FINDINGS

Perspective of Project

The team simulated improved energy performance. Based on historic data used for solar power installations and future weather files/conditions and future weather predictions associated with various global emissions projections and the resulting global temperatures.

Alongside the energy analysis, WSP conducted detailed thermal comfort modeling to evaluate the applicability of passive cooling and/or mixed mode operation of the air conditioning systems in the residential units. The thermal comfort modeling looked at both existing weather files/conditions and future weather predictions associated with various global emissions projections and the resulting global temperatures.

INTRODUCTION

WSP set out to create a whole-building energy model that represents a speculative future development of two five-story multi-family buildings in Waipahu, Hawaii. Each building is approximately 20,000 ft².

The goal of WSP’s effort is to demonstrate a process that can be used during an early design phase at multiple transit-oriented development (TOD) sites. WSP hopes that the results of this process can also be used to help inform designers, developers, and the state of which building features/building model inputs will provide the biggest impact on the energy performance, peak loads, energy cost, building operating emissions, and building energy consumption profiles throughout the day and throughout the year.

Approach

WSP’s approach is broken up into three main tasks:

1. Designing to the IECC 2015 code can be achieved without additional effort and designers/building operators have the tools to achieve built performance.
2. Driving building energy consumption down will take more than code minimum design.
3. parametric energy models with multiple design variables developed by WSP and by the Environmental Research & Development Design Lab (ERDL).

Each building is approximately 20,000 ft². WSP set out to create a whole-building energy model that represents a speculative future development of two five-story multi-family buildings in Waipahu, Hawaii. Each building is approximately 20,000 ft².

Thermal Comfort Analysis

- Strategies for peak electricity load reduction are presented and may be of interest for reducing demand on the grid or a customer’s demand charges. Peak electrical demand can be reduced by having no AC, high efficiency AC, minimum ventilation, lower window-to-wall ratio, higher shading ratio, and better window performance (lower solar heat gain coefficient). On-site battery storage can shave the peak electrical demand.
- Thermal Comfort - Based on historic data used to create a statistical Typical Meteorological Year, Honolulu’s climate allows for a good level of comfort throughout the year (more than 90% comfortable). We would encourage developers and designers to design for passive cooling and provide provisions for future installation of AC. Installation of AC in present day buildings may unnecessarily increase building energy use. The findings may also motivate the State to adopt more stringent energy targets which would mitigate climate change and decrease the need for future AC installation and energy use.

Thermal Comfort

Peak Cooling - Peak cooling demand can be reduced by providing minimum ventilation, building orientation with long north and south facades, lower window-to-wall ratio, higher shading ratio, and better window performance (lower solar heat gain coefficient).

Peak Electrical Demand

- Strategies for peak electricity load reduction are presented and may be of interest for reducing demand on the grid or a customer’s demand charges. Peak electrical demand can be reduced by having no AC, high efficiency AC, minimum ventilation, lower window-to-wall ratio, higher shading ratio, and better window performance (lower solar heat gain coefficient). On-site battery storage can shave the peak electrical demand.

Thermal Comfort

- Based on historic data used to create a statistical Typical Meteorological Year, Honolulu’s climate allows for a good level of comfort (87.7% “comfortable”) without supplemental air movement or mechanical cooling. By adding in ceiling fans/AIR movement, thermal comfort can be increased to 96.4% of the year (based on the ASHRAE 55 adaptive thermal comfort benchmark). For reference, a typical conditioned office space is considered properly designed when comfort targets are achieved 98% of the year.

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<th>Peak Cooling</th>
<th>Peak Electrical Demand</th>
<th>Thermal Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>TASK I: Energy Goal Setting</td>
<td>Create and compare energy targets from multiple sources and determine an appropriate energy goal for the proposed TOD building in Waipahu.</td>
<td>Based on historic data used for solar power installations and future weather files/conditions and future weather predictions associated with various global emissions projections and the resulting global temperatures.</td>
<td>- Strategies for peak electricity load reduction are presented and may be of interest for reducing demand on the grid or a customer’s demand charges. Peak electrical demand can be reduced by having no AC, high efficiency AC, minimum ventilation, lower window-to-wall ratio, higher shading ratio, and better window performance (lower solar heat gain coefficient). On-site battery storage can shave the peak electrical demand.</td>
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</tr>
</tbody>
</table>
TASK I: ENERGY GOAL SETTING

The first task of the project was to establish energy benchmarks that will help understand the spectrum of energy performance for residential buildings in Honolulu.

WSP reviewed data from the Commercial Building Energy Consumption Survey (CBECS), Energy Star, Hawaii Energy, and modeled the IECC 2015 baseline. The chart to the right shows Energy Use Intensity (EUI) for the building data available in the CBECS. Overlaid on top of the CBECS data are the benchmarks chosen for this project. Note that the National Average and Local Selection Average (based on Hawaii Energy Data) is much lower than most of the CBECS buildings and the Energy Star Median Property. Potential reasons for the discrepancies are CBECS data groups multifamily housing with dorms, hotels and even assisted living facilities. These all fall under the “lodging” category and may be more densely occupied and occupied for more house of the year than a typical residential building reflected in the Hawaii Energy data. In addition, Climate Zone 5 used for CBECS, groups Hawaii, Alaska, California, Washington and Oregon together.

The Residential Energy Consumption Survey (RECS) was also considered as a data source but the data available isn’t able to be organized to show a clear correlation to our proposed building in Hawaii. The main reason for this is that the RECS data is focused mainly on single family homes and not multifamily buildings.

TASK II: ENERGY ANALYSIS

INTERNATIONAL ENERGY CONSERVATION CODE (IECC) 2015 BASELINE

Using the IECC 2015 prescriptive requirements a baseline energy model was created to determine the energy performance for a code minimum building. This resulted in a EUI of 33.6 kBtu/ft²/year. The larger energy consumption end uses include cooling energy/ HVAC, equipment (plug loads), lighting energy, and domestic hot water, as shown in the charts to the far right.

Using this IECC 2015 model as reference WSP iteratively explored design modifications including envelope upgrades, internal load changes, and higher efficiency systems.

A detailed breakdown of the inputs used for this analysis is on the following pages.
TASK II: ENERGY ANALYSIS

IECC BASELINE DEMAND PROFILES

Based on the IECC 2015 baseline energy model, WSP developed total building electrical demand on an hourly basis.

The annual peak demand is around 87kW, with typical summer and fall daily peaks just under 70kW.

Daily peak demand consistently occurs in the late afternoon when the solar gain and external loading of the space cause the air conditioning system to work its hardest. This indicates an opportunity to reduce peak demand using battery storage systems. This will both help balance the load on the electrical grid and reduce building electrical demand costs if currently proposed demand and time of use pilot programs go into effect.
TASK II: ENERGY ANALYSIS

PARAMETRIC SIMULATION INPUTS

Once the IECC baseline energy model was established, the next step was to evaluate the impact of a number of different design variables on the overall building performance.

There are a number of different approaches for doing this type of analysis. For instance running a number of predetermined combination of design inputs or 'baskets' and comparing these scenarios to the baseline. An even more holistic approach is to run many parametric simulations with all of the possible combinations of design variables cross-referenced, creating a data set that represents the whole range of possible performance outcomes. Working from this complete data set, the ideal 'baskets', or combinations of design variables, can be determined based on which design elements are most impactful in combination with one another.

This approach requires running many more simulations than the standard approach, but leveraging the Rhino/Grasshopper platform with the Ladybug and Ironbug plugins allows us to perform these thousands of simulations automatically over about a week.

The table to the right includes all of the major inputs used in energy simulations completed as part of the parametric analysis. Although each of the input categories are sorted into the 'Base Case', 'Marketable', and 'High Performance' the input categories were cross-referenced in the parametric simulation. This means that for each of the three HVAC system for instance, the simulation was run with all three glazing percentage options (or lighting, plug load, solar heat gain, shading ratio options) for a total of nine cross referenced simulations. Certain related values, such as thermal properties (U-value) for the opaque envelope components, were grouped together to reduce the number of total iterations.

ENVELOPE SIMULATION INPUTS

Envelope design inputs are based on the IECC 2015 requirements for climate zone 1A. The higher performance envelope was based on the New Building Institute (NBI) Multifamily Guide.

Glazing systems were selected with a window to wall ratio of 30% and iterated up to 50%. This was coupled with solar heat gain coefficients (SHGC) from 0.20 to 0.30. For infiltration the base case also refers to the NBI which classifies 0.29 ACH as the air change rate for standard envelope construction. On the high performance end of the range NBI sets an air change target of 0.013 ACH. The mid market option represents a 60% reduction over the standard envelope.

OCCUPANCY SCHEDULE

Modeling occupant loads generally assumed that half of the roughly 690SF units had two full-time occupants, with one thermal zone and thermostat, and a generic ASHRAE 90.1 Hotel occupancy schedule shown to the right. Plug loads are based on project experience in multifamily buildings. A power density of 0.4 W/SF is generally achievable with standard appliances, while 0.2 W/SF takes a concerted effort to select the best energy star rated appliances, or limit the number of major appliances in the unit.
TASK II: ENERGY ANALYSIS

HVAC SIMULATION INPUTS

Four main approaches to HVAC were evaluated in this study: (i) the baseline (IECC) compliant split system with natural ventilation, (ii) higher performing (EER 14.1) but readily available split systems with integrated ventilation, (iii) best available split systems (EER 15.2) with heat recovery ventilation, and (iv) a fully passively cooled and naturally ventilated design. Each case was modeled with a basic programmable thermostat allowing a nighttime setback to 80°F. The highest performance case included a smart thermostat able to turn off the HVAC system during unoccupied hours throughout the day (unoccupied hours were defined as occupancy below 30%).

DOMESTIC HOT WATER

Domestic hot water use represents a large portion of the energy consumption in residential buildings. The options considered are (i) the IECC 2015 baseline with a standard 80% efficient gas water heater, (ii) an air source heat pump with a coefficient of performance (COP) of 2.0, (iii) higher efficiency (HEHP) heat pumps with COP’s over 3.8, (iv) a heat recovery heat pump which captures heat from the condenser of the AC system, (v) solar thermal (ST) systems coupled with electric back up. All five of these systems configurations were included in the analysis and their relative energy performance are show in the figures below.

PASSIVE COOLING AND MIXED MODE SIMULATIONS

Additional passive design models were run on the 30% WWR IECC baseline building. The parameters for the passive cooling studies were as follows:

- Operable Window Area: 50%
- Opening Area Percent of Floor Area: 18.1%

For the completely natural ventilated/passively cooled case, the windows were opened when the interior temperature reached 78°F, which is the Energy Star recommended set point for residential cooling. The results of these studies are included in the thermal comfort section of this report.

For the mixed mode case, it is assumed the occupant closes the windows and uses mechanical cooling when the outdoor temperature goes above 78°F. Results for the mixed mode simulations are shown on page 11.

PARAMETRIC SIMULATION INPUT VARIABLES

<table>
<thead>
<tr>
<th>Category</th>
<th>Variable</th>
<th>Base Case</th>
<th>Low Performance / Marketable</th>
<th>High Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC System</td>
<td>HVAC System - cooling</td>
<td>Split (11.2 EER) IECC Baseline EER</td>
<td>Split (high perf 19 SEER, 14.1 EER, 4.12 COP) Market EER - ie LG HSV5</td>
<td>Split (Best 20.5 SEER, 15.2 EER, 4.45 COP) Best Available EER - ie Mitsubishi MUY</td>
</tr>
<tr>
<td></td>
<td>HVAC System - ventilation</td>
<td>naturally ventilated</td>
<td>ventilation via Split</td>
<td>high performance ventilation - HRV or airflow panels</td>
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<tr>
<td></td>
<td>temperature</td>
<td>naturally ventilated</td>
<td>ASHRAE 62.1 and 62.2</td>
<td>ASHRAE 62.1 and 62.2 x 130%</td>
</tr>
<tr>
<td></td>
<td>HVAC sizing - are the units variable speed</td>
<td>Constant Speed</td>
<td>Variable Speed</td>
<td>Variable Speed</td>
</tr>
<tr>
<td></td>
<td>Temperature Reset</td>
<td>Programmable Thermostat setback to 80°F (10pm-6am)</td>
<td>Programmable Thermostat setback to 80°F (10pm-6am)</td>
<td>off during &quot;low occupancy&quot; (less than 30% occupied)</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>Domestic Hot Water</td>
<td>Gas for IECC Baseline Air source heat pump (HP) - 2.0 COP</td>
<td>Heat Pump with Heat Recovery (HR) from AC or High Eff Heat Pump (HEHP) - COP 3.84</td>
<td>Solar thermal (ST) hot water 60% fraction with electric back up</td>
</tr>
</tbody>
</table>

LIGHTING

- Lighting (LPD - W/ft²): 0.51 (ASHRAE 2010) for Low Performance, 0.40 for Base Case, 0.30 for High Performance

OTHER

- Solar Power: None for Low Performance, None for Base Case, max. 75% of roof space for High Performance
- Solar Thermal: None for Low Performance, None for Base Case, 60% Solar Fraction for High Performance
- Battery Storage: None for Low Performance, None for Base Case, 10% of Peak Load (LEED O+M Demand Response) for High Performance

DOMESTIC HOT WATER

- Energy (kWh): 21,945 (Std Heat Pump), 11,429 (High Eff Heat Pump), 13,167 (Heat Recovery Heat Pump), 17,556 (Solar Thermal + Electric), 54,861 (Gas IECC)
- EUI (kBtu/ SF): 1.82 (Std Heat Pump), 0.95 (High Eff Heat Pump), 1.09 (Heat Recovery Heat Pump), 1.45 (Solar Thermal + Electric), 4.54 (Gas IECC)
The graph to the right is called a parallel coordinate plot, and it is a useful tool for visualizing the entire parametric data set. Depicted are all of the simulations that were performed, each represented by a line which tracks from the input variables on the left across to the output metrics on the far right. The line colors indicate each iteration's relative performance in terms of energy consumption, green being the least amount of annual energy (most efficient), and red the highest energy consumption.

From this complete data, it’s visually apparent that almost all of the highest energy consumption design combinations (red and orange colors) emanated from the low and medium efficiency HVAC systems, which is a key driver for efficiency. This data was then used to develop energy conservation measure baskets. The baskets were labeled:

1. IECC baseline
2. Developer preferred design case - WSP believes that this represents a model with combined energy efficiency measures likely to be adopted by the State today.
3. Highest performance 1 - this represents a model with a combination of the most aggressive energy efficiency measures
4. Highest performance 2 - this represents a model with a combination of the most aggressive energy efficiency measures and that is passively cooled/naturally ventilated.

### DESIGN VARIABLE 'BASKETS'

<table>
<thead>
<tr>
<th>Case</th>
<th>WWR</th>
<th>Shading Ratio</th>
<th>Opaque Envelope</th>
<th>Glazing U-value</th>
<th>SHGC</th>
<th>Lighting (W/SF)</th>
<th>Plug (W/SF)</th>
<th>Infiltration (ACH)</th>
<th>Ventilation (CFM/SF)</th>
<th>DHW</th>
<th>HVAC</th>
<th>EUI (kBtu/sf/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IECC 2015</td>
<td>30%</td>
<td>0%</td>
<td>IECC</td>
<td>0.5</td>
<td>0.35</td>
<td>0.51</td>
<td>0.4</td>
<td>0.29</td>
<td>ASHRAE</td>
<td>0.78</td>
<td>ST</td>
<td>33.6</td>
</tr>
<tr>
<td>Developer Preferred</td>
<td>50%</td>
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<td>IECC</td>
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<td>0.3</td>
<td>0.4</td>
<td>0.2</td>
<td>0.29</td>
<td>ASHRAE</td>
<td>0.78</td>
<td>ST</td>
<td>27.0</td>
</tr>
<tr>
<td>Highest Performance 1</td>
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<td>50%</td>
<td>IECC</td>
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<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.12</td>
<td>ASHRAE</td>
<td>0.78</td>
<td>ST</td>
<td>14.9</td>
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<tr>
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<td>IECC</td>
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<td>0.2</td>
<td>0.12</td>
<td>ASHRAE</td>
<td>0.78</td>
<td>ST</td>
<td>10.9</td>
</tr>
</tbody>
</table>
**Simulated Results**

Each bar represents the range of energy (EUI) outcomes possible given a single fixed variable. The color legend indicates whether a given variable has a positive (i.e., low energy) or negative impact on energy performance, based on whether it eliminates high performance options (low EUI), or eliminates the worst performing options.

**Simulation Results**

Another way to understand the data is to look at the total differences or deltas of the lower energy and higher energy results for each input. For instance, infiltration when coupled with high performance features (particularly a low energy HVAC system), has little impact on the total building performance. All infiltration options when coupled with high performance features result in an EUI of just over 15kBTU/sf/yr. However, if coupled with lower performance features high infiltration can spike the EUI up to 38kBTU/sf/yr, while low infiltration is at 35kBTU/sf/yr or a delta of 3kBTU/sf/yr.

The variables that have the most impact include window-to-wall ratio, solar heat gain coefficient, lighting power density, plug loads, ventilation, and the HVAC performance.

---

**Energy Use Intensity (KBTU/sf/yr)**

- Negative Impact
- Slightly Negative to No Impact
- Slightly Positive Impact
- Positive Impact

- **Energy (EUI) Overall Impact**

- **Energy (EUI) Sensitivity**
TASK II: ENERGY ANALYSIS

PARAMETRIC SIMULATION RESULTS

- Negative Impact
- Slightly Negative to No Impact
- Slightly Positive Impact
- Positive Impact

Each bar represents the range of peak cooling demand outcomes possible given a single fixed variable. Peak cooling is expressed in BTU/SF. The color legend indicates whether a given variable has a positive impact (ie low peak demand) or a negative impact on peak cooling based on whether it eliminates low demand or high demand scenarios from the solution set.

Each bar represents the range of peak electrical demand outcomes possible given a single fixed variable. These peak electrical demand numbers represent electrical demand from the energy model, not necessarily sizing values for transformers or other electrical infrastructure. The color legend indicates whether a given variable has a positive impact (ie low peak demand) or a negative impact on peak cooling based on whether it eliminates low demand or high demand scenarios from the solution set.
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TASK II: ENERGY ANALYSIS

PARAMETRIC SIMULATION INPUTS

The parallel coordinate plots shown here represent the combined energy efficiency measure baskets discussed earlier. The top plot shows the developer preferred case, featuring high glazing percentages, an achievable envelope, and moderately high performing HVAC and DHW systems. Promisingly, this case demonstrates that developers can achieve the level of glazing area they desire (without additional shading costs) if they can pair that with a high performing HVAC system and a heat pump water heater. This combination still offers a more than 19% improvement over the IECC 2015 baseline, which includes a much less efficient gas boiler for domestic hot water.

The high performance cases are shown in the parallel coordinate plot below - one featuring full mechanical cooling, and the other design for passive cooling and natural ventilation. These results show that this type of multi-family building can realistically achieve under a 15 EUI with full cooling and under an 11 EUI without cooling offering a 56% and 68% energy reduction respectively, compared to the IECC baseline.

The passive cooling and natural ventilation approach does not allow for a heat recovery DHW system (as in the case with cooling) given that there is no cooling system to recover heat from. However the best available air-source heat pumps for domestic hot water have similar levels of efficiency.

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DEVELOPER BASKET

<table>
<thead>
<tr>
<th>WWR</th>
<th>Shading Ratio</th>
<th>Wall U-value</th>
<th>Window U-value</th>
<th>SHGC</th>
<th>LPD (W/SF)</th>
<th>Plug Loads (W/SF)</th>
<th>Infiltration (ACH)</th>
<th>Ventilation (CFM/P)</th>
<th>Ventilation (CFM/SF)</th>
<th>DHW</th>
<th>HVAC</th>
<th>PEAK COOLING (BTU/SF)</th>
<th>ENERGY (BTU/SF/YR)</th>
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<td>0.29</td>
<td>6.5</td>
<td>0.78</td>
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HIGHEST PERFORMANCE BASKETS

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<th>Wall U-value</th>
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<th>ENERGY (BTU/SF/YR)</th>
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</tbody>
</table>

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**TASK II: ENERGY ANALYSIS**

**POTENTIAL FOR NET ZERO ENERGY**

Using the data collected from the parametric energy modeling WSP sought to determine how this range of building designs would stack up against a Net Zero (Site) Energy target. A Net Zero Energy (NZE) building is defined here as a building that can produce as much or more energy on site than it consumes on an annual basis. Ideally a NZE building would be able to achieve this with solar photovoltaics (PV) mounted on the roof, while still leaving room for maintenance access and other rooftop equipment required. This typically comes out to about 75% of the total roof area. The available rooftop area for this particular building then allows for a 145kW PV system which can offset approximately 20 kBtu/ft²/yr of building energy.

The diagram to the right shows how much roof area would be required to achieve NZE performance for each of the combination of energy efficiency measure baskets (IECC baseline, developer preferred, and the two highest performing cases). The developer case would need an additional 38% more roof area for PV, in order to achieve NZE. The IECC baseline would need about twice as much roof area as the current building design.

<table>
<thead>
<tr>
<th>Case</th>
<th>WWR</th>
<th>Shading Ratio</th>
<th>Opaque Envelope</th>
<th>Glazing U-value</th>
<th>SHGC</th>
<th>Lighting (W/SF)</th>
<th>Plug (W/SF)</th>
<th>Infiltration (CFM/SF)</th>
<th>Ventilation</th>
<th>DHW</th>
<th>HVAC</th>
<th>EU (kBtu/ft²/yr)</th>
<th>PV Required for NZE (kW)</th>
<th>Energy Cost ($/yr)</th>
<th>GHG Emissions (metric tons CO2e/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IECC 2015</td>
<td>30%</td>
<td>0%</td>
<td>IECC</td>
<td>0.5</td>
<td>0.35</td>
<td>0.51</td>
<td>0.4</td>
<td>0.29</td>
<td>ASHRAE Gas Boiler, Split System</td>
<td>33.6</td>
<td>249</td>
<td>$107,000</td>
<td>1,682.6 lbs/MWh for electricity and 523.8 lbs/MWh for gas.</td>
<td></td>
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</tr>
<tr>
<td>Developer Preferred</td>
<td>50%</td>
<td>0%</td>
<td>IECC</td>
<td>0.5</td>
<td>0.3</td>
<td>0.4</td>
<td>0.2</td>
<td>0.29</td>
<td>ASHRAE Heat Pump, High Efficiency</td>
<td>27.0</td>
<td>200</td>
<td>$93,800</td>
<td>248</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest Performance 1</td>
<td>30%</td>
<td>50%</td>
<td>IECC</td>
<td>0.5</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.12</td>
<td>ASHRAE Heat Recovery, High Efficiency</td>
<td>14.9</td>
<td>130</td>
<td>$52,000</td>
<td>137</td>
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<td></td>
</tr>
<tr>
<td>Highest Performance 2</td>
<td>30%</td>
<td>50%</td>
<td>IECC</td>
<td>0.5</td>
<td>0.2</td>
<td>0.3</td>
<td>0.2</td>
<td>0.12</td>
<td>ASHRAE HE Heat Pump, No AC</td>
<td>10.9</td>
<td>80</td>
<td>$38,000</td>
<td>100</td>
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</tr>
</tbody>
</table>

**Basket Performance + Net Zero Energy**

**Net Zero Energy + PV Roof Requirements**

Highest Performance 2
EU: 10.9 kBtu/ft²/yr
PV Array Required for NZE: 80 kW
Roof Area Required: 6,320 ft²

Highest Performance 1
EU: 14.9 kBtu/ft²/yr
PV Array Required for NZE: 110 kW
Roof Area Required: 8,690 ft²

Developer Preferred
EU: 27 kBtu/ft²/yr
PV Array Required for NZE: 200 kW
Roof Area Required: 15,800 ft²

**Basket Performance + Net Zero Energy**

**PV Assumptions**

<table>
<thead>
<tr>
<th>PV Efficiency*</th>
<th>16%</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Losses</td>
<td>14%</td>
</tr>
<tr>
<td>Tilt</td>
<td>20°</td>
</tr>
<tr>
<td>Azimuth</td>
<td>180° (S)</td>
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</tbody>
</table>

*Standard efficiency PV panels were assumed. Higher efficiency panels at 18-22% efficient are available, which would allow for more kW capacity in the same area. Standard efficiency panels are about 17 Watts per square foot, and in Hawaii each kW of PV capacity produces about 1,628 kWh/year.
Simulations were conducted to study the EUI impact of mixed mode operation on the IECC Baseline case. The mixed mode model affects the amount of energy used in the building, and subsequently the amount of PV needed for net zero energy. It was assumed that natural ventilation would be used for comfort when outdoor temperatures were less than 78°F, and mechanical cooling would be used when outdoor temperatures exceeded that. Temperature increases under future climate scenarios mean the opportunity for natural ventilation will decrease over time, increasing the energy consumption of the building. The following graph shows the EUI of the mixed mode option under current and future climate scenarios.

A description of the future climate scenarios can be found on the next page.

The State recognizes that energy storage will be a critical component of the 100% Clean Energy Target. To help understand how energy storage can impact the peak load, WSP incorporated battery storage into the energy simulations. The intent is to determine what type of battery system could shed at least 10% of the building’s estimated peak electricity demand. This 10% value is reflective of the LEEDv4 demand response Energy and Atmosphere Credit (EAc4).

The graph to the right shows the impact of a 50kWh battery system on the fall equinox IECC Baseline electrical demand profile. The 50 kWh of energy discharge through the high load hours reduces the peak demand by ~10kW. This is more than a 10% reduction in peak demand and consistent with the LEEDv4 EAc4 Demand Response credit threshold.

This 50kWh battery system is comparable to 10 Tesla Powerwalls (the maximum number offered in a single residential Powerwall system).

The building design which is the basis for analysis has a fixed orientation, with long facades facing east and west. A sensitivity analysis rotating the fully conditioned IECC baseline by 90°, 180°, and 270° is shown below, both without shades and with horizontal overhangs that provide a 50% shading ratio between the height of the window and the shade projection.

The study shows that the long facades facing north and south would achieve 4% energy savings and 19% peak cooling savings (3% energy and 16% peak with shades). This finding confirms the importance of energy studies early in the design process to inform basic orientation and massing decisions.
THERMAL COMFORT

Introduction
Thermal comfort is a major factor affecting occupant satisfaction with a space. Air temperature is only one aspect of thermal comfort. Radiation of thermal energy from building surfaces or from direct sun can enhance or detract from occupant comfort. The movement of air is also a factor; a gentle breeze from an open window on a warm day can enhance comfort, but cold air blowing from a vent in close proximity to an occupant can detract from it. Other considerations influencing thermal comfort include an occupant’s activity level and clothing.

Hawaii has a pleasant, tropical climate where the conditions are comfortable the majority of the year. Many residential buildings use natural ventilation with no mechanical cooling.

However, to assess risks when building for the future, it is important to consider a warming climate. This section will use the IECC baseline model as a basis for comparing the level of thermal comfort without mechanical cooling under potential future climate scenarios.

IPCC Climate Scenarios
In 2014, the Intergovernmental Panel on Climate Change (IPCC) adopted different greenhouse gas concentrations pathways for its fifth Assessment Report.

Two of the four Representative Concentration Pathways (RCPs) are studied here. RCP 4.5 anticipates that global greenhouse gas emissions will peak around 2040, then decline. In the RCP 8.5 scenario, emissions will continue to rise through the year 2300, building up the greenhouse gas concentrations in the atmosphere.

Within each RCP, there is a range of possible projections. For the purposes of these exercises, the 50 and 90 percentile scenarios have been studied.

Climate Comparisons
Future weather files for the different IPCC climate scenarios were obtaining from the WeatherShift tool from Integrated Environmental Solutions.

The currently available TMY3 climate data for Honolulu has some warm periods during the summer but is generally in a comfortable range. The future climate projections show increased hours of high temperatures in the high eighties and above.
THERMAL COMFORT

Adaptive Thermal Comfort

The adaptive thermal comfort model from ASHRAE 55 is based on the idea that occupants can tolerate different indoor temperatures that depend on the time of the year. Studies have shown that occupants of naturally ventilated buildings can accept a wider range of temperatures than their counterparts in air-conditioned buildings because the preferences were based on outdoor temperature conditions.

The figure below from the ASHRAE standard shows a variable comfort band that demonstrates the relationship between the indoor and outdoor temperatures. The width of the band depends on if 90% or 80% acceptability is desired.

The Effect of Fans

As noted earlier, air temperature is only one factor in determining thermal comfort. Air movement caused by breezes or ceiling fans can also increase the feelings of comfort in warm spaces.

The following annual graphs show occupant thermal comfort in the IECC baseline building under each of the climate scenarios and using the Adaptive Comfort model. The yellow areas indicate hours of the year that are uncomfortable unless ceiling fans are used to increase air speeds to 1.78 miles per hour. The red areas indicate hours of the year that are uncomfortable even with fans, and in which natural ventilation will not be possible.

High Levels of Thermal Comfort

Australia’s LEED equivalent, the Green Star rating tool is a good reference to help determine a reasonable "comfortable target". Green Star calls for the internal temperatures to be within the 80% Acceptability Limit of ASHRAE 55-2010 for 98% of the year OR within PMV +/- 1. This would be representative of a fully conditioned office space. The modeling shows that with ceiling fans, the current climate in Honolulu is close (96.4%) but not better than the threshold of 98%.

Additional Comfort Strategies

These models use the IECC baseline as a basis for the thermal comfort studies. Additional design strategies such as exterior shading would be effective at reducing both temperature rise due to solar gains and the direct radiative solar effects. Therefore, shading would provide additional hours of thermal comfort.

The IECC baseline model does not include local external shading over the windows, but the design itself does provide some self shading due to the exterior walkways and close clustering of the residential blocks.
**THERMAL COMFORT**

**Predicted Mean Vote (PMV)**

Predicted Mean Vote is another metric to understand the predicted response in terms of how comfortable a large group of people will be in a particular thermal environment. Thermal comfort is quite subjective and is largely based on personal preference. If the occupants of a large room are surveyed, there will always be some people who will perceive the space to be too cold or too hot even if most of the occupants respond that they are comfortable. The goal of maintaining comfortable conditions is to satisfy as many people as possible, but with the understanding that no matter what the conditions, there will always be a small number of people dissatisfied.

Thermal comfort is provided by a number of environmental characteristics in addition to air temperature. The PMV metric considers:

- The humidity level in the air
- The radiant temperature from solar heat gain
- Fresh airflow and air movement
- The clothing a person is wearing
- How much physical activity a person is doing

The scale for the PMV index is measured from -3 (cold) to +3 (hot) where the value represents the average response of a large group of occupants in a particular environment. For the purposes of most spaces, achieving a PMV between -1 and +1 is the goal.

As in the adaptive comfort analysis on the previous page, this PMV study incorporates the effects of ceiling fan usage where required.

**Assumptions about Clothing**

Please note that for these studies, it is assumed that occupants will adjust their clothing to maintain comfort. Therefore, the CLO value used in the comfort calculation varies between 0.5 (summer clothing) and 1.0 (business clothing) hourly by temperature.