



Zero Net Energy Retrofits for Small
Commercial Buildings:
Berkeley Mental Health Clinic
Demonstration Package

Final, Updated 03/27/2023

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Summary of Changes

The following changes were made to the report:

- (Report date: 03-27-2023) Retitled to align with program and updated Integral Group to Introba
- (Report date: 12-19-2019) Added Construction Phase Package under ZNE Packages. Revised building operating hours per additional information from City of Berkeley. Updated air handler performance parameters to match construction phase approved submittal values. Updated energy model to include an electric resistance heating coil in each air handler which were added to operate when outside air temperature is below 45°F for freeze protection. Also made correction to air handler operating schedule to better reflect building occupancy hours.
- Added California's Title 24-2016 baseline results.
- Added the CA T24-2016 results to Figure 4, Figure 5 and Figure 6.
- (Report date: 07-19-2018) Removed draft watermark.
- (Report date: 07-19-2018) Added Figure 5, which shows the modeled annual energy use of each end-use.
- (Report date: 07-19-2018) Updated solar PV production numbers to reflect current design.
- (Report date: 04-02-2018) Added the five (5) existing skylights to remain in the geometry to match the 100% DD drawings
- (Report date: 04-02-2018) Updated the number of tubular daylighting devices from 38 to 35 to match the 100% DD drawings
- (Report date: 04-02-2018) Decreased R-value of added roof insulation from R-25 to R-19 between roof rafters to match the 100% DD drawings
- (Report date: 04-02-2018) Increased R-value of added wall cavity insulation from R-13 to R-19 between the existing 2x6 wall cavity to match the 100% DD drawings
- (Report date: 04-02-2018) Decreased HVAC Coefficient of Performance (COP) of the two air handlers from 3.96 to 3.28 (11.2 EER) and 3.58 (12.2 EER) respectively to match the 100% DD design values
- (Report date: 04-02-2018) Reduced cooling supply air temperature from 55 degF to 50 degF to match the 100% DD values
- (Report date: 04-02-2018) Reduced heating supply air temperature from 95 degF to 82 degF to match the 100% DD values
- (Report date: 04-02-2018) Decreased total energy recovery effectiveness on the two air handlers from 75% to 59% and 64% respectively to match the 100% DD design values
- (Report date: 04-02-2018) Increased fan static pressure of the two supply fans from 2.5 in. w.g. to 3.3 in. w.g. and 2.7 in. w.g. respectively to match the 100% DD design values
- (Report date: 04-02-2018) Added two (2) exhaust fans to the air handlers to match the 100% DD drawings
- (Report date: 04-02-2018) Increased efficiency of the instantaneous electric water heater from 95% to 98% to match the 100% DD design
- (Report date: 02-15-2018) Added text to clarify type of heat recovery used in proposed measure packages.
- (Report date: 02-15-2018) Split package 2 into 2a without heat recovery and 2b with heat recovery
- (Report date: 02-15-2018) Added operating schedule, thermostat schedule, and HVAC control notes

- (Report date: 02-15-2018) Added utility rates and calculated energy costs for each measure/package
- (Report date: 01-10-2018) Added text to clarify type of heat recovery used in proposed measure packages.
- (Report date: 11-09-2017) Reduced the number of package units in the Package 2 model to two.
- (Report date: 11-09-2017) Added description of Prior ZNE Study package energy efficiency measures.
- (Report date: 11-09-2017) Added note about Demand Response.
- (Report date: 11-09-2017) Further specified lighting and plug load connected and operating load densities, envelope details, glazing details, and plug load reduction strategies.
- (Report date: 10-18-2017) Rebuilt building geometry in OpenStudio v2.3 to include building's L-shape and correct glazing
- (Report date: 10-18-2017) Updated zoning to reflect proposed floor plan as of 10/10/17.
- (Report date: 10-18-2017) Input 2015 Berkeley weather data to calibrate the baseline energy model to 2015 utility data
- (Report date: 10-18-2017) Updated baseline model inputs to more closely match model results to annual and monthly natural gas and electric utility data
- (Report date: 10-18-2017) Increased number of skylights to 38 in proposed models

Baseline Model

The baseline energy model was updated to OpenStudio version 2.3 software (created in collection with NREL, LBNL, ANL, ORNL, and PNNL), and building model geometry was revised to reflect the L-shaped building and correct window locations. Previous reports showed results based on the baseline model originally built in the Commercial Building Energy Saver (CBES) tool (created by LBNL), which limits building geometry to rectangular shapes. Results are presented in annual Energy Use Intensity (EUI) values as a measure of the annual total energy use per gross square foot of building area. See Figure 1 for the Utility EUI vs. the modeled EUI.

Berkeley Mental Health Clinic

Utility Data

Historic Energy Data gathered from utility meters was used from the year 2015 as the baseline. This was calculated to be 73,120 kWh/yr and 1475 therms/yr, resulting in an EUI of 45.2 kBtu/sf-yr. Annual Meteorological Year (AMY) weather data for Berkeley for 2015 was used in the baseline model to align results with the utility data.

Description & Inputs

Envelope

- Roof Solar Reflectance: 0.63
- Roof Insulation R-value: 4.29
- External Wall Insulation R-value: 4
- Ground Floor Insulation R-value: 4.29
- Window U-value: 1.0, SHGC: 0.82, VT: 0.81
- Infiltration (cfm/ft² exterior surface area): 0.085

Internal Loads

- Occupant Density (ft²/person): 200
- Lighting (W/sf): 1.0
- Equipment (W/sf): 0.7 + 0.8 W/sf of Electric Space Heaters Nov - Mar

External Lighting

- Lighting Power per Fixture (W): 30
- Number of Fixtures: 10

Setpoints and Operating Schedule

- 78°F Cooling, no setback
- 68°F Heating 7am-7pm, 65°F setback, off July 1st – Sept 30th
- HVAC units are always ON

HVAC

- System Type: Packaged Rooftop AC
- Cooling COP: 2.7
- Cooling Supply Air Temp: 55 degF
- Heating Efficiency: 0.8
- Heating Supply Air Temp: 95 degF
- Constant Volume Fan
- Fan Efficiency: 0.6
- Fan Motor Efficiency: 0.85
- Fan Pressure Rise: 2.5 in. w.g.
- Economizer Type: None
- Demand Control Ventilation: No

Domestic Hot Water

- Type: Gas Storage
- Efficiency: 0.78
- Temperature: 135 degF
- Tank Volume (gallon): 30
- Use Rate (gal/min): 0.05

Berkeley Mental Health Building Baseline EUI Calibration

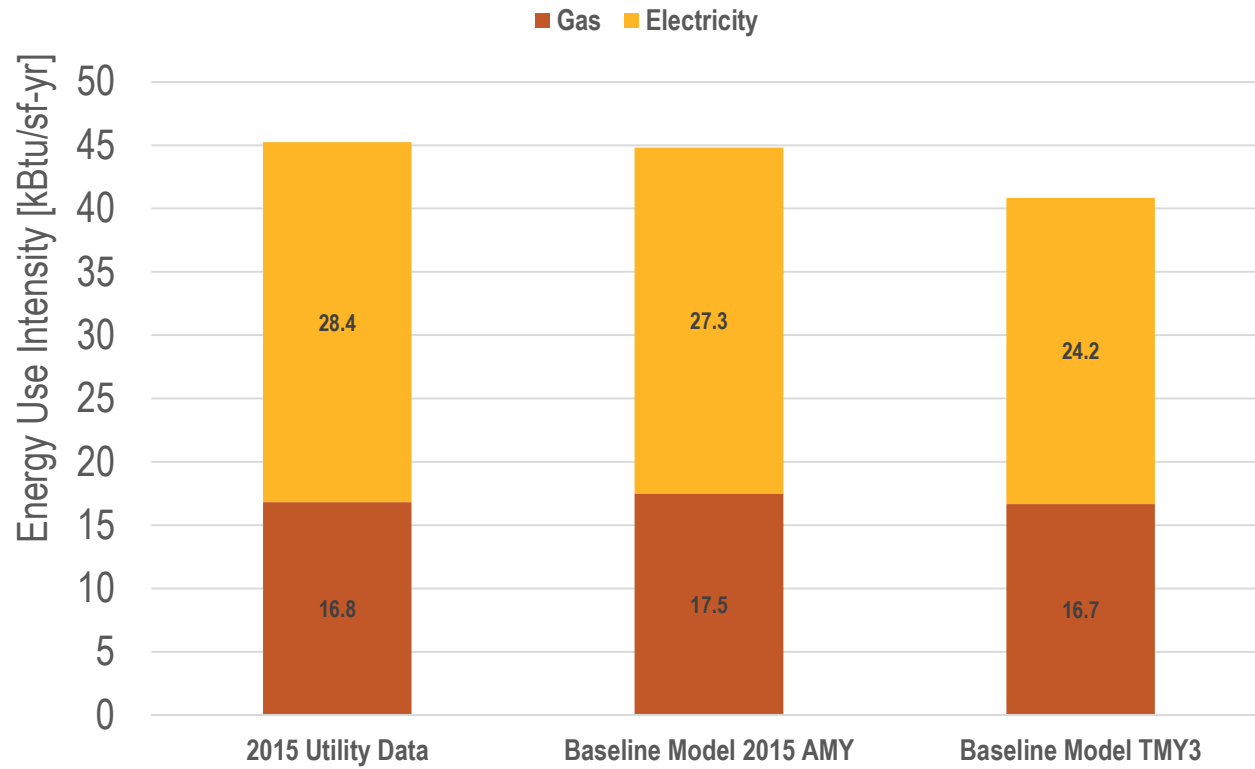
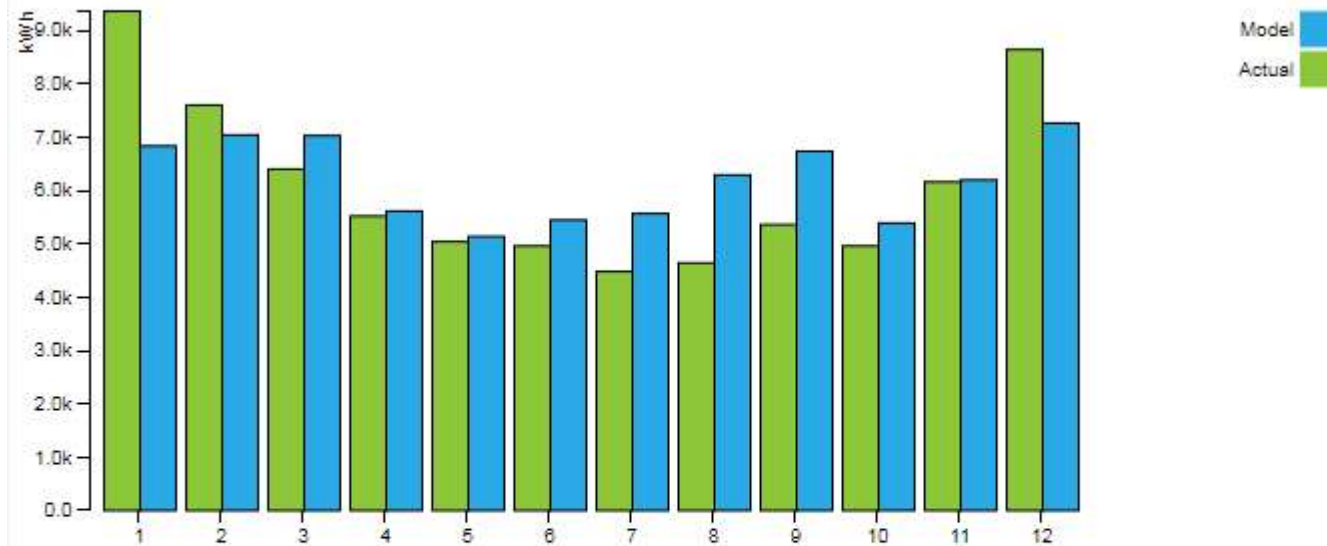


Figure 1 - Baseline Model Calibration Results

Electricity Consumption (kWh)

CV(RMSE) = 19.30

NMBE = -2.10



	1	2	3	4	5	6	7	8	9	10	11	12
Start	12/29	1/28	2/27	3/30	4/30	5/29	6/29	7/28	8/27	9/29	10/28	11/25
End	1/28	2/27	3/30	4/30	5/29	6/29	7/28	8/27	9/29	10/28	11/25	12/28
Actual	9,380	7,600	6,400	5,520	5,040	4,960	4,480	4,640	5,360	4,960	6,160	8,640
Model	6,834	7,040	7,027	5,613	5,136	5,446	5,566	6,290	6,733	5,388	6,196	7,261
NMBE	-26.99%	-7.37%	9.79%	1.68%	1.91%	9.79%	24.24%	35.57%	25.61%	8.63%	0.59%	-15.96%

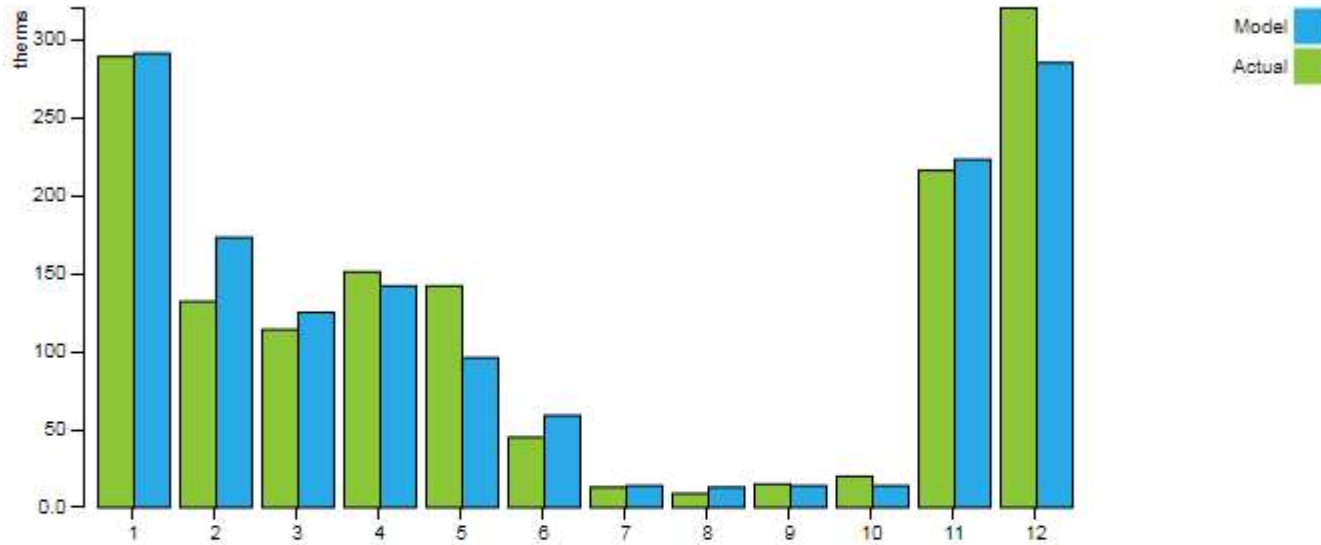
Figure 2 - Electricity Calibration to 2015 Utility Data

CV(RMSE) = Coefficient of Variation of the Root Mean Squared Error; NMBE = Normalized Mean Bias Error. ASHRAE Guideline 14 targets $CV(RMSE) \leq \pm 15\%$ and $NMBE \leq \pm 5\%$.

Natural Gas Consumption (therms)

CV(RMSE) = 18.33

NMBE = 1.22



	1	2	3	4	5	6	7	8	9	10	11	12
Start	12/30	1/29	3/2	3/31	5/1	6/1	6/30	7/29	8/28	9/29	10/28	11/30
End	1/29	3/2	3/31	4/30	6/1	6/30	7/29	8/28	9/29	10/28	11/30	12/29
Actual	289	132	114	151	142	45	13	9	15	20	216	320
Model	291	173	125	142	96	59	14	13	14	14	223	285
NMBE	0.73%	30.99%	9.8%	-5.99%	-32.43%	31.63%	5.09%	43.81%	-4.22%	-31.21%	3.31%	-10.85%

Figure 3 - Natural Gas Calibration to 2015 Utility Data

CV(RMSE) = Coefficient of Variation of the Root Mean Squared Error; NMBE = Normalized Mean Bias Error. ASHRAE Guideline 14 targets CV(RMSE) $\leq \pm 15\%$ and NMBE $\leq \pm 5\%$.

California Title 24-2016 Code Baseline Models

The Title 24-2016 baseline model for the Berkeley Mental Health Building is developed in CBECC-Com 2016.3.0 SP2. Instead of showing the California Time Dependent Valuation (TDV) values¹, the energy use intensity (kBtu/sf) values are reported in this report for apples-to-apples comparison. The results are only intended to present a comparison among different scenarios and to inform design decisions. The report is not as an indicator of code compliance which is based on a different energy usage matrix (i.e. TDV value).

¹ Time Dependent Valuation (TDV) energy is a normalized format for comparing electricity and natural gas cost savings that takes into account the cost of electricity and natural gas consumed during each hour of the year.

Berkeley T24-2016 Code Baseline Building

Description & Inputs

Weather File: California Energy Commission Climate Zone 3
(CZ03_OAKLAND_724930_CZ2010.epw)

Envelope

- Roof Assembly U-value: 0.034
 - 14" Metal ceiling joist with R-30 Batt cavity Insulation. ¾" roof sheathing with TPO roof membrane.
 - Interior 5/8" gyp ceiling.
- Roof Solar Reflectance: 0.63
- External Wall Insulation Assembly U-value: 0.082
 - 6in Metal-framed Wall with R-10 Batt Cavity Insulation
- Ground Floor Insulation R-value: 0
- Window, 33% WWR on all façades, U-value: 0.36 (includes frame), SHGC: 0.25, VT: 0.42; Double pane, clear glass in aluminum frame

Internal Loads

- Occupant Density (ft²/person): 200
- Lighting: 0.75 W/sf
- Daylight Control Type and Area: Continuous, perimeter zones
- Equipment: 1.50 W/sf
- Occupant Schedule: Title 24 defaults
- Lighting Schedule: Title 24 defaults
- Equipment Schedule: Title 24 defaults
- Infiltration (cfm/ft² ext wall area): 0.0448
- OA/occ (cfm/person): 15
- OA/SF (cfm/sf): 0.15

External Lighting

- Lighting Power per Fixture (W): 30, same as proposed
- Number of Fixtures: 10, same as proposed

Setpoints and Operating Schedule

- 75°F Cooling, 85°F setback
- 70°F Heating, 60°F setback
- HVAC operation: 6am-midnight Mon-Fri, 6am-8pm Sat, 6am-6pm Sun

HVAC

- System Type: Packaged Single Zone Constant Volume DX Unit with Gas Heating
- DX Cooling COP: 3.16
- Heating Efficiency: 80%
- Fan Efficiency: 42.75%
- Fan Motor Efficiency: 85.5%
- Supply Fan Pressure Rise: 2.5 in. w.g.
- Economizer Type: No
- Demand Control Ventilation: No
- Energy Recovery Type: None

Domestic Hot Water

- Type: Gas Storage
- Efficiency: 80%
- Temperature: 135 degF
- Tank Volume: 30 gallons
- Use Rate: 0.05 gpm peak
- Hot Water Schedule: Title 24 defaults

ZNE Packages

After the Baseline model was calibrated to 2015 monthly utility data, packages were developed and modeled in OpenStudio to see if ZNE could be achieved. Tubular Daylighting Devices with daylight sensors were added to model the lighting impact of this measure. The prior ZNE study is included, and consists of packaged rooftop heat pumps with heat recovery and tubular daylighting diffusers. Changes to the HVAC are assumed to add ventilation to the building, as the majority of the current building is unventilated, and to eliminate the need for electric space heaters. Lighting use is higher in this ZNE package than in the proposed packages below, because the prior ZNE study assumed 0.8 W/sf of lighting while the following packages assume 0.6 W/sf of lighting and occupancy sensors.

Berkeley Mental Health Clinic

For the Berkeley Mental Health Clinic, four ZNE packages are suggested with the only difference being the HVAC system type and window replacement. Below is a description of each package. In addition, after receiving the 100% DD drawings, Introba updated the energy efficiency measures to match the drawings in order to understand the impacts of the modifications. The results are provided in this section. Model inputs are the same as the baseline building, including envelope, internal loads, thermostat setpoints, hours of operation, HVAC system, and domestic hot water inputs except where noted.

Prior ZNE Study

- HVAC: Packaged Rooftop Units with Heat Pump and Energy Recovery (enthalpy wheel)
 - Multizone VAV with reheat and airside economizer (maximum airflow sized for peak load condition, 82.4°F maximum limit temperature)
- Domestic Hot Water (DHW): same as existing
- Lighting:
 - 38 tubular daylighting devices, modeled as 2ft x 2ft skylights with U-1.05 SHGC-0.93 VT-0.9
 - Daylight sensors added to zones with tubular daylighting devices
 - 0.8 W/sf: 0.8 W/sf is connected load, 65% diversity, 0.52 W/sf max operating load.
- Envelope: same as existing
- Plug Loads: eliminate electric space heaters
- Operating schedule 6am-midnight Mon-Fri, 6am-7pm Sat, 6am-6pm Sun
- Temperature setpoints are same as Baseline.
- DHW: replace with electric instantaneous (efficiency: 0.95) and install low flow fixtures
- Lighting:
 - 38 tubular skylights
 - Replace existing lighting with LED upgrade (0.6 W/sf): 0.6 W/sf is connected load, 65% diversity, 0.39 W/sf max operating load.
 - Install daylighting sensors for interior lighting control
 - Install wall-mounted occupancy sensors
- Envelope:
 - Reroof and add R-25 roof insulation
 - Add crawlspace insulation (R-13 cavity insulation)
- Plug Loads: reduce by 30% from 0.7 W/sf to 0.49 W/sf*. 0.7 W/sf is connected load, 90% diversity, 0.63 W/sf max operating load.

Package 1a: DOAS + VRF (Dedicated Outside Air System + Variable Refrigerant Flow), No Window Replacement

- HVAC: DOAS with VAV fan, Energy Recovery Ventilator (enthalpy wheel), no economizer, and VRF (with heat recovery)

Package 1b: DOAS + VRF, Window Replacement

- HVAC: same as Package 1a
- DHW: same as Package 1a
- Lighting: same as Package 1a
- Envelope:
 - Reroof and add R-25 roof insulation
 - Add crawlspace insulation (R-13 cavity insulation)
 - Replace all windows with SB70XL (U-factor 0.40 and SHGC 0.28) including aluminum frames with thermal break.
- Plug Loads: same as Package 1a

Package 2a: Heat Pump

- HVAC: Packaged Rooftop Units with Heat Pump, multi-zone VAV fan, 100% outdoor air (maximum airflow sized for peak ventilation condition), demand controlled ventilation, no economizer
 - Operating schedule 6am-midnight Mon-Fri, 6am-7pm Sat, 6am-6pm Sun
 - Temperature setpoints are same as Baseline.
- DHW: same as Package 1a
- Lighting: same as Package 1a
- Envelope: same as Package 1a
- Plug Loads: same as Package 1a

Package 2b: Heat Pump with ERV (Energy Recovery Ventilator)

- Same as 2a, adding Energy Recovery (enthalpy wheel)
- DHW: same as Package 1a
- Lighting: same as Package 1a
- Envelope: same as Package 1a
- Plug Loads: same as Package 1a

Package 100% DD: Heat Pump with ERV (Energy Recovery Ventilator)

- HVAC: System type is the same as 2b, with the following modifications:
 - Reduce Cooling Coefficient of Performance (COP) to 3.28 (11.2 EER) and 3.58 (12.2 EER)
 - Reduce Cooling Supply Air Temp from 55 degF to 50 degF
 - Reduce Heating Supply Air Temp from 95 degF to 82 degF
 - Increase supply fan total static pressure to 3.3 in. w.g. and 2.7 in. w.g.
 - Reduce total energy recovery effectiveness to 59% and 64%, and sensible energy recovery effectiveness to 60% and 65% for each enthalpy wheel
- DHW: same as Package 1a, with the efficiency changed from 0.95 to 0.98
- Lighting: same as Package 1a, except the number of tubular skylights changed from 38 to 35 and 5 existing skylights remain
- Envelope:
 - Reroof and add R-19 roof insulation
 - Add batt insulation to 2x6 wall (R-19 cavity insulation)
 - No window replacement
- Plug Loads: same as Package 1a

Package Construction Phase Updates: Heat Pump with ERV (Energy Recovery Ventilator)

- HVAC: System type is the same as 2b, with the following modifications from the Package 100%DD to match parameters in the approved equipment submittal:
 - Occupancy Schedule changed to 7am-10pm M-F; 11:30am – 10pm Saturdays, Sundays and Holidays.
 - Increase Cooling Coefficient of Performance (COP) to 3.43 (11.7 EER) and 3.69 (12.6 EER)
 - Add electric resistance heating coils in AHUs to operate, instead of heat pump DX heating, when outside air temperature below 45 deg F.
 - Increase Cooling Supply Air Temp to 53.3 deg F and 57.4 deg F.
 - Decrease AHU-2 heating supply air temp from 82 deg F to 78.4 deg F.
 - Increase AHU-2 supply fan total static pressure from 2.7 in. w.g. to 3.0 in. w.g.
 - Increase total energy recovery effectiveness to 64% and 65%, and sensible energy recovery effectiveness to 65% and 67% for each enthalpy wheel.
- DHW: same as Package 100%DD
- Lighting: same as Package 100% DD
- Envelope: same as Package 100%DD
- Plug Loads: same as Package 100%DD
- Energy Simulation Model Update: Air handler operating hours in the model were revised to match occupancy schedule described above and to provide morning warmup as needed during weekdays.

* Plug Load Reduction Strategies

- Utilize “smart” plug strips at workstations to control and monitor employee plug load usage based on occupancy

- Use laptops instead of desktop computers
- Replace equipment/appliances with high efficiency (e.g. ENERGY STAR) models
- Consolidate printers, fax machines, etc. to a common branch panel and enable branch panel security system power off control
- Virtualize servers or use offsite servers

Previous plug load studies done by Introba were used as the basis for potential 30% reduction savings estimates.

* Observations from Construction Phase Model Updates

- Compared to a more conventional commercial office building operating schedule, this building will operate during significantly more nighttime hours when the air handlers will operate in heating mode.
- Submittal review of these air handlers revealed that these units are equipped to operate in recirculation mode for more energy efficient morning warm-up operations.
- During occupied hours, the air handlers are currently intended to operate as 100% outside air units. During occupied hour heating mode when outside air temperatures are particularly cold, these units could operate more efficiently if the 100% outside air mode is overridden to recirculation mode with code minimum outside air.

Solar Photovoltaic (PV) EUI

The rooftop solar PV design is estimated to produce 53,563 kWh/yr. This corresponds to a building EUI of 20.8 kBtu/sf-yr.

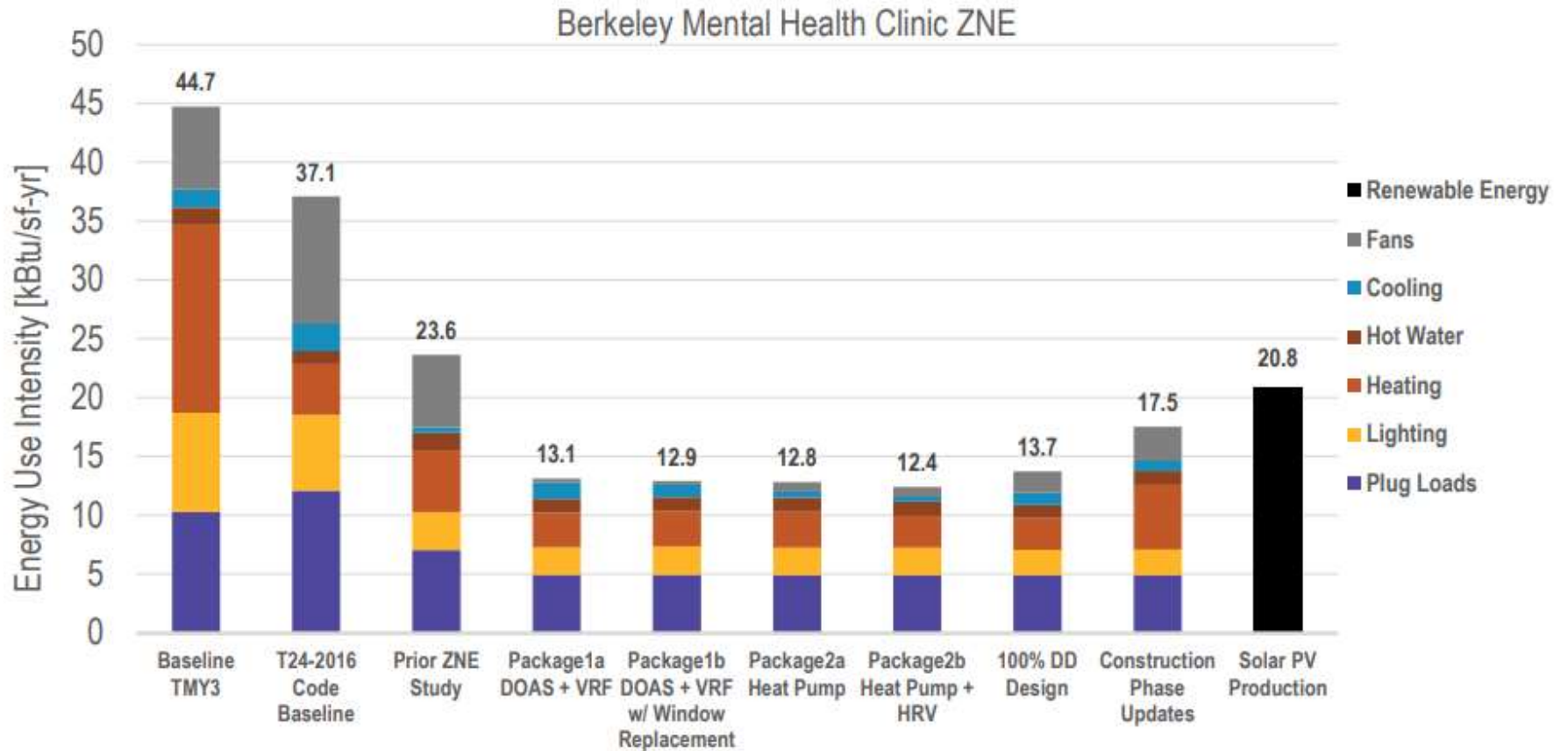


Figure 4 - The main difference between Package 1 & 2a/2b is the HVAC system type. Package 1 has a DOAS + VRF system, while Package 2, 100% DD, and Construction Phase Updates have a packaged 100% outside air heat pump. All packages are able to meet ZNE.

Berkeley Mental Health Clinic ZNE (Area = 8,774 sqft)										
Packages	Baseline TMY3	Prior ZNE Study	T24-2016 Code Baseline	Package1a DOAS + VRF	Package1b DOAS + VRF w/ Window Replacement	Package2a Heat Pump	Package2b Heat Pump + HRV	100% DD Design	Construction Phase Updates	Solar PV Production
Detailed Breakdown	kBtu/yr	kBtu/yr	kBtu/yr	kBtu/yr	kBtu/yr	kBtu/yr	kBtu/yr	kBtu/yr	kBtu/yr	kBtu/yr
Plug Loads	90,248	61,796	106,114	43,257	43,257	43,115	43,115	43,116	43,118	0
Lighting	73,984	28,310	56,441	20,557	21,392	20,444	20,444	18,748	19,004	0
Heating	139,594	45,797	37,638	25,751	26,273	26,832	23,998	23,657	48,405	0
Hot Water	13,279	13,279	10,056	10,359	10,359	10,350	10,350	10,037	10,037	0
Cooling	13,572	4,246	20,302	12,350	9,402	4,815	3,696	8,966	7,810	0
Pumps	0	0	0	0	0	0	0	0	0	0
Fans	61,663	53,863	94,864	2,796	2,540	6,919	7,270	15,838	25,458	0
Renewable Energy	0	0	0	0	0	0	0	0	0	182,757
Total Energy (kBtu/yr)	392,341	207,291	325,414	115,071	113,222	112,474	108,872	120,363	153,832	182,757

Figure 5 - This table shows the annual energy by end use (kBtu/yr) for each of the measure packages

Berkeley Mental Health Clinic ZNE

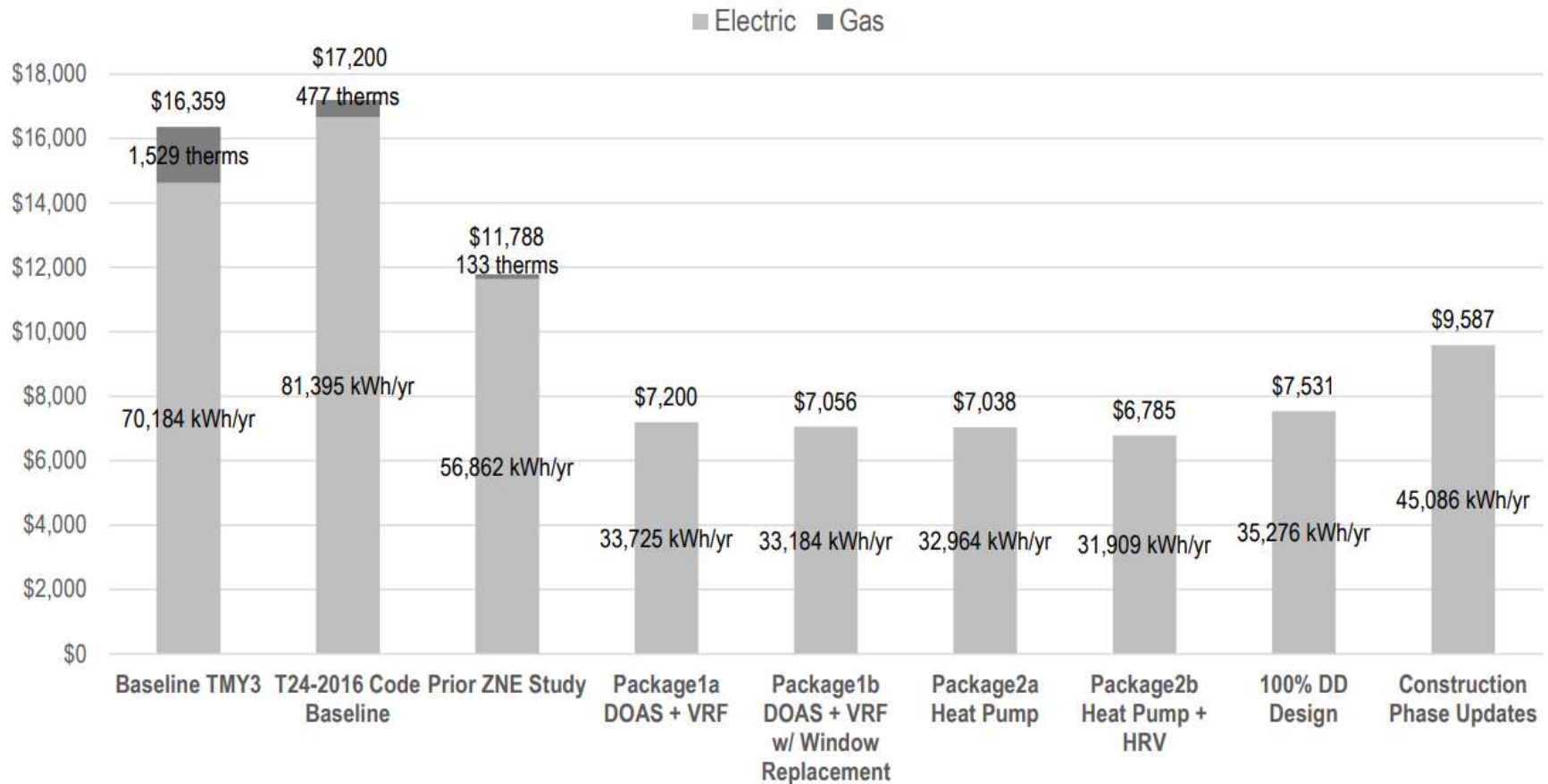


Figure 6 - This chart gives electric and annual gas costs of the different packages using the PG&E A-10 Time-of-Use rate and G-NR1 gas rate. The gas rate assumes the winter gas rate, when most of the gas consumption occurs. Electric and annual gas costs include building energy consumption only and do not include the impact of solar PV production.

Demand Response

Demand response (DR) measures are not considered as part of the ZNE modeling, as they have a marginal impact on a building's annual energy use due to the infrequency of DR event days. In California and depending on which DR program a building is enrolled, demand response event days are limited to no more 0-15 days per year, meaning that a building's operation due to demand response changes for less than 5% of the year.