHP_VRF	596,680 ↓20%	33 ↓21%	41,942 ↓20%	212,826 ↓31%	33,144 ↓10%
20% Lighting Power Reduction	518484 (31%)	29 (31%)	* ~ 26 kBTU/sf/yr target		
HVAC_HighEff_RooftopDX	786,257 ↑5%	44 ↑5%	54,438 ↑3%	297,375 ↓4%	155,919 ↑325%
20% Lighting Power Reduction	669140 (11%)	37.5 (11%)	> 26 kBTU/sf/yr target		

TABLE 3. WHAT FIGURE 6 MEANS

Bundle of strategies	Design's % better than ASHRAE 90.1-2007 Baseline	Design kBtu/ft²/year
GSHP/VRF + envelope improvements + LPD improvement	31%	29
High Eff. VAV Rooftop + envelope improvements + LPD improvement	11% (inconclusive)	37.5 (inconclusive)

4. CASE STUDY 1 – DISCUSSION

As discussed earlier, the modeling process was not completely fair to the High Efficiency Rooftop VAV system. The analysis however shows that modest envelope and lighting improvements coupled with a very high efficiency HVAC system such as a GSHP or a VRF system should help the project meet the federal mandate's requirement of exceeding an ASHRAE 90.1-2004 baseline by 30%.

Greater emphasis will be placed on quantifying the effects of passive solar, daylighting, and natural ventilation in later stages of design. As detailed plug loads and exhibit lighting information becomes available, these will be input into the later stage energy models, along with HVAC system modeling with a greater degree of detail. Feedback was provided to the manufacturer of the analysis program on the need for the following:
- Increased ability to test passive strategies
- More HVAC system types
- The ability to model lighting power density improvements parametrically.

5. CASE STUDY 2 – INTRODUCTION

The Marine Research and Education Center (MREC) is a partnership project between the National Park Service and Joint Institute for Caribbean Marine Studies to build a marine biology research laboratory campus on the island of St. Croix in the U.S. Virgin Islands. The program is intended to:

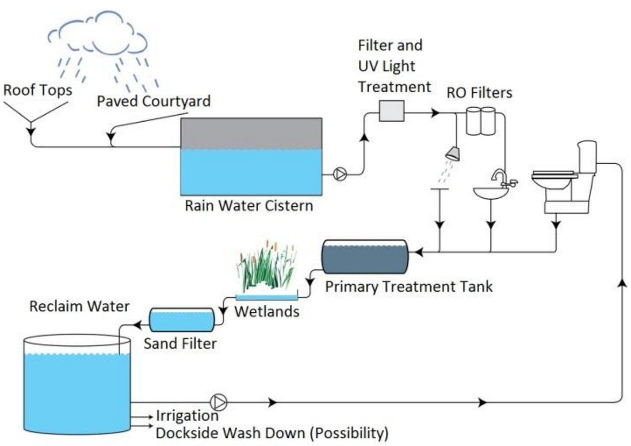
- Build a better understanding of the sustainability and health of tropical and subtropical marine ecosystems through scientific studies

- Educate both students and the public of the economic and cultural heritage associated with coral reef systems

The island of St. Croix is in a hurricane prone location and the island's municipal electricity supply is not only the most expensive in the United States at $0.49 per kilowatt hour, is prone to frequent and spontaneous outages. These power outages are a challenge to the laboratory research being performed on site, which requires a reliable and continuous source of electricity. Another challenging aspect of the project is the lack of freshwater sources on the island, so all water that is consumed must either be collected or produced via desalinization. Consequently, local building code requires that a minimum of 10 gallons of water storage are constructed for every square foot of roof; this is equivalent to around 600,000 gallons of water for the MREC project.

The project which is currently in the schematic design phase is pursuing both LEED Platinum and a minimum of three petals under the Living Building Challenge certification with full Living Building Certification being a reach goal for the project. Due to the local electrical and water issues, it was determined early on that the net-zero energy and water petals were not just sustainability goals, but a necessity to allow the project to function in its remote, hurricane prone location. These goals challenged the project team to generate enough energy on-site to fully support the program and to collect and store enough water for all occupant and project uses. In addition, the project needed to treat wastewater on site, as task conceptually solved as shown in Figure 7 courtesy of Natural Systems International (5).

FIGURE 7. SITE WATER CYCLE DIAGRAM



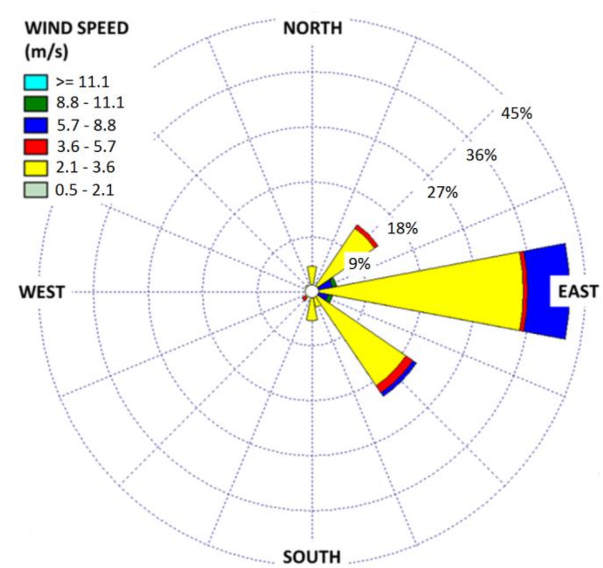
6. CASE STUDY 2 – METHODOLOGY

A sustainable building design must harness the local climate conditions in order to meet the program needs in an environmentally responsive manner. One of the first steps in the design process was a thorough climate analysis which was performed using Ecotect, Climate Consultant and round tables with key program members and locals of St. Croix. This comprehensive analysis helped the team narrow in on both passive and active strategies to help reduce the total energy and water consumption of the project.

The climate analysis included both a wind rose and solar radiation study and analysis of this data helped the team select which renewable technologies would produce the greatest energy generation with the smallest impact to the projects overall budget and development footprint. The analysis drove the team to focus on solar energy technology first – both photovoltaics and solar thermal – and this early decision contributed to further design decisions. The campus buildings needed to be designed in a way that could both harness the high amount of solar radiation, while reducing unwanted heat gains within the spaces. Proper building orientation and sun shading placements are key to this campus responding to the climactic solar radiation in a beneficial manner. This early analysis allowed the team to determine that the optimal solar orientation of the buildings would take precedence in the site design

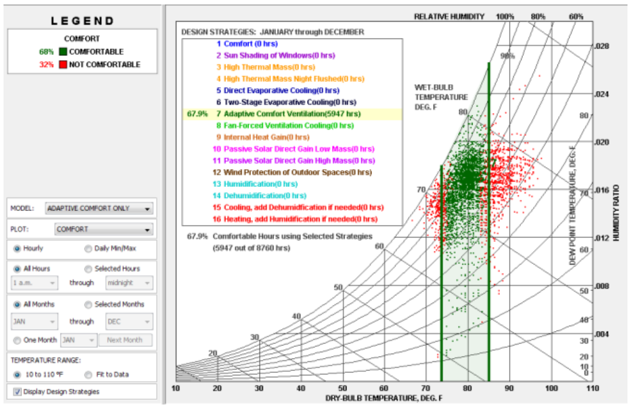
While the climate analysis leant the design team to focus on harnessing solar energy, the project will still utilize wind energy to smaller degree. Wind rose data will be taken into account for appropriate siting, sizing and selection of wind turbines. The turbines will be configured in a way that takes advantage of the strong easterly winds in the range of wind speeds in figure 8 (6).

FIGURE 8. WIND ROSE DIAGRAM FOR ST. CROIX



An adaptive comfort analysis was performed during the projects programming phase and became one of the most important design strategies used to achieve the energy reduction goals. The use of adaptive comfort ventilation, which assumes that occupants adjust their clothing to the local weather conditions and that the windows are operable, can meet comfort conditions for about 68 percent of the time as seen below in Figure 9 (7). Every point represents an hour of the 8760 hours in a year and those points in green represent the hours that are within acceptable comfort ranges according to the ASHRAE 55 Adaptive Comfort Model.

FIGURE 9. PSYCHROMETRIC CHART –ADAPTIVE COMFORT ANALYSIS



A detailed programming effort in collaboration with the users and owner combined with the adaptive comfort analysis helped create distinct project "conditioning zones" which help minimize the square footage of HVAC controlled spaces and maximize the square footage that can be passively conditioned. Only through this programming effort was it concluded that traditional laboratory environments, which often require steady temperature and single pass air, were not required to support anticipated research at the facility. Three conditioning zones with varying levels of stringency were created in order to support the programs as shown in Table 4.

TABLE 4. CONDITIONING ZONES

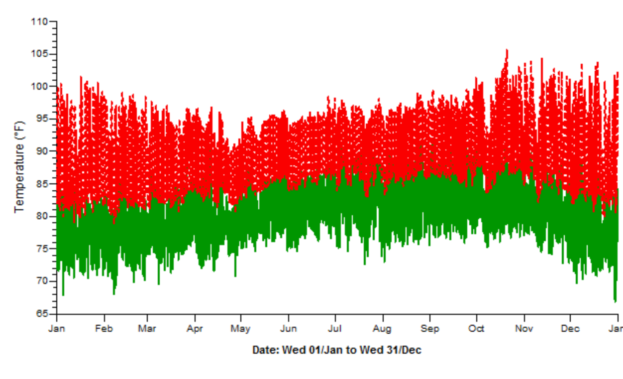
Zone	Temperature Control	Humidity Control
M	72°F ± 3°F	45-60%
A	Ambient to 78°F	60% max
C	Ambient	Ambient

The tiered project conditioning zones allow the project energy requirements and cost to be dramatically reduced while still effectively meeting all program requirements. Zone M represents the most stringent of the zones and serves a small museum archival storage space which requires strict temperature and humidity controls in order to comply with Federal Archival standards (this is about 1.5% of the total project). Zone A space is comprised of core research labs, the auditorium and some support spaces – in total about 25% of the project's total square footage. This space relies on the adaptive comfort model and since these spaces are marine research labs with saltwater tanks the humidity control will be especially important to create a comfortable environment. Zone C space is the least stringent of the zones and represents the vast majority of the project area. It was determined through analyses that occupant comfort could be achieved with the use of passive design strategies which include cross and stack natural ventilation, high-mass construction, proper orientation, solar shading and the use of ceiling fans to increase air movement and increase occupant comfort.

Computational Fluid Dynamic (CFD) models were developed to help verify that the schematic design Zone C spaces were designed to help promote the comfort of the occupants in these naturally ventilated spaces. Typical housing units and Zone C, naturally ventilated lab spaces were modeled using IES VE Pro Macroflo and Microflo software.

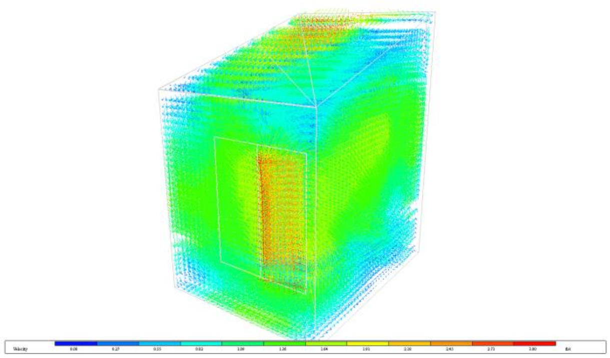
Macroflo analysis shows over a 10°F difference in air temperature year round within a typical housing unit when comparing a unit with the windows closed to one with 50% of the window area open. Figure 10 (8) below depicts the annual temperature variation with the red representing the housing unit with windows closed and temperature varying from 80-100°F and the green represents the windows being open 50% and a variation between 70-85°F. This graphic demonstrates that the current schematic design allows for a significantly cooler housing unit just by opening windows – further sustainable design strategies can help increase the comfortable hours further.

FIGURE 10. MACROFLO TEMPERATURE COMPARISON FOR TYPICAL HOUSING UNIT



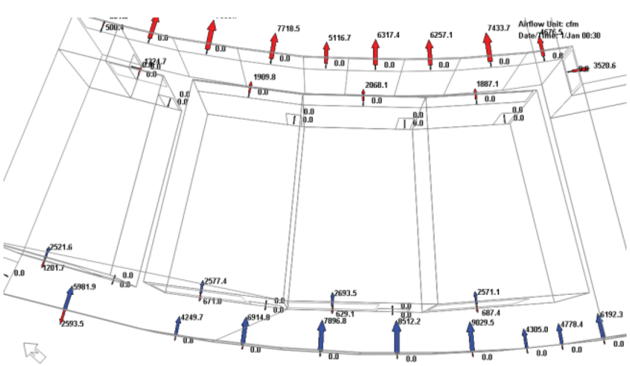
The velocity vector diagram below in Figure 11 (8) shows a CFD model that was performed for one of the bedroom units on August 1st, statistically the hottest day of the year. The analysis helps confirm that stack ventilation is working in the space to help promote air movement and occupant thermal comfort within the spaces. The colors in the image denote velocity from zero feet per second in blue to three feet per second in red. Microflo analysis was also used to show that the average temperature in the typical room sits around 81°F at 5 feet in height on the hottest day.

FIGURE 11. MICROFLO VELOCITY VECTORS FOR TYPICAL HOUSING UNIT TO ANALYZE STACK EFFECT VENTILATION



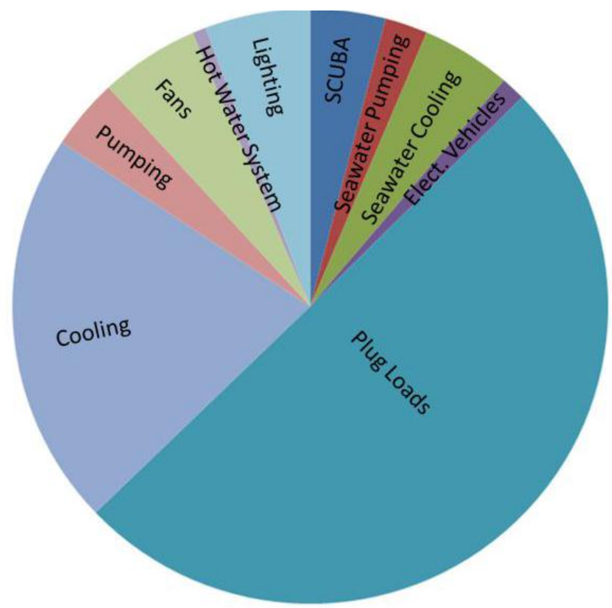
One of the proposed laboratory spaces was modeled to verify that the current design is suited to pull air through the spaces to supply occupant thermal comfort. Figure 12 (8) below shows the air being drawn in from the southern façade and circulating through and up out of the higher windows on the north façade. Since it is planned for these spaces to be screened, the openings were considered 90% open for the purpose of the analysis.

FIGURE 12. MACROFLO VELOCITY ARROWS DEMONSTRATE CROSS AND STACK VENTILATION IN OPEN LAB SPACES



A preliminary design energy model was run for the project using eQuest (9) in order to estimate the sites annual energy usage. These first pass models were used to determine whether net-zero energy target is achievable and help identify potential areas of energy reduction. Based upon these early estimates, the largest area of power consumption are plug loads as shown in the largest blue slab below in Figure 13 courtesy of Integral Group (10).

FIGURE 13. CAMPUS ANNUAL POWER USAGE BY CATEGORY



7. CASE STUDY 2 – RESULTS

The early design analyses and collaborative design efforts resulted in the schematic design site plan shown below in Figure 14. The plan combines the outreach and laboratory components of the program into a larger structure that follows the contours of the existing hill, grouping our project conditioning zones together for efficiency. The living portion of the project, all of which is naturally ventilated, is located to the east of the main lab building and clustered into three bar buildings which cascade down the hill. This site plan was selected based upon the outcome of a Choosing By Advantages (CBA) meeting where major project stakeholders were present to help assign value to the elements that are important to the mission of the project. The high-reaching sustainability goals of the project weighed heavily in the CBA and the overall site plan is an optimization of all project and deep-green goals.

FIGURE 14. MARINE RESEACH & EDUCATION CENTER SCHEMATIC DESIGN SITE PLAN

8. CASE STUDY 2 – DISCUSSION

The use of multiple preliminary design analyses and engaging with team members in an integrated design process is a necessity to achieve the high-reaching project goals. The process included a detailed climate analysis, adaptive comfort study, program evaluation, computational fluid dynamic analysis and preliminary energy analysis, all of which allowed the project team members to collaboratively target effective strategies to meet the lofty goals of net-zero energy and water. The analyses both informed and validated that the sustainable design strategies that the team employed were effective. As the project moves forward into later design phases the analyses will be further refined to continue to assure that the project progresses towards its overall project mission and sustainable design goals.

9. ACKNOWLEDGMENTS

Case Study 1 - Input of Todd Mowinski of Newcomb & Boyd, the project's mechanical engineer, was crucial to the analysis process. Meg Needle, the project's PM from Lord, Aeck & Sargent was also an active participant in the collaborative design process.

Case Study 2 – The input of John Weale, Senior Technical Engineer at Integral Group, was critical in the preliminary energy model and early innovative mechanical design strategies. Joshua Gassman, the Project Manager from Lord, Aeck & Sargent also played an active role in leading and coordinating the team throughout the early design.

10. REFERENCES

(1) U.S. Department of Energy, Energy Information Administration. (n.d.). *2003 CBECS National median source energy Use*. Retrieved from website: http://www.energystar.gov/ia/business/tools_resources/new_bldg_design/2003_CBECSPerformanceTargetsTable.pdf?167b-3052

(2) Sefaira Ltd. (2012). *Sefaira concept*. Retrieved from http://www.sefaira.com/products/sefaira-concept/

(3) Mitsubishi Electric US, Inc. (2012). *Energy efficient hvac design*. Retrieved from http://www.mitsubishipro.com/en/professional/overview-and-benefits/benefits-variable-refrigeration-system/energy-efficiency

(4) Mitsubishi Electric US, Inc. (2009). *Energypro building energy analysis - hotel building*. Retrieved from http://vrf.mitsubishipro.com/media/226516/energypro-hotel.pdf

(5) Natural Systems International. (2013). Retrieved from http://www.natsys-inc.com/

(6) Lakes Environmental Software. (2013). Retrieved from http://www.weblakes.com/products/wrplot/index.html

(7) Milne, M. (2013). Retrieved from http://www.energy-design-tools.aud.ucla.edu/

(8) Integrated Environmental Solutions Limited. (2013). Retrieved from http://www.iesve.com/

(9) Hirsch, J. (2009). Retrieved from http://www.doe2.com/equest/

(10) Integral Group. (2013). Retrieved from http://www.integralgroup.com/services/mechanical/