Martha's Vineyard YMCA

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Energy Analysis and HVAC System Options

April 11, 2023
BVH #22.6201.253

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Martha's Vineyard YMCA

Executive Summary

A full building energy analysis of the Martha's Vineyard YMCA has been developed using Cove.Tool energy simulation software. The existing building and the new proposed addition have been modeled and evaluated both individually and as a combined model. The objective of this energy analysis is to quantify and compare the difference in annual energy consumption for the proposed addition's HVAC system, as well as evaluating combining the new and existing building on a central, all-electric air or ground source heat pump system. The addition and combined building have been modeled using a "baseline building" system in order to compare the proposed building energy use to a baseline building of the same size and use. The baseline building systems are modeled in accordance with ASHRAE 90.1-2010 Appendix G, which is the accepted standard for baseline building energy modeling. The three proposed HVAC options are described in detail in *Table 4*.

Along with modeling the building energy consumption, we were able to quantify the estimated reduction of energy use of installing on-site renewables in the form of photovoltaic (PV) solar panels. An estimated 28,500 $ft^2$of available area is available for new PV panels. This total area is composed of new roof mounted PV panels in the location of existing solar domestic hot water panels, along with additional panels on the low addition roof. The other and most impactful portion is composed of the proposed new solar PV canopies over the existing parking lot and adjacent ice rink parking lot. The available area for a PV canopy over the parking lot is roughly 24,000 ft^2. Assuming 90% of the available area will be actual PV panel, a simulation was run with 25,650 ft^2 of mono-crystalline silicon PV panels to evaluate the estimated energy reduction of the proposed on-site renewables. The proposed PV locations are shown in *Figure B.1* in Appendix A.

Because the building and system design is still in an early stage, a number of assumptions were made during this analysis. Major assumptions are listed and described in the following sections of this report. Domestic hot water (DHW) use for the combined building was assumed to be 1,000,000 gallons per year based off of available information from the U.S. Energy Information Administration and a building of similar use. Domestic hot water was modeled to be generated by an electric boiler in the addition only renovation, and generated by the central air source or ground source heat pumps in the combined renovations. Actual water usage will differ from the estimated usage and depend on actual demand and occupancy. The pool heating system usage was not modeled in any of the simulations. For these reasons, and other unpredictable building factors, the modeled energy consumption is lower than the actual building energy use and should be used for reference purposes only to compare different HVAC options and their effects on energy consumption for the building.

Results

The main indicator analyzed for each building system is the energy usage intensity, or EUI, and is described as the buildings annual total energy use (kbtu/yr) per square foot (ft^2). This includes energy used from electricity along with energy from fossil fuels burned on site. The actual building EUI was calculated to be 167 and was calculated using 2018 utility data. A summary of the findings from the various energy models and simulation iterations are shown in *Table 1* below. Estimated energy reduction with the addition of the on-site PV panels is estimated to be roughly 475,000 kWh per year, resulting in a EUI reduction of 22 for the combined building. This energy estimate is purely a high level estimate and shall be evaluated in detail by a solar engineer. Actual energy generation values will differ than the estimated energy values.

Table 1: Combined Building (Existing + Addition) Energy Analysis Results Summary

Combined Building Energy Analysis (Existing + Addition)												
Option #	Renovation Options	EUI (kBtu/ft²/yr)	Emmisions (Tonne CO2/yr)	CO_2 Reduction (%)	Electricity Consumption (kWh)	Electricity Cost ($) ($0.19 / kWh)	Propane Consumption (Gal)	Propane Cost ($) ($2.97 / gal)	Total Energy Cost ($)	Annual Energy Cost Savings (%)	Total Energy Consumption (Gas + Electric) (kWh)	Total Energy Consumption Savings (%)
-	Baseline (Gas Boiler)	59.1	355	-	568,874	$ 108,086	26,126	$77,593	$ 185,679	-	1,281,121	-
1	Addition Only (VRF)	49.2	341	4%	683,622	$ 129,888	13,894	$41,265	$ 187,660	-1%	1,064,969	17%
2	ASHP (Full Building)	36.5	314	6%	786,826	$ 149,497	-	$ -	$ 149,497	19%	786,826	39%
3	GSHP (Geothermal)	31.0	267	15%	668,395	$ 126,995	-	$ -	$ 126,995	32%	668,395	48%

Table 2: New Addition Energy Analysis Results Summary

New Addition Building Energy Analysis												
Option #	Renovation Options	EUI (kBtu/ft²/yr)	Emmisions (Tonne CO2/yr)	CO_2 Reduction (%)	Electricity Consumption (kWh)	Electricity Cost ($)	Propane Consumption (Gal)	Propane Cost ($)	Total Energy Cost ($)	Annual Energy Cost Savings (%)	Total Energy Consumption (Gas + Electric) (kWh)	Total Energy Consumption Savings (%)
-	Baseline (Gas Boiler)	48.5	160	-	278,195	$ 52,857	10,061	$29,881	$ 82,738	-	481,788	-
1	VRF w/ DOAS	35.3	139	11%	348,584	$ 66,231	-	$ -	$ 66,231	20%	348,584	28%

Note: "Neither the proposed building performance nor the baseline building performance re predictions of actual energy consumption or costs for the proposed design after construction. Actual experience will differ from these calculations due to variations such as occupancy, building operation and maintenance, weather, energy use not covered by this procedure, changes in energy rates between design of the building and occupancy, and the precision of the calculation tool." *(Text from ASHRAE Standard 90.1-2010, Appendix)*

Operating Schedules

- Schedules are modeled identically between the Proposed and Baseline models.
- The building is designed around different space and usage types:
    - General occupancy is modeled from 6 am to 9 pm, Monday to Friday, with reduced hours on the weekends and minimal use during unoccupied overnight hours.
- Lighting and plug load schedules generally follow the associated space's occupancy schedule. Lighting loads are scheduled to be reduced during the daytime due to daylight sensors and will reduce to a minimum during unoccupied times.

Baseline and Proposed Model Comparison

The Baseline Model is based on *ASHRAE Standard 90.1-2010, Appendix G*. This baseline system uses a variable air volume packaged rooftop air conditioner with DX cooling and a fossil fuel furnace for heating and reheat at the zone VAV boxes. Interior lighting was calculated using the building area method presented in *ASHRAE Standard 90.1-2010, Appendix G*. The baseline interior lighting power density (LPD) is based on the building area type method of an exercise e center and is modeled at 0.88 W/sf. Equipment load was modeled at 1 W/SF for all options. The baseline and proposed envelope values for the addition are shown in *Table 3* below.

Table 3: Energy Model Envelope U and R Values and Infiltration

Model	Exterior Wall	Roof	Fenestration	Infiltration
Baseline	R-15.4	R-20	U = 0.55 / SHGC = 0.40	0.05 cfm/ft^2
Addition	R-27	R-30	U = 0.29 / SHGC = 0.40	0.01 cfm/ft^2
Combined	R-20	R-28	U = 0.40 / SHGC = 0.40	0.03 cfm/ft^2

<u>Summary</u>

The results in *Table 1* show an estimated total energy savings of 17%, 39%, and 48% over the baseline building for the combined building proposed HVAC systems. This energy reduction is due to the high performing envelope system modeled in the addition, as well as the full replacement of the existing roof and north façade. Along with these envelope improvements, the high efficiency all electric VRF, air-source, and ground source heating & cooling systems removed all the on-site fossil fuel usage for the HVAC and DHW system, which drastically improved the buildings energy usage. The estimated annual total energy consumption was reduced from 1,281,121kWh for the baseline system to 1,064,969 kWh, 786,826, and 668,395kWh respectively.

The results in *Table 2* show an estimated total energy savings of 28% over the baseline building for the new addition with the proposed all electric HVAC system. This energy reduction is due to high energy performing envelope system modeled and the high efficiency all electric VRF system as described in *Table 4* below. The estimated annual total energy consumption was reduced from 481,788kWh on the baseline system to 348,584 kWh. The EUI of the baseline addition is 48.5, lower than the combined baseline due to the addition being modeled with a shared wall and no heat loss on one side of the building.

The energy savings for all proposed options is recognizable due to the high energy efficiency of the air and ground source heat pumps being proposed, as well as the much improved envelope values over the baseline. HVAC equipment efficiency is often compared using the coefficient of performance, or COP, which is the ratio of energy in vs energy out. Standard fossil fuel hot water condensing boilers operate in the range of a COP of 0.80-0.96. The proposed air source VRF system operates in a heating COP of anywhere from 2.2-3.5 depending on ambient temperature. The air-source heat pump (heat recovery chiller) operates at an even higher efficiency of a COP of anywhere from 2.0-5.5 depending on ambient temperature and simultaneous heating and cooling load. Lastly, the most efficient heating and cooling source is a geothermal ground source heat pump (heat recovery chiller), which operates at the highest efficiency of a COP of 3.0-8.0 depending on ground temperature and the amount of simultaneous load present. It is apparent that operating with a fully electric VRF, air-source heat pump, or geothermal ground source system can result in heating efficiencies roughly 3 to 10 times greater than a fossil fuel furnace.

With the addition of 28,500 ft^2 of PV solar panels to the site, the onsite renewables are estimated to reduce the building EUI by 22. This translate to 475,000 kWh of electricity saved per year.

Table 4: Proposed HVAC Systems Comparison

System Option	HVAC System Description
Option 1: VRF w/ DOAS & Packaged RTU (Addition only)	The proposed fully electric standalone HVAC system for the new addition is to provide a roof mounted heat pump dedicated outdoor air system (DOAS) with energy recovery, paired to a heat recovery VRF system. The DOAS will consist of ductwork distribution to VAV terminal boxes ducted to the return plenum of indoor ducted VRF units. Air terminal units will be wired to space occupancy sensors for occupied/unoccupied operation. The heat recovery VRF system will consist of (2) outdoor, heat recovery air-cooled condensing units mounted on the roof and on grade, indoor heat recovery refrigerant control units (branch controllers), indoor concealed ducted fan coil units, interconnecting refrigerant piping and valving, and wall mounted wired controllers. Indoor VRF fan coil units will be hung in the ceiling plenum from the building structure and ducted to ceiling supply and return diffusers/grilles in each space. The Field House will be served by (2) dedicated packaged heat pump rooftop air handling units (RTU's). These units will be single zone, VAV heat pump rooftop units and will be equipped with VFD's on the compressors and fans for increased part-load performance and energy efficiency. These units will have backup electric resistance heaters for low-ambient conditions. Building exhaust for bathrooms, locker rooms, mechanical rooms, janitor closets, etc. will be accomplished by the central DOAS ERV to recover normally wasted heat energy and remove contaminants from the building. All new equipment will be provided with packaged factory controllers with BACnet interface capability and the existing BMS shall be expanded as needed to integrate and monitor all new packaged controllers on the existing BMS head end.
Option 2: Air-Source Heat Pump (ASHP) (Combined Building)	The Option 1 HVAC system for the combined building (addition and existing) proposed to fully electrify the entire building will consist of an air-cooled modular heat recovery chiller, (3) VAV central air handling units mounted on the roof, terminal VAV air terminals with reheat coils, and all associated ductwork and controls. The existing ductwork distribution will remain and new air handling units and air terminal units will be provided and sized for low temp hot water. The air-cooled heat recovery chiller is a simultaneous system that will generate hot and chilled water simultaneously to heat and cool the building. (4) New variable/primary, variable secondary, redundant base mounted pumps will pump the hot and chilled water through the chiller and throughout the building to the central air handling units and associated air terminal units. All pumps, fans, and compressors will be equipped with VFD's for increased part-load performance and energy efficiency. Building exhaust for bathrooms, locker rooms, mechanical rooms, janitor closets, etc. will be accomplished by constant volume roof mounted centrifugal fans to remove contaminants from the building. The existing BMS shall be expanded as needed and provided with new sensors, valves, actuators, controllers, routers, control points, etc. to integrate new equipment into existing BMS head end.

Option 3: Ground Source Heat Pump (GSHP) (Combined Building)	The Option 2 HVAC system for the combined building (addition and existing) proposed to fully electrify the entire building will consist of a ground source geothermal modular heat recovery chiller, (3) VAV central air handling units mounted on the roof, terminal VAV air terminals with reheat coils, and all associated ductwork and controls. This option is completely reliant on a geothermal well field being installed on the site. The existing ductwork distribution will remain and new air handling units and air terminal units will be provided and sized for low temp hot water. The ground-source heat recovery chiller is a simultaneous system that will generate hot and chilled water simultaneously to heat and cool the building. Ambient condenser water will decouple from the geothermal loop to (2) new redundant base mounted condenser water pumps that will pump the condenser water through the new chiller. (4) New variable/primary, variable secondary, redundant base mounted pumps will pump the hot and chilled water through the chiller and throughout the building to the central air handling units and associated air terminal units. All pumps, fans, and compressors will be equipped with VFD's for increased part-load performance and energy efficiency. Building exhaust for bathrooms, locker rooms, mechanical rooms, janitor closets, etc. will be accomplished by constant volume roof mounted centrifugal fans to remove contaminants from the building. The existing BMS shall be expanded as needed and provided with new sensors, valves, actuators, controllers, routers, control points, etc. to integrate new equipment into existing BMS head end.

Table 5: HVAC Options Comparison Table

	Option 1: VRF w/ Heat Pump DOAS (Addition Only)	**Option 2:** Air Source Heat Pump	**Option 3:** Ground Source Heat Pump (Geothermal)
First Cost (only HVAC & electrical cost)	- Lowest first cost - **$5,980,000** (from Metric early cost estimate)	- Higher first cost - **$8,415,000** (from Metric early cost estimate)	- Highest first cost - **$9,610,000** (from Metric early cost estimate)
Cost Difference	-	**+$2,435,000**	**+$3,630,000**
Operational Cost Savings (Based off preliminary comparative modeling)	-Highest operational cost -HVAC energy cost estimated to be **1% higher** than a gas baseline system. This is due to the higher price of electricity vs. gas.	- Lower operational cost - HVAC energy cost estimated to be **19% lower** than a gas baseline system. This is due to the entire building being converted to high efficiency heat pumps.	- Lowest operational cost - HVAC energy cost estimated to be **32% lower** than a gas baseline system. This is due to the increased efficiency of the geothermal.
Maintenance/ Repair	-Lowest maintenance cost -Most maintenance (changing filters, checking gages, fan replacement, etc.) can be easily accomplished. -Refrigerant piping instead of hot/chilled water. Need licensing for repair. -More vigorous repairs/replacements would require certified installer to repair. -Local supply distributers carry stock. (Mitsubishi)	-Higher maintenance costs. -Some maintenance is similar to the current system, but with addition of a heat pump chiller. (Replacing valves, fittings, vav units, pumps, hot/chilled water piping, etc.) -Requires glycol water treatment -More vigorous repair of the heat pump would likely need assistance from the factory/service contract. - Heat pump parts likely shipped to order. (Multistack), terminal VAV equipment easily sourced.	-Highest maintenance costs. -Some maintenance is similar to the current system. (Replacing valves, fittings, vav units, pumps, hot/chilled water piping, etc.) -Requires glycol water treatment -More vigorous repair of the heat pump would likely need assistance from the factory. - Heat pump parts likely shipped to order. (Multistack), terminal VAV equipment easily sourced. -Any issues with geothermal could require excavation and additional contractors to repair.
Controls	-Simple, pre-packaged controls provided with units and programmed by factory. - Controls installed by VRF manufacturer and then tied into existing BMS. Not as much control/visibility on BMS as other systems) -BACnet IP compatible.	-Complex & extensive controls required. -Easily integrated into existing BMS, but on site controls installation and programming required. -BACnet IP compatible.	-Complex & extensive controls required. (additional monitoring and components required over ASHP) -Easily integrated into existing BMS, but extensive on site controls installation and programming required. -BACnet IP compatible.
Mechanical Space Required	- Least mechanical space needed. -No mechanical room needed. -Condensing units can be located on grade or on roof. -Rooftop units for gymnasium will need space directly above gymnasium. -No appreciable effect on usable roof area for solar panels.	-Large mechanical space needed. -Large mechanical room or roof penthouse required for hot water/chilled water tanks, pumps, auxiliary equipment, etc. -No appreciable effect on usable roof area for solar panels.	-Largest mechanical space needed. -Largest mechanical room or roof penthouse required for indoor heat pump modules, hot water/chilled water tanks, pumps, auxiliary equipment, etc. -No appreciable effect on usable roof area for solar panels.

Appendix A

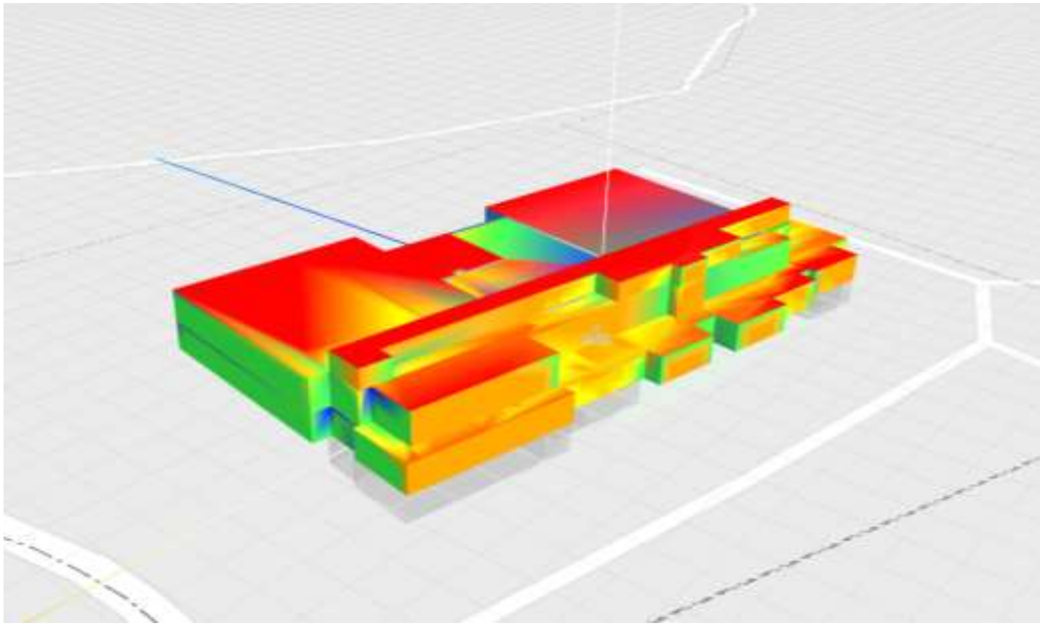

Figure A.1: Combined Building Sun Hours Model

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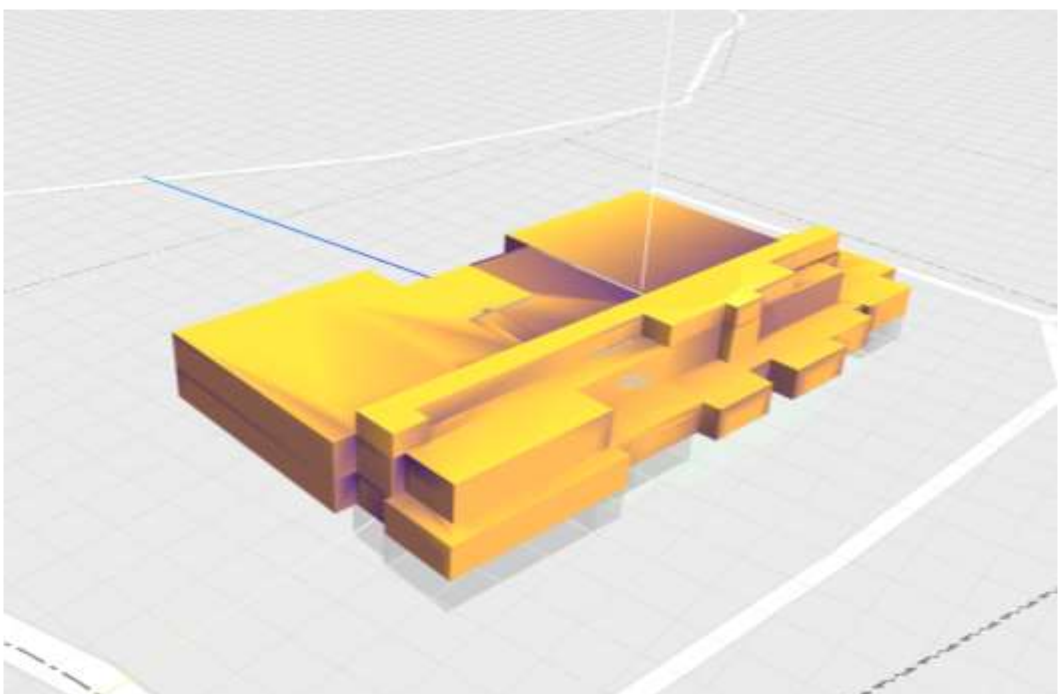

Figure A.2: Combined Building Radiation Model