

SEP 29, 2023

Greenwich Central Middle School

SD Energy Analysis & LCCA

Thornton Tomasetti

GOAL

- Compare three HVAC options from life cycle cost perspective.
- Compare outright purchase of HVAC options to Power Purchase Agreement (PPA) financing options for geothermal, photo-voltaic (PV), or both.
- PV potential assessment.

CRITICAL ASSUMPTIONS:

- Window to Wall Ratio (WWR) – 26.6% (based on Revit model)
- Wall – assembly R-30 (CFMF with 5" XPS and Brick Veneer)
- Roof – assembly R-50 (Continuous polyiso insulation)
- Slab on grade (SOG) – 3" of continuous XPS insulation under the entire slab
- Fenestration – double-pane IGU with thermally-broken frame
- LPD – 0.55 W/sf (assumed)
- Plug loads – avg 0.53 W/ sf (assumed space by space method)

Base Cost Estimate:

CTHPBS Envelope: 4" wall, R-40 roof

Alt#1 ZNE envelope:

upgrade to 5" wall, R-50 roof, full SOG insulation

Agreed for the SD level LCCA will model all systems using the ZNE envelope for an apples to apples comparison

HVAC OPTIONS OVERVIEW

Base: Boilers and chillers

- Air-side: ACB with ASHP DOAS, ASHP RTU
- Water-side: Natural gas boilers, air cooled chillers

Alt 1: Geothermal (All electric)

- Air side: ACB with ASHP DOAS, ASHP RTU
- Water-side: GSHP

Alt 2: VRF system

- VRF + ASHP DOAS system, ASHP RTU
- Gas-fired boiler for perimeter heating and ASHP coil preheat

Glossary of Terms:

ACB - Active Chilled Beams

ASHP - Air Source Heat Pump

COP - Coefficient of Performance

DOAS - Dedicated Outside Air System

Geo - Geothermal

GSHP - Ground Source Heat Pump

HW - Hot Water

HVAC - Heating, Ventilation and Air Conditioning

IGU - Insulated Glass Unit

kW - Kilowatt

LPD - Lighting Power Density

MWh - Mega-watt hours

pEUI - predicted Energy Use Intensity (kBtu/sf-yr)

PPA - Power Purchase Agreement

PV - Photo-voltaic system (solar panels)

RTU - Roof Top Unit

UH - Unit Heater

VRF - Variable Refrigerant Flow

W - Watt

WWR - Window to Wall Ratio

HVAC ASSUMPTIONS – AIR SIDE

	Base	Alt 1 Geo	Alt 2 VRF
All Other Areas	ACB + ASHP DOAS	ACB + ASHP DOAS	VRF + ASHP DOAS
Auditorium		ASHP (RTU-3)	
Cafeteria & Kitchen		ASHP (RTU-2)	
Gym		ASHP (RTU-1)	
Data/Tel/Security		Ductless split units	
Stairs, Vestibules		Hot Water Unit Heater	
DHW		Heat pump water heater	

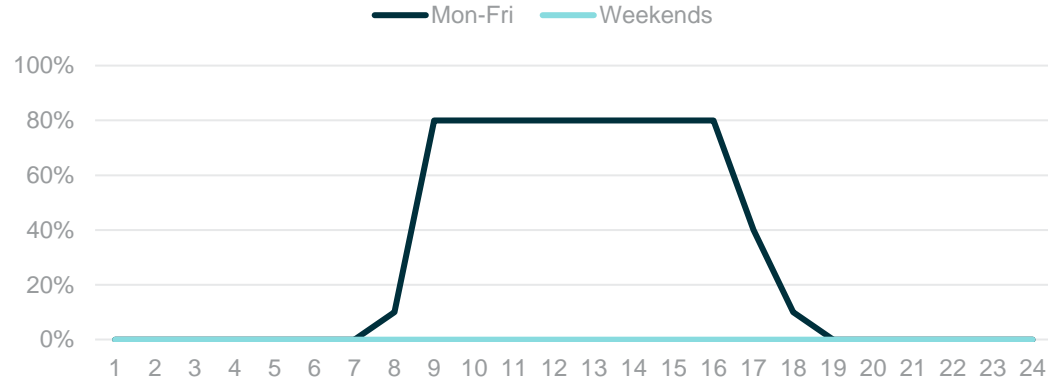
HVAC ASSUMPTIONS – WATER SIDE

	Base	Alt 1 Geo	Alt 2 VRF
Primary Heating Source	Gas-fired boilers 96% eff. (COP 0.96)	Ground-source Heat Pump COP 3.1	Gas-fired boiler for perimeter heating & pre-heat (COP 0.96)
Primary Cooling Source	Air-cooled chillers COP 4	Ground-source Heat Pump COP 5.6	-
Geothermal Wells	-	65 wells 500 ft deep	-

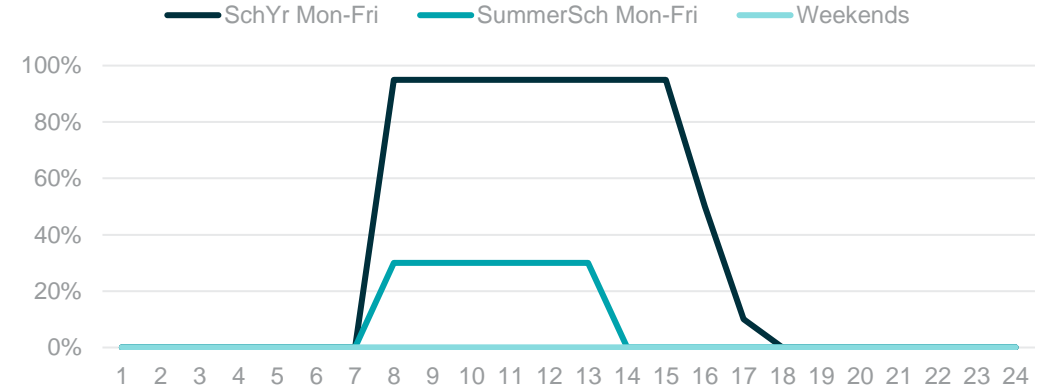
COP: Coefficient of Performance = Output energy / Input energy
(Higher the COP, the more efficient HVAC)

SCHEDULES

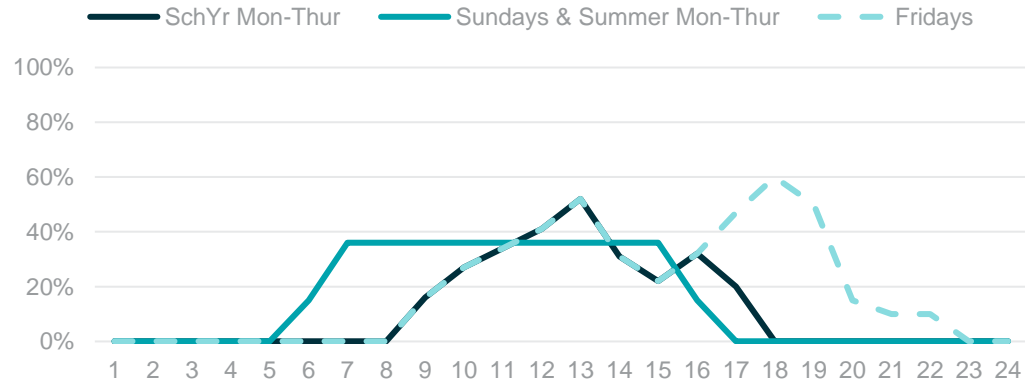
Admin Schedules



Classroom Schedules



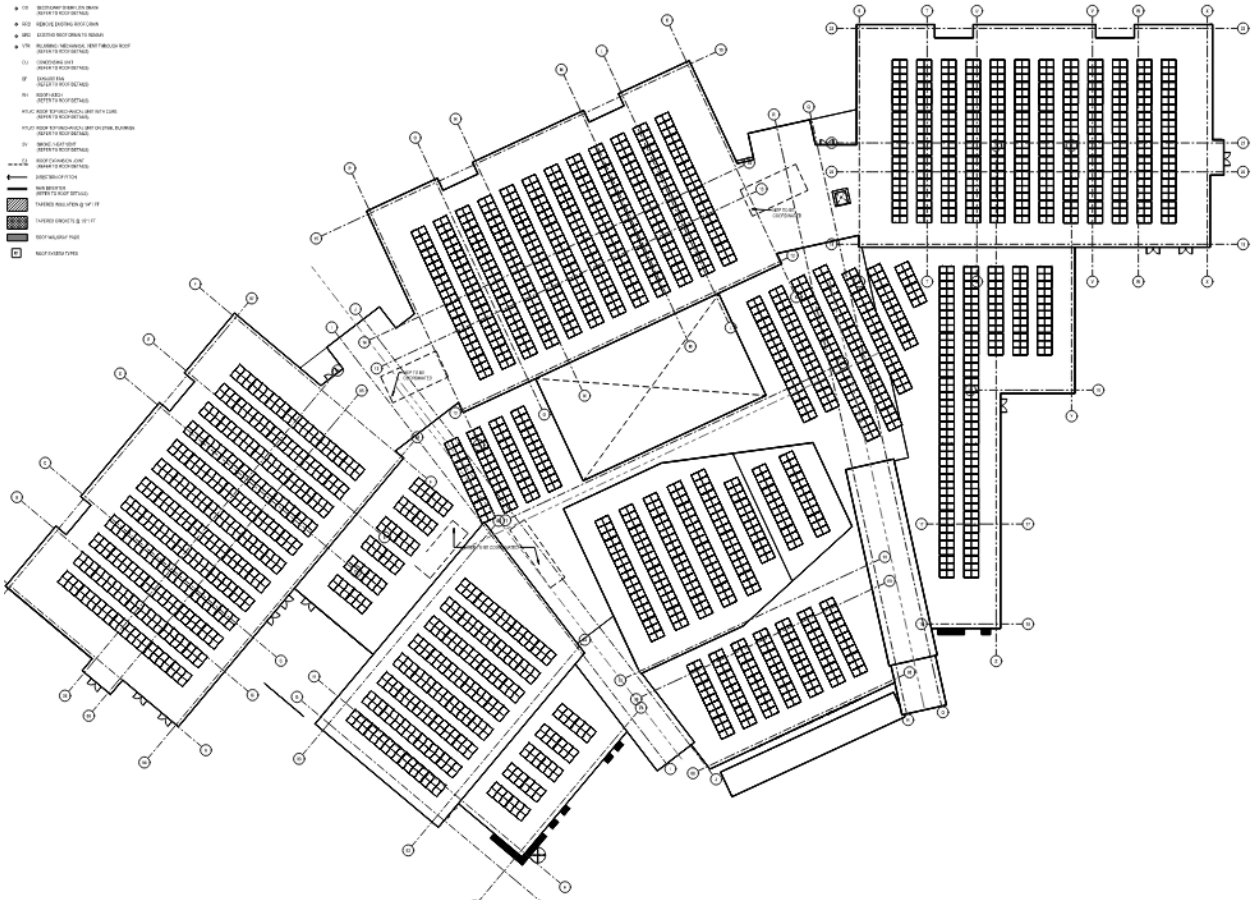
Assembly Spaces Schedule



PV POTENTIAL

ROOF PLAN GRAPHIC LEGEND

- 1.01 SHOWN AS NOT AVAILABLE FOR PV
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PV panel area only: 33,240 SF
 Potential Capacity: 587 kW
 Annual Production: **760 MWh (~20.7 EUI)**

Assumptions:

- Module Efficiency: 19%
- Fixed roof mount
- System Losses: 14.08%
- Tilt: 20 dg
- Azimuth: 180 deg (south)

ENERGY USE INTENSITY (pEUI)

Before PV pEUI:

- Base: 38.8 EUI
- Alt 1 Geo: 27.7 EUI
- Alt 2 VRF: 35.3 EUI

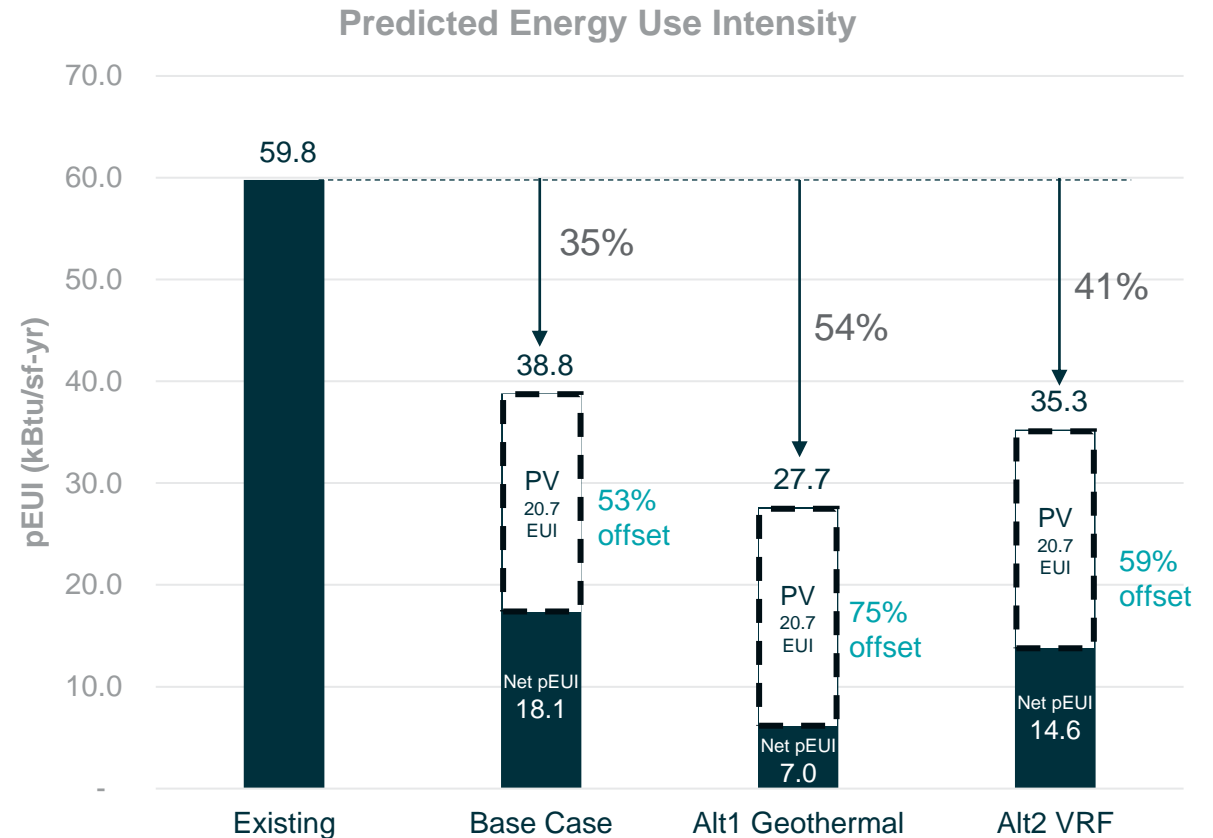
After PV Net pEUI:

- Base: 18.1 EUI
- Alt 1 Geo: 7.0 EUI
- Alt 2 VRF: 14.6 EUI

To achieve a Zero Net Energy (ZNE) project, the Net pEUI for all systems will require additional on-site energy generation at additional cost, or purchase of off-site green energy

Additional PV required for ZNE:

- Base: 515 kW
- Alt 1 Geo: 198 kW *Best opportunity for ZNE*
- Alt 2 VRF: 414 kW



From Energy Star
Portfolio Manager
2019 data

FIRST YEAR COST

- PPA PV: assuming \$0.08/ kWh (PPA rate may vary depending on the PPA agreement with the vendor).
- PPV Geo: pay 10% of geothermal well costs every year for 25yrs, no escalation /inflation increase.
- In DD, the design team will work to get the system ALT1 baseline pEUI to 25, or below. Doing so will enable the pursuit of full Energize CT incentive rebates.

First Year	Base Case	Alt 1 Geo	Alt 2 VRF	Alt 1 w/PPA PV	Alt 2 w/PPA PV	Alt 1 w/PPA PV & Geo
HVAC Cost	\$9.6M	\$9.8M	\$8.6M	\$9.8M	\$8.6M	\$9.8M
PV Cost	\$3.0M	\$3.0M	\$3.0M	-	-	-
Geothermal Well Cost	-	\$3.1M	-	\$3.1M	-	-
Geothermal PPA Cost	-	-	-	-	-	\$0.3M
pEUI	38.8	27.7	35.3	27.7	35.3	27.7
Net pEUI	18.1	7.0	14.6	7.0 + 20.7 PPA	14.6 + 20.7 PPA	7.0 + 20.7 PPA
Energy Rates	Grid Electricity: \$0.16 / kWh Natural gas: \$1.04 / therm	Grid Electricity: \$0.16 / kWh	Grid Electricity: \$0.16 / kWh Natural gas: \$1.04 / therm	Grid Electricity: \$0.16 / kWh PPA Electricity: \$0.08 / kWh	Grid Electricity: \$0.16 / kWh PPA Electricity: \$0.08 / kWh Natural gas: \$1.04 / therm	Grid Electricity: \$0.16 / kWh PPA Electricity: \$0.08 / kWh
Energy Cost/ SF	\$0.21	\$0.15	\$0.39	\$0.72	\$0.96	\$0.72
Energy Cost	\$26,335	\$18,811	\$48,909	\$90,293	\$120,391	\$90,293
Annual Maintenance Cost	\$22,573	\$22,573	\$28,217	\$22,573	\$28,217	\$22,573
Total First Year Cost	\$12.7M	\$15.9M	\$11.7M	\$13.0M	\$8.8M	\$10.2M
IRA 40% Geothermal Rebate	-	- \$5.2M	-	- \$5.2M	-	- \$3.9M
Potential Energize CT Incentive	-	- \$0.8M	- \$0.4M	- \$0.8M	- \$0.4M	- \$0.8M
First Year Net Cost	\$12.7M	\$10.0M	\$11.3M	\$7.0M	\$8.4M	\$5.5M

REPLACEMENT COSTS

	Base Case	Alt 1 Geo	Alt 2 VRF	Alt 1 w/PPA PV	Alt 2 w/PPA PV	Alt 1 w/PPA PV & Geo
Water-side HVAC Capital Cost <i>Useful life: 25 Years</i>	\$0.7M	\$0.2M	\$0.4M	\$0.2M	\$0.4M	\$0.2M
ASHP/VRF Capital Cost <i>Useful life: 20 Years</i>	\$2.6M	\$2.6M	\$8.7M	\$2.6M	\$8.7M	\$2.6M
PV Capital Cost <i>Useful life: 25 Years</i>	\$3.0M	\$3.0M	\$3.0M	-	-	-

Replacement Schedule

Year 20 (<i>replace ASHP/VRF</i>)	\$5.4M	\$5.4M	\$18.3M	\$5.4M	\$18.3M	\$5.4M
Year 25 (<i>replace Water-side & PV</i>)	\$9.4M	\$8.2M	\$8.6M	\$0.6M	\$1.0M	\$0.6M
Year 40 (<i>replace ASHP/VRF</i>)	\$11.4M	\$11.4M	\$38.7M	\$11.4M	\$38.7M	\$11.4M
Total Replacement Cost	\$26.2M	\$25.0M	\$65.6M	\$17.4M	\$58.0M	\$17.4M

- Capital Costs are from Turner Schematic Estimate dated 07-21-2023
- Replacement costs includes Escalation Rate: 1.5% & Inflation Rate: 2.3%

LIFE CYCLE COST ANALYSIS

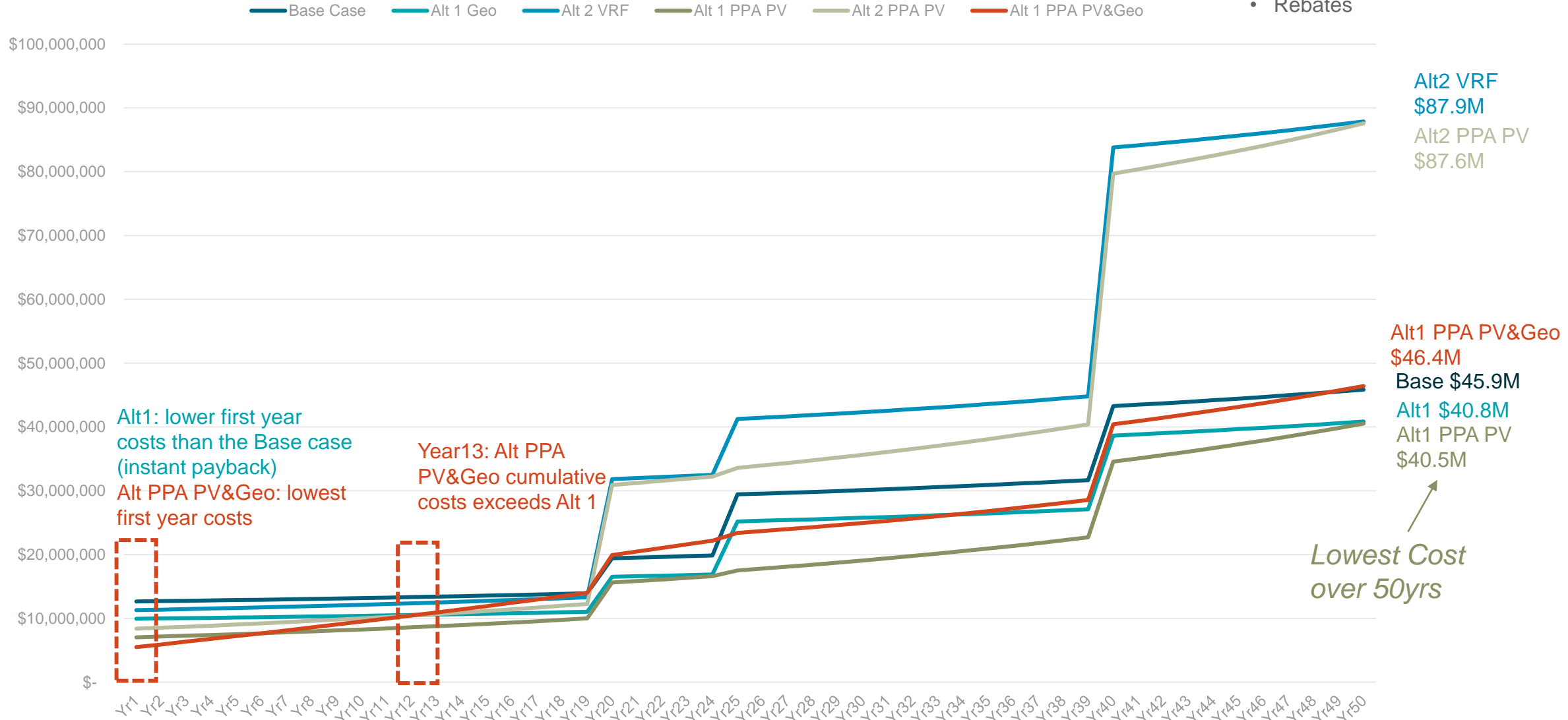
- Escalation Rate: 1.5%
- Inflation Rate: 2.3%
- Nominal Discount Rate: 5.5%
- Real Discount Rate: 3.13%

50 Years	Base Case	Alt 1 Geo	Alt 2 VRF	Alt 1 w/PPA PV	Alt 2 w/PPA PV	Alt 1 w/PPA PV & Geo
HVAC Cost (Turner)	\$9.6M	\$12.9M	\$8.6M	\$12.9M	\$8.6M	\$9.8M
PV Cost	\$3.0M	\$3.0M	\$3.0M	-	-	-
Geothermal PPA Cost	-	-	-	-	-	\$7.7M
Energy Costs	\$3.8M	\$2.7M	\$7.0M	\$13.0M	\$17.3M	\$13.0M
Maintenance Cost	\$3.2M	\$3.2M	\$4.1M	\$3.2M	\$4.1M	\$3.2M
Replacement Cost	\$26.2M	\$25.0M	\$65.6M	\$17.4M	\$58.0M	\$17.4M
Potential Rebate	-	-\$6.0M	-\$0.4M	-\$6.0M	-\$0.4M	-\$4.7M
Total 50yrs Cost	\$45.9M	\$40.8M	\$87.9M	\$40.5M	\$87.6M	\$46.4M
Net Present Value (Compares initial investment and return)	-	\$3.0M	-\$7.0M	\$5.6M	-\$4.5M	\$3.2M

CUMULATIVE CASH FLOW

Includes:

- Utility cost
- Maintenance cost
- Replacement cost
- Rebates



CONCLUSION

- Alt 1 Geothermal PPA PV has the [best](#) opportunity to be net-zero energy and shows [lowest](#) costs over 50 years.
- Alt 1 Geothermal (outright purchase) has the [best](#) opportunity to be net-zero energy and shows [similar](#) costs as PPA PV over 50 years.
- PV can significantly reduce energy costs.
- PPA reduces first cost but has higher overall costs over 50 years.
- The results may change depending on the PPA agreement with the vendor.
- Alt 2 VRF is cost-prohibitive because of high replacement costs.