Building Energy Efficiency Analysis for a Small Hotel and LG Multi V™ VRF Systems

Contents

Executive Summary

LG Electronics U.S.A., Inc. performed a Small Hotel[1] energy efficiency analysis that compared LG Variable Refrigerant Flow (VRF) systems with other conventional Heating, Ventilating, and Air Conditioning (HVAC) systems[2]. The analysis reviewed performance in fourteen various climate zones: Miami, FL (1A); Houston, TX (2A); Phoenix, AZ (2B); Atlanta, GA (3A); Los Angeles, CA (3B);San Francisco, CA (3C); Baltimore, MD (4A); New York, NY (4A); Albuquerque, NM (4B); Seattle, WA (4C); Chicago, IL (5A); Boulder, CO (5B); Minneapolis, MN (6A); and Helena, MT (6B). The HVAC energy analysis baseline followed was American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE®[3]) Standard 90.1. The conventional HVAC baseline system was based upon the ASHRAE Standard 90.1-2013 system.

In the energy analysis, conventional HVAC systems' minimum efficiencies were compared to LG VRF's specifications using the same conditions such as floor plans, occupancy schedules, lighting power density, ventilation, and envelope types. Table 1 depicts the results of the analysis, the annual HVAC and domestic water heating energy cost saving (%) and the payback period comparing LG VRF to ASHRAE baseline HVAC systems used under similar conditions.

Table 1: Summary of Annual HVAC and Domestic Water Heating Energy Cost Savings and Savings % by Proposed System.

Location (Climate Zone)	Annual HVAC and Domestic Water Heating Energy Cost Savings by Proposed: LG VRF + Hydro Kit ($)	HVAC and Domestic Water Heating Energy Cost Savings by Proposed: LG VRF + Hydro Kit (%)	Payback Period (Year)
Miami, FL (1A)	36,768	76%	1 year, 0 months
Houston, TX (2A)	31,105	74%	1 year, 2 months
Phoenix, AZ (2B)	33,014	75%	1 year, 4 months
Atlanta, GA (3A)	26,339	75%	1 year, 4 months
Los Angeles, CA (3B)	45,141	81%	0 year, 8 months
San Francisco, CA (3C)	40,331	79%	0 year, 8 months
Baltimore, MD (4A)	31,284	60%	1 year, 3 months
New York, NY (4A)	38,905	57%	0 years, 11 months
Albuquerque, NM (4B)	25,739	62%	0 years, 11 months
Seattle, WA (4C)	20,061	65%	1 year, 5 months
Chicago, IL (5A)	27,450	50%	1 year, 4 months
Boulder, CO (5B)	26,931	60%	1 year, 0 months
Minneapolis, MN (6A)	24,820	44%	1 year, 5 months
Helena, MT(6B)	27,366	52%	1 year, 0 months
Average	31,090	65%	1 year, 1 month

[*Compared to the baseline HVAC & DHW system: ASHRAE Standard 90.1-2013.]

Legal Disclaimer: The models described in this report are intended to demonstrate the potential cost-effectiveness of possible energy improvements for new or existing facilities under the conditions as identified in the white paper. The choice of models was subject to the professional judgment of LG Electronics U.S.A., Inc., in accordance with industry standards. The models and conclusions of this report do not guarantee actual energy costs or savings.

[1] Commercial Reference Buildings | Department of Energy - https://www.energy.gov/eere/buildings/commercial-reference-buildings
[2] ASHRAE Standard 90.1-2013-https://www.ashrae.org/technical-resources/bookstore/standard-90-1-appendix-g-2013-performance-rating-method
[3] American Society of Heating, Refrigerating and Air-Conditioning Engineers - https://www.ashrae.org/

Small Hotels

Overview

To model the baseline and proposed design, LGE U.S. Air-Conditioning Technologies (ACT) used the LG Net Zero Energy Design and Evaluation Program (LNZEP). LNZEP, a building energy simulation program jointly developed by LGE and Dr. Heejin Cho's research team of Mississippi State University[4], is based on the U.S. Department of Energy's (DOE) EnergyPlus™ open-source whole-building energy modeling (BEM) engine, which provides general year-long building load estimation and energy use calculations. LNZEP includes DOE's commercial prototype building models in its database; analyzes VRF's cooling, heating, and water heating energy savings; calculates solar panels or solar thermal collectors required to implement Net Zero energy goals; and analyzes the life cycle cost. Using LNZEP, LGE U.S. ACT performed a building and HVAC and Domestic Hot Water (DHW) energy comparison analysis between the baseline HVAC systems and the proposed systems.

Utilizing the data comprising a Small Hotel, as described further within this Section, the study collected the following information of a Small Hotel from DOE's commercial prototype building models[5].

- Envelope properties
- Floor plans and geometry
- Occupancy schedules
- Lighting and equipment schedules

To determine the potential for energy savings by using LG VRF, the Small Hotel building energy consumption was compared with other conventional cooling / heating systems, based upon the ASHRAE Standard 90.1-2013 system. Unless specifically stated below, the prototype building total conditioned area, insulation level, equipment load, interior lighting zones, energy source, and average utility rates utilized in the study were the same for both the baseline HVAC system and the proposed system.

Hotel Building Construction and Energy Costs

The ENERGY STAR® [6]Building Upgrade Manual Facility Type: Hotels and Motels Chapter 12 report — *ENERGY STAR Building Manual 212. Facility Type: Hotels and Motels*[7] — identified potential energy savings for Hotels. According to the report, the 47,000 hotels and motels in the United States spend an average of $2,196 per available room each year on energy costs, an amount that represents about 6% of all hotel and motel operating costs. Typically, nearly 75% of the total energy use of hotels and motels can be attributed to space heating and cooling, water heating, lighting, and fan power. Energy intensity in hotels and motels varies widely depending on climate, number of rooms, and types of on-site amenities, and ranges from less than 15,000 Btu/ft² to more than 300,000 Btu/ft². When creating an energy-saving strategy for the purpose of an energy use profile, the largest energy loads of hotels and motels should be considered.

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[4] https://www.me.msstate.edu/people/faculty/heejin-cho/

[5] DOE Prototype Building Models-http://www.energycodes.gov/development/commercial/prototype_models

[6] ENERGY STAR - https://www.energystar.gov/

[7] Energy Star Building Upgrade Manual Facility Type: Hotels and Motels Chapter 12 - https://www.energystar.gov/sites/default/files/buildings/tools/EPA_BUM_CH12_HotelsMotels.pdf

Studied Model of Small Hotels

ASHRAE Standard 90.1 prototype building models, which served as the baseline for the HVAC energy analysis, were developed by Pacific Northwest National Laboratory (PNNL) in support of DOE's Building Energy Codes Program. These prototype buildings were derived from DOE's *Commercial Reference Building Models*[8]. This study reviewed the building and HVAC energy use of the baseline HVAC systems and proposed systems by assigning multiple climate conditions to a Small Hotel as shown in the floor plan below.

The four story Small Hotel studied in this paper had a total conditioned area of 43,200 ft² with 35 guest rooms, accounting for 63% of the total floor area. The types of conditioned spaces are summarized in Table 2. The building operation is expected to be open for 24 hours a day and 7 days a week.

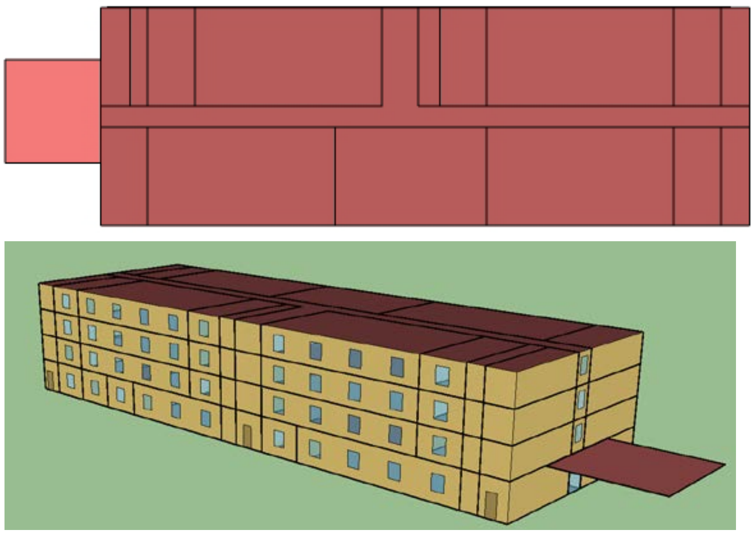


Figure 1: Floor Plan and Thermal Zones of the Small Hotel Building.[9]

Table 2: Space Types and Sizes of Conditioned Zones.

Space Types	Size (ft²)
Guest room	27,274
Laundry	1,053
Meeting	1,215
Retail	1,558
Corridor	7,399
Exercise	351
Lobby	1,755
Office	1,402
Restroom	351
Storage rooms	1,402
Mechanical	351
Elevator core	648
Total	43,200

[8] National Renewable Energy Laboratory (NREL), U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. - https://www.nrel.gov/docs/fy11osti/46861.pdf,
[9] DOE Prototype Building Models-https://www.energycodes.gov/prototype-building-models

Building Envelope

Different U values are required depending on the insulation of the building (exterior walls, roofs, windows, etc.). The insulation levels, for the purpose of this study, were calculated according to the ASHRAE Standard 90.1-2013 minimum requirements, as follows.

Table 3: Building Envelope.

Exterior Walls	
Construction	Steel-Frame Walls (2x4 16 in. OC) 1 in. Stucco + 5/8 in. gypsum board + wall Insulation + 5/8 in. gypsum board
U-factor (Btu / h * ft² * °F) and/or R-value (h * ft² * °F / Btu)	Requirements in codes or standards Nonresidential; Walls, Above-Grade, Steel-Framed
Roof	
Construction	Built-up roof : Roof membrane + roof insulation + metal decking
U-factor (Btu / h * ft² * °F) and/or R-value (h * ft² * °F / Btu)	Requirements in codes or standards Nonresidential; Roofs, Insulation entirely above deck
Window	
Dimensions	Based on window fraction, location, glazing sill height, floor area and aspect ratio
Glass-Type and frame	Hypothetical window with weighted U-factor and SHGC
U-factor (Btu / h * ft² * °F)	Requirements in codes or standards
SHGC (all)	Nonresidential; Vertical Glazing
Visible transmittance	Same as above requirements
Operable area	0%
Foundation	
Foundation Type	Slab-on-grade floors (unheated)
Construction	6 in. concrete slab poured directly on to the earth with carpet
Thermal properties for slab-on-grade floor	Requirements in codes or standards
Interior Partitions	
Construction	2 x 4 uninsulated stud wall
Dimensions	Based on floor plan and floor-to-floor height
Internal Mass	6 inches standard wood (16.6 lb/ft²)
Air Barrier System	
Infiltration	Peak: 0.2016 cfm/sf of above grade exterior wall surface area, adjusted by wind (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on) Additional infiltration through building entrance

Equipment Load

The building equipment loads for both the baseline HVAC system and the proposed system were calculated according to the ASHRAE Standard 90.1-2013, which is 0.95 W/ft².

Interior Lighting

The interior lighting, for purposes of the baseline HVAC system and the proposed system, was as provided in the ASHRAE Standard 90.1 - 2013 for Small Hotels, depicted in Table 4.

Table 4: Space Types and Sizes of Interior Lighting per Zones.

Space Types	Lighting[2] [W/ft²]
Guest room	1.1
Laundry	0.6
Meeting	1.3
Corridor	0.5
Exercise	0.9
Lobby	1.1
Office	1.1
Restroom	0.9
Storage rooms	0.8
Mechanical	1.5
Elevator core	0.0

Water Heater

More than many other facility types, water heating is a major load for hotels and motels. It accounts for more than a third of hotel facility energy consumption, of which about 40% is used for laundry and kitchen operations.[10] In general, Net Zero energy buildings avoid the use of natural gas, so in this study, the energy source of the water heating was assumed as electricity, and the conditions studied were as follows:

- SWH type :Main water heater and laundry water heater, both with storage tank
- Fuel type: electricity
- Thermal efficiency (%):Requirements in codes or standards
- Tank Volume (gal): 300 (main); 200 (laundry)
- Water temperature set point: 140°F for guest rooms and 180°F for laundry

[10]DOE Prototype Building Models- http://www.energycodes.gov/development/commercial/prototype_models

Average Utility Rates

The electricity and natural gas rates[11] utilized in the study were based upon the rates provided by the U.S. Energy Information Administration, for DATE/TIMEFRAME (identify dates for electrical and natural gas), as follows:

Table 5: Average Utility Rates.

Weather Zone	1A	2A	2B	3A	3B	3C	4A
State	FL	TX	AZ	GA	CA	CA	MD
City	Miami	Houston	Phoenix	Atlanta	Los Angeles	San Francisco	Baltimore
Electricity (Cents/kWh)	11.99	11.51	12.21	10.7	18.34	18.34	13.07
Electricity CO^2 Emission (lb/kWh)	1.11	1.17	1.03	1.11	0.51	0.51	1.13
Natural Gas ($/Therm)	2.06	1.10	1.48	1.35	1.19	1.19	1.14
Natural Gas CO^2 Emission (lb/ Therm)	13	13	13	13	13	13	13
Weather Zone	4A	4B	4C	5A	5B	6A	6B
State	NY	NM	WA	IL	CO	MN	MT
City	New York City	Albuquerqu e	Seattle	Chicago	Boulder	Minneapoli s	Helena
Electricity (Cents/kWh)	17.29	12.21	9.31	12.19	11.89	10.83	12.79
Electricity CO^2 Emission (lb/kWh)	0.55	1.69	0.21	0.92	1.57	1.11	1.37
Natural Gas ($/Therm)	1.19	0.76	0.99	0.79	0.75	0.84	0.71
Natural Gas CO^2 Emission (lb/ Therm)	13	13	13	13	13	13	13

[11] Average Price (Oct. 2021) of Electricity by End-Use Sector, by State. http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a;
Average Price (Oct. 2021) of Natural Gas Prices.http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_m.htm.

Space Cooling / Heating Systems for Small Hotels

Heating and air conditioning account for nearly 40% of the electricity, and more than 50% of the natural gas used by hotels and motels. Many hotels heat and cool guestrooms regardless of whether or not they are occupied. Hotels allow this apparent waste of energy because hotel and motel proprietors prioritize guest comfort over energy use. It is necessary, therefore, for hotel and motel owners or operators to find the right operation, control, and efficient technology that will provide energy savings opportunities without compromising customer comfort.[12]

Heating and cooling load calculations imposed on a building HVAC system are performed for a space temperature fixed in time, and are commonly referred to as load calculations. As weather conditions and internal activity change over time, and the building mass absorbs and releases heat, load calculations provide information on how much heat should be added or extracted using an HVAC system to keep the space at a target temperature. Table 6 shows the load calculation results required, for the purposes of the study, for each floor and the entire building according to the Heating and cooling load calculations below.

HVAC Loads

Table 6: Baseline/Proposed HVAC Systems Sizing/Floor (Outdoor Units, Cooling Tons).

Weather Zone	1A	2A	2B	3A	3B	3C	4A
State	FL	TX	AZ	GA	CA	CA	MD
City	Miami	Houston	Phoenix	Atlanta	Los Angeles	San Francisco	Baltimore
1st	18	18	18	16	12	10	18
2nd	18	18	18	16	12	12	18
3rd	12	12	12	12	8	8	14
4th	14	14	16	14	10	10	16
Total	62	62	64	58	42	40	66
Weather Zone	4A	4B	4C	5A	5B	6A	6B
State	NY	NM	WA	IL	CO	MN	MT
City	New York City	Albuquerque	Seattle	Chicago	Boulder	Minneapolis	Helena
1st	16	10	12	16	12	18	14
2nd	18	12	14	18	12	16	12
3rd	12	8	10	14	8	12	8
4th	14	12	10	14	10	14	10
Total	60	42	46	62	42	60	44

[12] Energy Savings Tips for Small Businesses: Lodging : https://www.energystar.gov/buildings/resources_audience/small_biz/lodging

Baseline: Packaged Systems

Many Small Hotels meet the space cooling and heating requirements through packaged units as follows:

- Guest rooms: Packaged terminal air conditioner (PTAC) with gas heating or packaged terminal heat pump (PTHP) with electric resistance supplemental heating.
- Public spaces (office, laundry, lobby, and meeting rooms): PTAC with gas heating, or a packaged single-zone heat pump.
- Storage and stairs: Electric cabinet heaters.

Packaged unit controls often make managing heating, cooling and ventilation easier. The controls provide Small Hotel occupants the ability to more effectively control indoor climate. In this study, according to the ASHRAE Standard 90.1-2013 criteria (see Table 2), the baseline systems were determined as follows:

- System 1 - Packaged Terminal Air Conditioner (PTAC; ASHRAE Standard 90.1-2013): PTAC systems are commonly used in hotels to provide heating and cooling for individual rooms.
- System 2 - Packaged Terminal Heat Pump (PTHP; ASHRAE Standard 90.1-2013): PTHP systems are commonly used in hotels to provide heating and cooling for individual rooms. PTHP is an ASHRAE Standard Baseline System No. 2 that can use either a refrigerating system in a reverse cycle or heat pump mode to provide heat.

Figure 2: Packaged Terminal Air Conditioner or Heat Pump (PTAC or PTHP)[13]

- System 3 – Packaged Single Zone – Air Conditioner (PSZ-AC, ASHRAE Standard 90.1-2013): Packaged single-zone rooftop air conditioners, combined with combustion furnaces and ductwork, are designed primarily for commercial buildings like Small Hotels to provide heating and cooling for a single room or zone. It is usually supplied with an outside/return air damper economizer, air filters, a gas or oil furnace, a direct exchange (DX) cooling coil, a supply fan, compressor, and air cooled condenser. If the unit is very large (>30,000 CFM), a return fan may be included.
- System 4 – Packaged Single Zone – Heat Pump (PSZ-HP, ASHRAE Standard 90.1-2013): Packaged single-zone heat pumps with ductwork, are widely used in commercial applications like Small Hotels. PSZ-HP units include continuous indoor fan operation during occupancy and ventilation for occupants. The cooling coil is direct expansion, and the heating is furnished by an air-to-air heat pump.

Figure 2: Packaged HVAC System (called Rooftop Unit)[14]**.**

[13]LG Electronics U.S.A., Inc.:https://lghvac.com/residential-light-commercial/product-type/?productTypeId=a2x44000003XR1g&iscommercial=false&class=PTAC.
[14]LG Electronics U.S.A., Inc.: https://lghvac.com/commercial/product-type/?productTypeId=a2x2S00000BTy7z&iscommercial=true&class=Air%20Technologies.

Table 7: Baseline HVAC System Type (ASHRAE Standard 90.1-2013).

BUILDING TYPE	SPACE TYPE	CLIMATE ZONES 3B, 3C AND 4-8	CLIMATE ZONES 1-3A
Residential	Guest rooms	System 1 - PTAC	System 2 - PTHP
Retail and 2 floors or fewer	Corridor, office and others	System 3 - PSZ-AC	System 4 - PSZ-HP

Table 8: Baseline HVAC Systems (ASHRAE Standard 90.1-2013).

Climate Zone	System No.	System Type	COP (Cooling)	COP OR % (Heating)
1A_MIAMI_FL	System 2, System 4	PTHP, PSZ-HP	3.00	3.0 (Heat Pump)
2A_HOUSTON, TX	System 2, System 4	PTHP, PSZ-HP	3.00	3.0 (Heat Pump)
2B _PHOENIX, AZ	System 2, System 4	PTHP, PSZ-HP	3.00	3.0 (Heat Pump)
3A_ATLANTA, GA	System 2, System 4	PTHP, PSZ-HP	3.00	3.0 (Heat Pump)
3B_LOS ANGELES, CA	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
3C _SAN FRANCISCO, CA	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
4A _BALTIMORE, MD	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
4A_NEW YORK CITY, NY	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
4B _ALBUQUERQUE, NM	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
4C _SEATTLE, WA	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
5A_CHICAGO, IL	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
5B _BOULDER, CO	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
6A_MINNEAPOLIS, MN	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)
6B _HELENA, MT	System 1, System 3	PTAC, PSZ-AC	3.00	80% (Gas Furnace)

Proposed: Variable Refrigerant Flow (VRF) Systems

The proposed VRF equipment, for purposes of the study, included various configurations of LG Multi V™ air-source VRF heat pump or heat recovery systems, which were designed for small to medium-scale facilities such as offices, retail, hospitals, schools, and Hotels. LG Multi V systems feature higher energy efficiencies than the ASHRAE standard minimum required efficiency, long piping capabilities, and are certified using Air-Conditioning, Heating and Refrigeration Institute (AHRI®[15]) Standard 1230[16]. LG's high-side shell compressor has a wide inverter range for a better response to load matching. The built-in, concealed-ducted indoor unit that was included in the study can help maintain existing ceilings without additional ductwork. Table 9 and 10, below, describe ...

Table 9: Proposed Outdoor Units Efficiency Data.

System Type	Tons(Nominal)	Model Name	COP (Cooling)	COP (Heating)
VRF(HP/HR)	8	ARUM096DTE5	5.3	4.7
	10	ARUM121DTE5	4.5	4.3
	12	ARUM144DTE5	4.5	4.5
	14	ARUM168DTE5	4.0	3.96
	16	ARUM192DTE5	4.1	4.09
	18	ARUM216DTE5	4.1	4.01

Table 10: Proposed Indoor Units Q'ty /floor: Low Static Duct Type (ARNU073L1G4).

Weather Zone	1A	2A	2B	3A	3B	3C	4A
State	FL	TX	AZ	GA	CA	CA	MD
City	Miami	Houston	Phoenix	Atlanta	Los Angeles	San Francisco	Baltimore
First Floor	29	29	29	26	20	16	29
Second Floor	29	29	29	26	20	20	29
Third Floor	20	20	20	20	13	13	23
Fourth Floor	23	23	26	23	16	16	26
Total	101	101	104	95	69	65	107
Weather Zone	4A	4B	4C	5A	5B	6A	6B
State	NY	NM	WA	IL	CO	MN	MT
City	New York City	Albuquerque	Seattle	Chicago	Boulder	Minneapolis	Helena
First Floor	26	16	20	26	20	29	23
Second Floor	29	20	23	29	20	26	20
Third Floor	20	13	16	23	13	20	13
Fourth Floor	23	20	16	23	16	23	16
Total	98	69	75	101	69	98	72

15 AHRI - https://ahrinet.org/home

16 AHRI 1230 I-P (2021): Performance Rating of Variable Refrigerant Flow (VRF) Multi-Split Air-Conditioning and Heat Pump Equipment- https://ahrinet.org/App_Content/ahri/files/STANDARDS/AHRI/AHRI_Standard_1230-2021.pdf

Multi V heat pump system (Figure 2) operation is limited to a single mode (heating or cooling) at a time for the entire space. A single 500 gallon electric water heater could supply hot water to the entire Small Hotel building considered in this study.

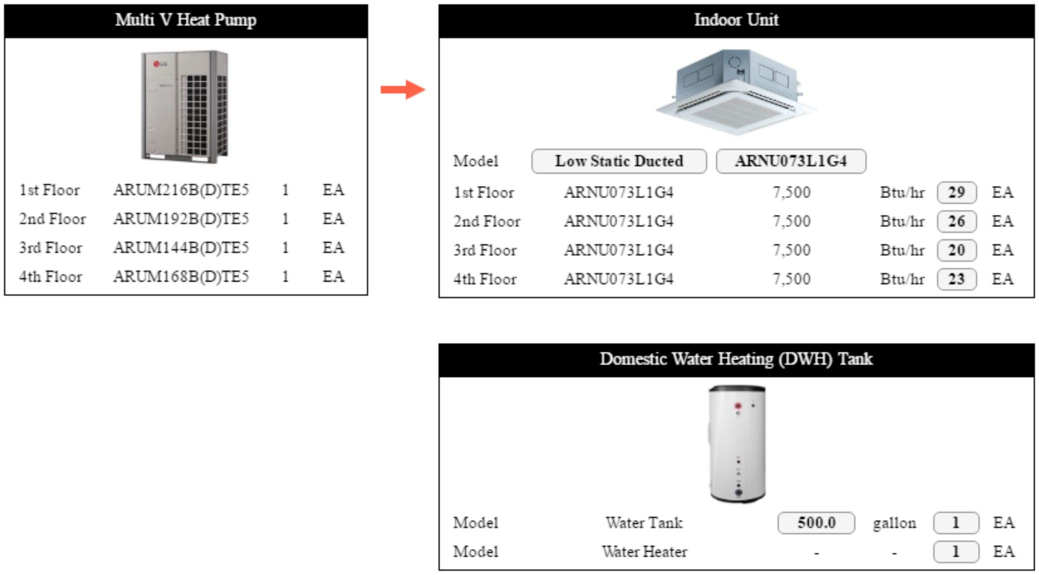


Figure 2: Proposed [1]: VRF Heat Pump System and a 500-Gallon Electric Water Heater.

A Multi V heat recovery system (Figure 3) redistributes the energy discarded from the indoor unit zones to zones that require heating, therefore, it assists in saving energy through simultaneous heating and cooling while providing comfort to individual zones. A single 500 gallon electric water heater could supply hot water to the entire Small Hotel building considered in this study.

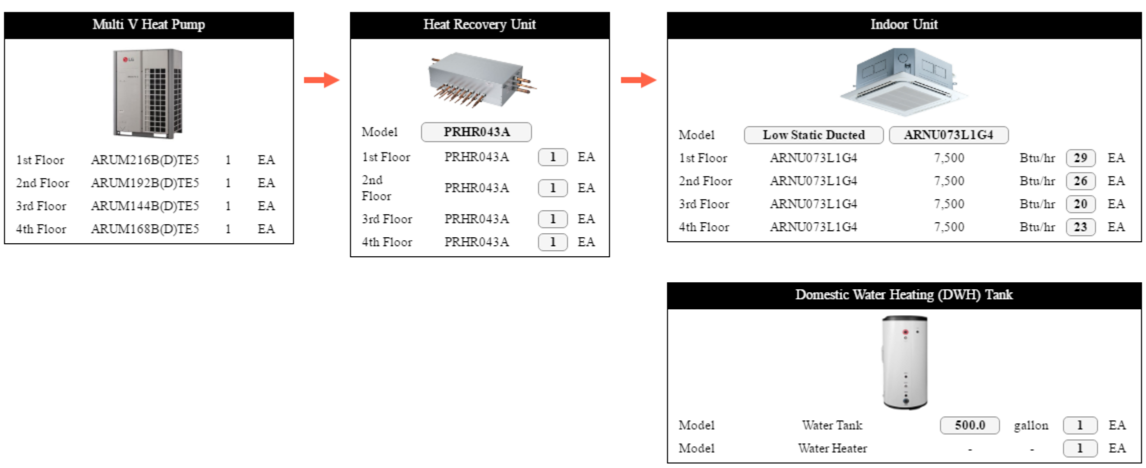


Figure 3: Proposed [2]: VRF Heat Recovery System and a 500--Gallon Electric Water Heater.

The proposed (3) system (Figure 4) a Hydro Kit uses a refrigerant-to-water heat exchanger to distribute hot thermal energy from the Multi V Heat Recovery outdoor unit to the buffer tank. During this operation, in addition to capturing waste heat, unnecessary outdoor unit fan operation can be avoided, thereby reducing HVAC CO2 emissions.

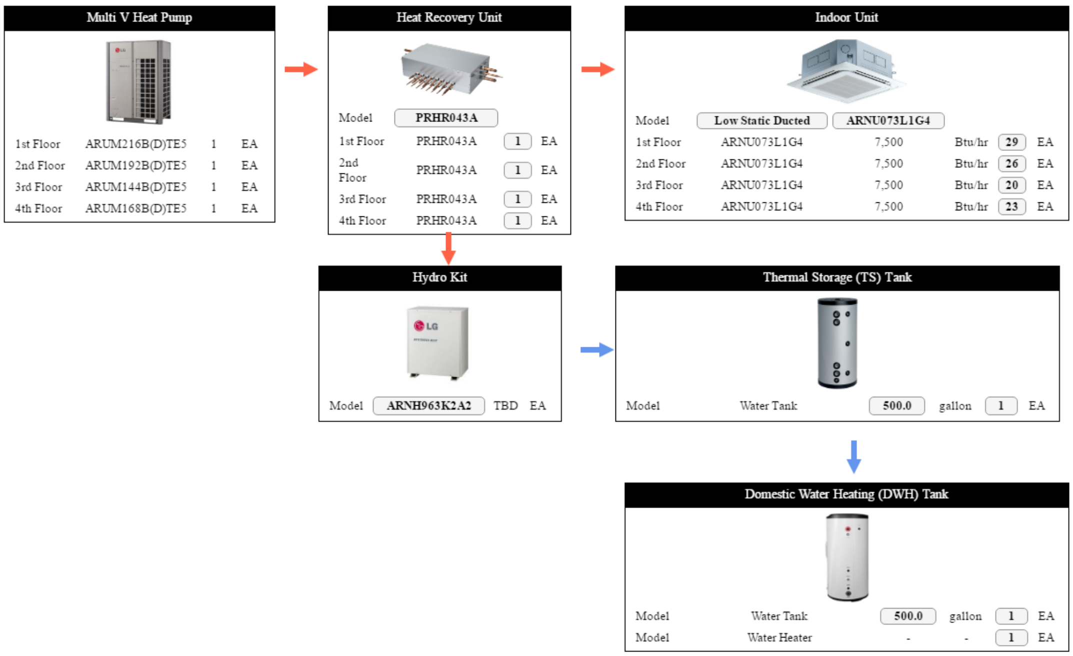


Figure 4: Proposed [3]: VRF Heat Recovery System and Hydro Kit.

Ventilation

A Dedicated Outdoor Air System (DOAS) was included for ventilation purposes, and its energy consumption was included as a component of the overall proposed VRF system. Detailed LG DOAS and LG VRF performance information can be found on the LG HVAC website[17].

[17] Home > Commercial > Split DOAS (Dedicated Outdoor Air System).- https://lghvac.com/

Building Energy and Life Cycle Cost Analysis Study Results

Energy Study Parameters

The baseline HVAC systems and the proposed LG VRF systems were compared and examined based on the following conditions:

- Climate zones(Weather)[18]: Miami, FL (1A); Houston, TX (2A); Phoenix, AZ (2B); Atlanta, GA (3A); Los Angeles, CA (3B); San Francisco, CA (3C); Baltimore, MD (4A); New York, NY (4A); Albuquerque, NM (4B); Seattle, WA (4C); Chicago, IL (5A); Boulder, CO (5B); Minneapolis, MN (6A).
- Small Hotel Building Parameters: Eight (67) zones, average 51 Tons cooling capacity, DHW (500 gallons, electric).

Table 11: HVAC System Type and Cost Data.

	System Type	Climate Zones 3B, 3C AND 4-8	Climate Zones 1-3A
Baseline-ASHRAE	Packaged Terminal Air Conditioner /Packaged Rooftop	System 1 - PTAC System 3 - PSZ-AC	System 2 - PTHP System 4 - PSZ-HP
	Installation Cost	865 $/Tons	865 $/Tons
	Maintenance Cost	0.3 $/Ft²	0.3 $/Ft²
	DWH Installation Cost (500 Gallon Water Heater)	10 $/Gal	10 $/Gal
Proposed [1]	Multi V 5 Heat Pump + Ducted Indoor Units	LG Multi V 5	LG Multi V 5
	Installation Cost	1,081 $/Tons	1,081 $/Tons
	Maintenance Cost	0.3 $/Ft²	0.3 $/Ft²
	DWH Installation Cost (500 Gallon Water Heater)	10 $/Gal	10 $/Gal
Proposed [2]	Multi V 5 Heat Recovery + Heat Recovery Unit +Ducted Indoor Units	LG Multi V 5	LG Multi V 5
	Installation Cost	1,181 $/Tons	1,181 $/Tons
	Maintenance Cost	0.3 $/Ft²	0.3 $/Ft²
	DWH Installation Cost (500 Gallon Water Heater)	10 $/Gal	10 $/Gal
Proposed [3]	Multi V 5 Heat Recovery + Heat Recovery Unit + Hydro Kit +Ducted Indoor Units	LG Multi V 5	LG Multi V 5
	Installation Cost	1,361 $/Tons	1,361 $/Tons
	Maintenance Cost	0.3 $/Ft²	0.3 $/Ft²
	DWH Installation Cost (500 Gallon Water Heater + 500 Gallon Thermal Storage (TS) Tank)	10 $/Gal	10 $/Gal

[18] Climate zones used to create the reference buildings- https://www.energy.gov/eere/buildings/commercial-reference-buildings

Summary – Building Energy and Energy Cost

As depicted in the following Tables, the overall HVAC energy cost savings realized with the Multi V system was an average of 38% compared to the ASHRAE Standard 90.1-2013 system. This energy cost saving increases to an average of 65% when domestic hot water energy is conserved through heat recovery (Hydro Kit), which also greatly contributes to lowering the initial investment cost for the Net Zero Energy (NZE) building, a concept which is discussed further in the next section.

Table 12: Annual ASHRAE 90.1-2013 Baseline System Energy and Energy Cost Summary.

Weather Zone		1A	2A	2B	3A	3B	3C	4A
State		FL	TX	AZ	GA	CA	CA	MD
City		Miami	Houston	Phoenix	Atlanta	Los Angeles	San Francisco	Baltimore
Thermal Peak Load (MBtu)	Cooling	572.1	599	587.9	533	382.1	343.8	593.6
	Heating	61	201.3	101.8	272.2	48.8	77.1	288.1
	DWH	124.1	124.1	129.8	145.2	133.4	133.3	157.4
HVAC Capacity (tons)	Cooling	62	64	64	58	42	40	66
	Heating	70	72	72	65	47	45	74
	DWH	12	12	13	15	13	13	16
Energy Consumption (kWh)	Cooling	223,035	170,799	179,879	122,500	102,065	68,683	98,381
	Heating	137	3,707	1,435	9,401	2,302	9,676	70,129
	Fan	78,434	78,888	81,051	79,128	77,855	77,905	78,523
	DWH	102,583	102,579	103,098	118,066	119,832	119,831	130,239
Energy Cost ($)	Cooling	26,742	19,659	21,963	13,108	18,719	12,596	12,858
	Heating	17	427	175	1,006	94	393	2,728
	Fan	9,404	9,080	9,896	8,467	14,279	14,288	10,263
	DWH	12,300	11,807	12,588	12,633	21,977	21,977	17,022

Weather Zone		4A	4B	4C	5A	5B	6A	6B	Average
State		NY	NM	WA	IL	CO	MN	MT	
City		New York	Albuquerque	Seattle	Chicago	Boulder	Minneapolis	Helena	
Thermal Peak Load (MBtu)	Cooling	558.1	393.2	410.3	585.8	405.5	541.1	374.5	491.4
	Heating	313.9	160.1	190.7	414.9	261.2	455.3	360.8	229.1
	DWH	157.4	153.2	152.3	166.8	162.5	177.6	173.5	149.3
HVAC Capacity (tons)	Cooling	60	42	46	62	44	60	44	54
	Heating	68	47	52	70	50	68	50	61
	DWH	16	15	15	17	17	18	17	15
Energy Consumption (kWh)	Cooling	90,703	88,795	59,498	80,532	78,316	65,573	56,195	106,068
	Heating	78,262	34,272	42,540	122,857	63,903	183,619	104,533	51,912
	Fan	78,200	80,243	78,653	78,758	82,487	78,795	81,133	79,289
	DWH	130,236	126,806	133,867	140,520	137,618	148,191	146,233	125,693
Energy Cost ($)	Cooling	15,683	10,842	5,539	9,817	9,312	7,102	7,187	13,652
	Heating	3,178	889	1,437	3,312	1,635	5,263	2,532	1,649
	Fan	13,521	9,798	7,323	9,601	9,808	8,533	10,377	10,331
	DWH	22,518	15,483	12,463	17,129	16,363	16,049	18,703	16,358

As the results summarized in Table 13 show, regardless of the type of the VRF system used in the study, heat pump or heat recovery, use of a VRF system can save about 25 to 50% of the HVAC energy costs, depending on use and climate conditions. Applying hydro kit, the recovery of waste heat drastically increased the energy savings, as depicted in the Table below, from 43% to 81% of the HVAC + DHW energy costs.

Table 13: HVAC + DHW Energy Cost Saving Summary.

	Baseline	Proposed [1] : VRF-HP			Proposed [2] : VRF-HR			Proposed [3] : VRF-Hydro		
City	Energy Cost ($)	Energy Cost ($)	Saving ($)	%	Energy Cost ($)	Saving ($)	%	Energy Cost ($)	Saving ($)	%
Miami, FL (1A)	48,462	24,059	24,403	50.4%	24,054	24,408	50.4%	11,694	36,768	75.9%
Houston, TX (2A)	40,972	20,990	19,982	48.8%	20,977	19,996	48.8%	9,867	31,105	75.9%
Phoenix, AZ (2B)	44,623	23,570	21,053	47.2%	23,551	21,072	47.2%	11,609	33,014	74.0%
Atlanta, GA (3A)	35,213	19,549	15,664	44.5%	19,529	15,684	44.5%	8,874	26,339	74.8%
Los Angeles, CA (3B)	55,490	30,888	24,602	44.3%	30,843	24,648	44.4%	10,350	45,141	81.3%
San Francisco, CA (3C)	51,029	29,943	21,085	41.3%	29,884	21,144	41.4%	10,698	40,331	79.0%
Baltimore, MD (4A)	52,037	33,894	18,143	34.9%	33,855	18,182	34.9%	20,753	31,284	60.1%
New York, NY (4A)	68,430	45,908	22,523	32.9%	45,848	22,582	33.0%	29,525	38,905	56.9%
Albuquerque, NM (4B)	41,196	26,050	15,145	36.8%	26,025	15,171	36.8%	15,457	25,739	62.5%
Seattle, WA (4C)	30,723	19,995	10,727	34.9%	19,971	10,751	35.0%	10,661	20,061	65.3%
Chicago, IL (5A)	54,835	39,176	15,659	28.6%	39,123	15,712	28.7%	27,385	27,450	50.1%
Boulder, CO (5B)	44,716	30,064	14,652	32.8%	30,038	14,678	32.8%	17,785	26,931	60.2%
Minneapolis, MN (6A)	56,833	42,224	14,609	25.7%	42,162	14,671	25.8%	32,013	24,820	43.7%
Helena, MT (6B)	52,633	38,034	14,599	27.7%	38,004	14,629	27.8%	25,267	27,366	52.0%
Average	48,371	30,310	18,061	37.9%	30,276	18,095	38.0%	17,281	31,090	65.1%

The proposed [3], Hydro kit application increased HVAC system and installation costs by an average of 62%, but saved building energy cost by an average of 30%. As a result, the payback period of the proposed VRF system [3] is expected to be about 1 year, 1 month.

Table 14: Building Investment Cost Summary.

	Initial Cost ($)				Additional Investment Cost (%)		
	Baseline	VRF-HP	VRF-HR	VRF-Hydro	VRF-HP	VRF-HR	VRF-Hydro
Miami, FL (1A)	58,630	72,022	78,222	94,382	23%	33%	61%
Houston, TX (2A)	58,630	72,022	78,222	94,382	23%	33%	61%
Phoenix, AZ (2B)	60,360	74,184	80,584	97,104	23%	34%	61%
Atlanta, GA (3A)	55,170	67,698	73,498	88,938	23%	33%	61%
Los Angeles, CA (3B)	41,330	50,402	54,602	67,162	22%	32%	63%
San Francisco, CA (3C)	39,600	48,240	52,240	64,440	22%	32%	63%
Baltimore, MD (4A)	62,090	76,346	82,946	99,826	23%	34%	61%
New York, NY (4A)	56,900	69,860	75,860	91,660	23%	33%	61%
Albuquerque, NM (4B)	41,330	50,402	54,602	67,162	22%	32%	63%
Seattle, WA (4C)	44,790	54,726	59,326	72,606	22%	32%	62%
Chicago, IL (5A)	58,630	72,022	78,222	94,382	23%	33%	61%
Boulder, CO (5B)	41,330	50,402	54,602	67,162	22%	32%	63%
Minneapolis, MN (6A)	56,900	69,860	75,860	91,660	23%	33%	61%
Helena, MT (6B)	43,060	52,564	56,964	69,884	22%	32%	62%
Average	51,339	62,911	68,268	82,911	22%	33%	62%

Table 15: Annual Building Cost and Cost Saving Summary.

	Annual Building Cost ($) = Maintenance + Energy							
		Proposed [1]		Proposed [2]		Proposed [3]		
	Baseline	VRF-HP	Savings	VRF-HR	Savings	VRF-Hydro	Savings	Payback Period
Miami, FL (1A)	107,088	82,685	23%	82,680	23%	70,320	34%	1 year 0 month
Houston, TX (2A)	97,821	77,839	20%	77,825	20%	66,716	32%	1 year 2 month
Phoenix, AZ (2B)	104,183	83,129	20%	83,111	20%	71,168	32%	1 year 4 month
Atlanta, GA (3A)	104,183	83,129	20%	83,111	20%	71,168	32%	1 year 4 month
Los Angeles, CA (3B)	137,930	113,342	18%	113,297	18%	92,804	33%	0 year 8 month
San Francisco, CA (3C)	132,188	111,102	16%	111,044	16%	91,857	31%	0 year 8 month
Baltimore, MD (4A)	105,452	87,308	17%	87,270	17%	74,167	30%	1 year 3 month
New York, NY (4A)	105,902	87,308	18%	87,270	18%	74,167	30%	0 year 11 month
Albuquerque, NM (4B)	96,352	81,206	16%	81,181	16%	68,411	29%	0 year 11 month
Seattle, WA (4C)	75,131	64,404	14%	64,380	14%	55,070	27%	1 year 5 month
Chicago, IL (5A)	99,094	83,434	16%	83,382	16%	71,643	28%	1 year 4 month
Boulder, CO (5B)	95,233	80,581	15%	80,555	15%	68,302	28%	1 year 0 month
Minneapolis, MN (6A)	91,077	76,468	16%	76,406	16%	66,257	27%	1 year 5 month
Helena, MT (6B)	100,830	86,231	14%	86,201	15%	73,464	27%	1 year 0 month
Average	103,747	85,583	17%	85,551	17%	72,537	30%	1 year1 month

What Is a Net Zero Energy (NZE) Building?

Net Zero Energy (NZE) buildings are efficient Small Hotels that produce renewable energy as consumed throughout the year. DOE defines NZE buildings[19] as "a high-performance building so energy efficient all or most annual energy consumption can be offset with renewable energy." NZE buildings minimize energy consumption, and include the latest materials, technologies, and controls to produce more energy than the building consumes. As NZE home building design needs increase, HVAC engineers must strive to develop highly efficient products and systems to achieve these performance goals. This report considers and describes NZE HVAC applications for Small Hotels that can maximize HVAC and Domestic Hot Water (DHW) energy savings.

Design NZE Small Hotel Buildings

In terms of total cost, current NZE buildings can be more cost effective than standard efficiency buildings--if designed correctly. To achieve this, HVAC engineers need to review the integrated approach as a whole process. For example, additional insulation in a NZE building can offset some of the incremental costs by reducing the size of the heating and cooling system. In addition, California's NZE code requirements[20], which came into effect in 2020, are expected to further reduce NZE buildings construction costs as it increases the market for NZE equipment and manufacturers.

Solar Photovoltaic (PV)

Solar PV represents both the most significant incremental cost in reaching NZE today—and the most significant opportunity for future cost savings. It is important to note that most of the cost savings potential for solar PV stems not from projected material cost savings, but from soft-cost reductions, which incentivizing policies can accelerate.[21] The investment cost, installation and maintenance cost of PV panel were assumed as follows through an interview with industry PV panel experts.

- Initial and Installation Cost: $1,788/kWp
- Maintenance Cost: $19.0/kWp

Figure 5: Solar Panel - LG NeON®2 PV Panel (LG Electronics).[22]

[19] A Common Definition for Zero Energy Buildings(DOE)- https://www.energy.gov/sites/default/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf
[20] State of California, Public Utilities Commission, Zero Net Energy- https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/energy-efficiency/zero-net-energy
[21] Zero Energy Ready Homes (DOE)- https://www.energy.gov/eere/buildings/zero-energy-ready-homes
[22] LG Solar Panels and Installation-https://www.lg.com/us/business/neon%C2%AE-2/lg-lg400n2t-j5.

Table 16: LG Solar PV Specifications.[23]

	LG NeON®2 BiFacial	LG NeON®2 (Commercial)	LG NeON®R
Cell Properties (Material/Type)	Monocrystalline/N-type	Monocrystalline/N-type	Monocrystalline/N-type
DC System Size	400W	410W	370W
Module Type	High Efficiency	High Efficiency	High Efficiency
Array Type	Fixed (Roof Mount)	Fixed (Roof Mount)	Fixed (Roof Mount)
Array Tilt	20°	20°	20°
Array Azimuth	180°	180°	180°
Module Efficiency [%] - STC	19.3%	19.8%	21.4%
Inverter Efficiency	96%	98%	98%
Module Dimensions(L x W x H)	79.68 inch x 40.31 inchx 1.5748 inch	79.68 inch x 40.31 inchx 1.5748 inch	66.93 inch x 40 inchx 1.5748 inch

Most NZE buildings can produce energy through use of PV panels. Assuming that a building only has the roof available for PV installation, a single-story building is much more likely to achieve net zero than a tall building, so achieving a net zero goal is very difficult in high-rise buildings, or buildings that use a lot of energy. The problem is even more difficult if the building contains energy-intensive data centers, laboratories, or other high-energy use zones. The data below demonstrates how the number of PV modules can be reduced for the model building, that is, the PV installation area can be reduced if combined with high-efficiency HVACs.

Table 17: Selected PV Module Information.

PV Model	LG NeON 2 Commercial	-
Maximum Power	410.0	Wp
Peak Efficiency	0.198	-
Inverter Efficiency	0.98	-
Length of PV	6.6	ft
Width of PV	3.4	ft
Net Area	20.3	ft²
PV Area	22.3	ft²
Single PV Installation Area	39.4	ft²

Net Metering

Net metering, also called net energy metering or NEM, is a utility rate program that requires an electric company to purchase the excess solar energy from solar panels produce at the full-retail rate of electricity. This study assumed a net metering of the electricity generation by solar without any energy storage system or Feed-in tariffs (FiT). FiT is a mechanism for selected customers to export all solar energy produced to grid.

[23] LG Solar Panels and Installation-https://www.lg.com/us/business/solar

Net Zero Building Energy and Life Cycle Cost Analysis Study Results

Summary – Net Zero Building Energy and Energy Cost

With use of the proposed system, HVAC and DWH energy and energy cost savings of 17 to 65% are possible and the total number of PV panels required to achieve NZE can be reduced, thereby reducing the initial investment for building construction. Compared to the baseline ASHRAE Std. 90.1-2013 NZE baseline HVAC system, the average initial investment costs savings (%) of the proposed (1) and (2), heat pump and heat recovery type VRF systems is about 20%, and the proposed (3), VRF-Hydro, provides additional waste heat recovery savings. As a result, the proposed (3) could save approximately 31% of the baseline NZEB initial investment, with HVAC and DWH energy savings of approximately 70%.

Table 18: Initial Cost and Initial Cost Saving (%).

	Initial Cost ($)					Initial Cost Saving (%)		
	Std. 90.1-2013 (Baseline)	NZEB				Over Baseline NZEB Std. 90.1-2013		
Location		NZEB Std. 90.1-2013 (Baseline)	NZEB VRF-HP	NZEB VRF-HR	NZEB VRF-Hydro	NZEB VRF-HP	NZEB VRF-HR	NZEB VRF-Hydro
Miami, FL (1A)	58,630	924,155	713,390	719,590	622,063	23%	22%	33%
Houston, TX (2A)	60,360	923,440	733,768	739,253	642,619	21%	20%	30%
Phoenix, AZ (2B)	60,360	714,062	577,018	583,418	514,136	19%	18%	28%
Atlanta, GA (3A)	55,170	843,831	693,514	699,314	604,106	18%	17%	28%
Los Angeles, CA (3B)	41,330	737,575	608,113	612,313	511,365	18%	17%	31%
San Francisco, CA (3C)	39,600	744,604	623,469	627,469	526,876	16%	16%	29%
Baltimore, MD (4A)	62,090	975,342	775,451	781,336	675,055	20%	20%	31%
New York, NY (4A)	56,900	1,004,473	794,706	799,991	695,490	21%	20%	31%
Albuquerque, NM (4B)	41,330	681,089	558,956	563,156	480,440	18%	17%	29%
Seattle, WA (4C)	44,790	1,059,038	871,094	875,694	740,966	18%	17%	30%
Chicago, IL (5A)	58,630	1,080,207	831,367	837,567	726,812	23%	22%	33%
Boulder, CO (5B)	41,330	815,333	653,517	657,717	561,058	20%	19%	31%
Minneapolis, MN (6A)	56,900	1,284,580	947,898	953,183	829,019	26%	26%	35%
Helena, MT (6B)	43,060	949,698	747,379	751,779	643,683	21%	21%	32%
Average	51,463	909,816	723,546	728,699	626,692	20%	20%	31%

For purposes of the study, the proposed (3) NZEB, Hydro kit application saved PV panel installation costs by an average of 31%, and also saved building operating cost by an average of 15%. As a result, the payback period of the proposed l [3] NZEB is expected to be about 7 years and 1 month based on the ASHRAE Standard 90.1-2013 NZEB baseline.

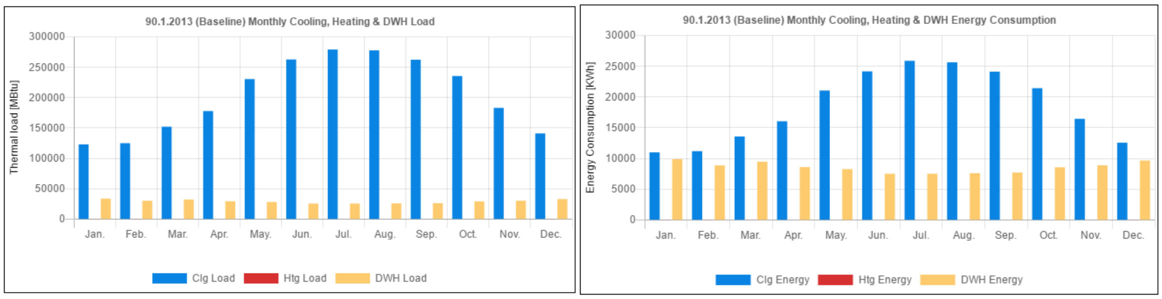
Table 19: Annual Building Cost and Cost Saving Summary.

	Annual Building Cost ($) = Maintenance + Energy								
	Std. 90.1-2013 (Baseline)	NZEB Std. 90.1-2013 (Baseline)	Proposed (1)		Proposed (2)		Proposed (3)		
			NZEB VRF-HP	Savings over NZEB Baseline	NZEB VRF-HR	Savings over NZEB Baseline	NZEB VRF-Hydro	Savings over NZEB Baseline	Payback Period
Miami, FL (1A)	107,088	22,160	19,776	11%	19,776	11%	18,569	16%	6 years, 5 months
Houston, TX (2A)	97,821	22,152	19,994	10%	19,987	10%	18,787	15%	7 years, 5 months
Phoenix, AZ (2B)	104,183	19,909	18,304	8%	18,304	8%	17,393	13%	5 years, 3 months
Atlanta, GA (3A)	104,183	19,909	18,304	8%	18,304	8%	17,393	13%	7 years, 10 months
Los Angeles, CA (3B)	137,930	20,361	18,888	7%	18,888	7%	17,681	13%	3 years, 11 months
San Francisco, CA (3C)	132,188	20,454	19,075	7%	19,075	7%	17,876	13%	4 years, 4 months
Baltimore, MD (4A)	105,452	22,666	20,392	10%	20,384	10%	19,075	16%	7 years, 2 months
New York, NY (4A)	105,902	23,033	20,664	10%	20,657	10%	19,379	16%	5 years, 8 months
Albuquerque, NM (4B)	96,352	19,761	18,366	7%	18,366	7%	17,354	12%	5 years, 8 months
Seattle, WA (4C)	75,131	23,741	21,638	9%	21,638	9%	20,065	15%	12 years, 8 months
Chicago, IL (5A)	99,094	23,819	21,030	12%	21,030	12%	19,683	17%	8 years, 5 months
Boulder, CO (5B)	95,233	21,186	19,371	9%	19,371	9%	18,211	14%	6 years, 9 months
Minneapolis, MN (6A)	91,077	26,008	22,292	14%	22,285	14%	20,797	20%	11 years, 0 months
Helena, MT (6B)	100,830	22,596	20,345	10%	20,345	10%	19,060	16%	7 years, 0 months
Average	103,747	21,983	19,889	9%	19,886	9%	18,666	15%	7 years, 1 month

Appendix A. Building Loads, Energy, and Energy Cost (Non-NZEB)

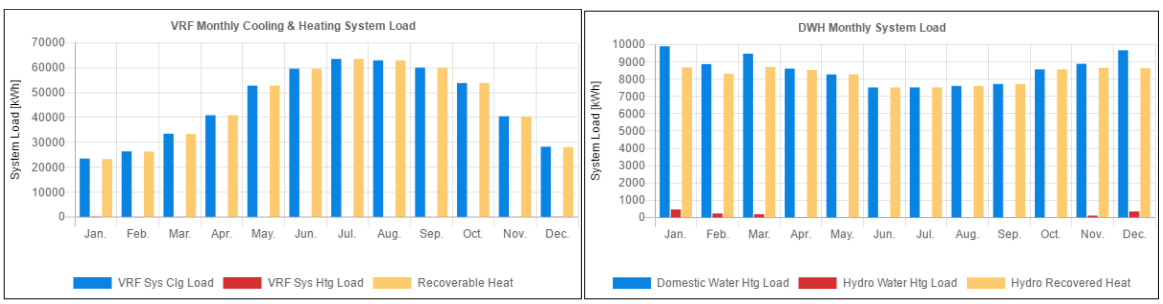
1) Results – Miami, FL (1A)

Annual HVAC energy consumption and energy cost for Miami, FL (Climate Zone 1A) were as follows:



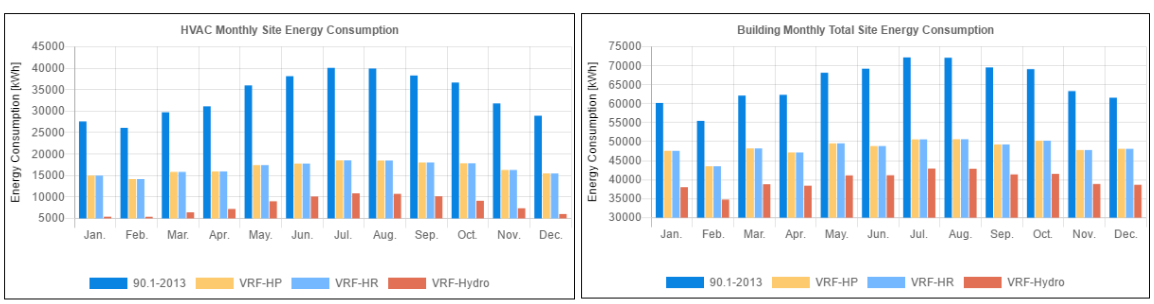
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 6: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 7: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 8: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 25.9%. Additionally, the building energy cost savings using the Multi V heat recovery VRF system (Proposed [2]) was 25.9%.

Table 20: Miami Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	785,057	0.0	94,128	0	94,128	0	0
Proposed (1): VRF-HP	581,529	0.0	69,725	0	69,725	24,403	25.9%
Proposed (2): VRF-HR	581,488	0.0	69,720	0	69,720	24,408	25.9%
Proposed (3): VRF-Hydro	478,401	0.0	57,360	0	57,360	36,768	39.1%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 50.3%. Additionally, the HVAC energy cost savings using the Multi V heat recovery VRF system (Proposed [2]) was 50.3%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop, the HVAC energy cost savings increased by 75.9% compared to the ASHRAE Standard 90.1-2013 baseline. Also, the simple payback period was about 2 years 3 months compared to the ASHRAE Standard 90.1-2013 baseline.

Table 21: Miami Annual HVAC + DHW Energy Consumption and Energy Cost.

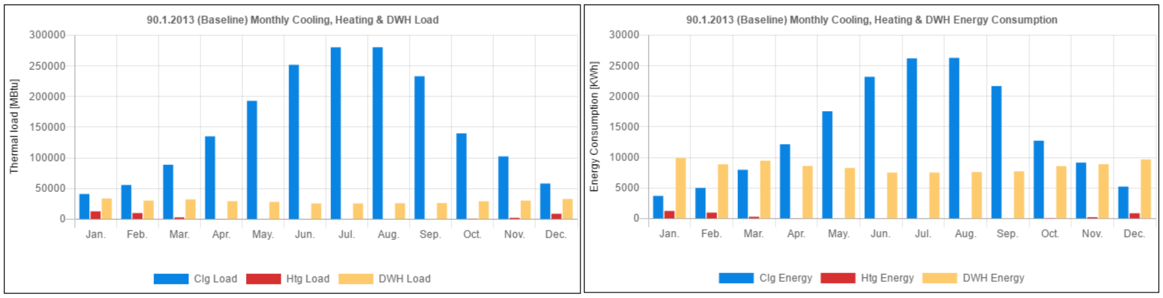
System	Annual HVAC Energy		Annual HVAC Energy Cost($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	404,190	0.0	48,462	0	48,462	0	-
Proposed [1] : VRF-HP	200,662	0.0	24,059	0	24,059	24,403	50.4%
Proposed [2] : VRF-HR	200,621	0.0	24,054	0	24,054	24,408	50.4%
Proposed [3] : VRF-Hydro	97,534	0.0	11,694	0	11,694	36,768	75.9%

Table 22: Miami Estimated HVAC + DHW Cost Analysis ($).

System	Initial Cost ($)	Building Annual Cost ($)			Building Annual Cost Saving		Payback Period
		Maintenance	Electricity	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	58,630	12,960	94,128	107,088	0	-	-
Proposed (1): VRF-HP	72,022	12,960	69,725	82,685	24,403	22.8%	0 years, 6 months
Proposed (2): VRF-HR	78,222	12,960	69,720	82,680	24,408	22.8%	0 years, 10 months
Proposed (3): VRF-Hydro	94,382	12,960	57,360	70,320	36,768	34.3%	1 year, 0 months

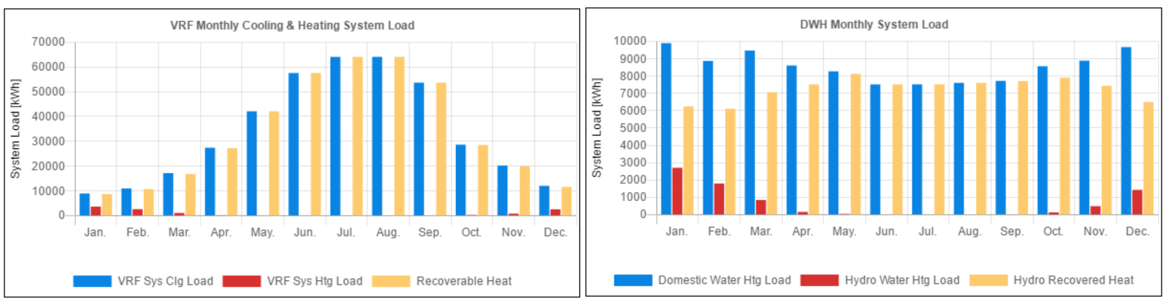
2) Results – Houston, TX (2A)

Annual HVAC energy consumption and energy cost for Houston, TX (Climate Zone 2A) were as follows:



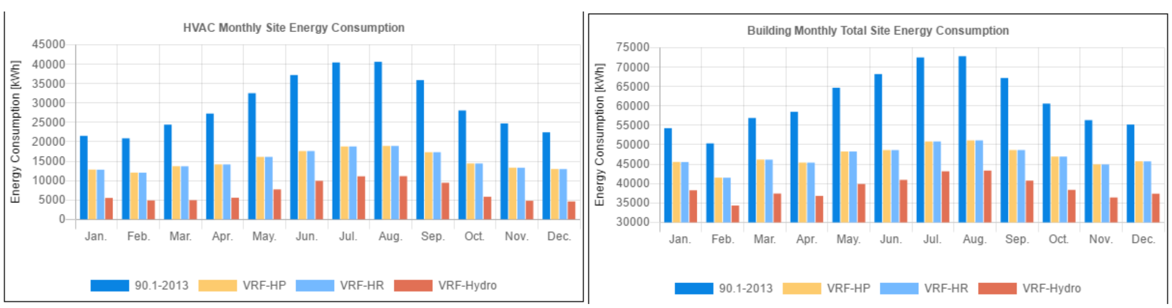
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 9: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 10: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 11: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 23.5%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [3]) was 36.7%.

Table 23: Houston Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	737,281	0.0	84,861	0	84,861	0	0
Proposed (1): VRF-HP	563,674	0.0	64,879	0	64,879	19,982	23.5%
Proposed (2): VRF-HR	563,557	0.0	64,865	0	64,865	19,996	23.6%
Proposed (3): VRF-Hydro	467,033	0.0	53,755	0	53,755	31,105	36.7%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 48.8%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 48.8%. When Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop, the HVAC energy cost savings increased by 75.9% compared to the ASHRAE Standard 90.1-2013 baseline. The simple payback period was about 1 year, 2 months compared to the ASHRAE Standard 90.1-2013 baseline.

Table 24: Houston Annual HVAC Energy Consumption and Energy Cost.

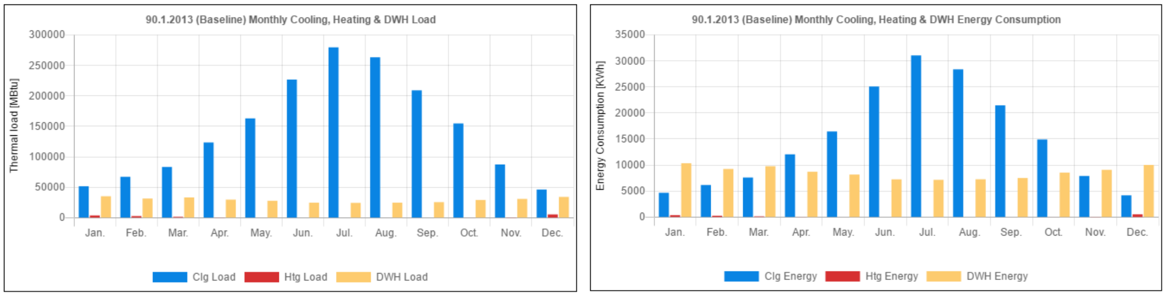
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	355,973	0.0	40,972	0	40,972	0	-
Proposed (1): VRF-HP	182,366	0.0	20,990	0	20,990	19,982	48.8%
Proposed (2): VRF-HR	182,249	0.0	20,977	0	20,977	19,996	48.8%
Proposed (3): VRF-Hydro	85,725	0.0	9,867	0	9,867	31,105	75.9%

Table 25: Houston Estimated HVAC + DHW Cost Analysis ($).

System	Initial Cost ($)	Annual Energy Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	58,630	12,960	84,861	0	97,821	0	-	-
Proposed (1) : VRF-HP	72,022	12,960	64,879	0	77,839	19,982	20.4%	0 years, 9 months
Proposed (2): VRF-HR	78,222	12,960	64,865	0	77,825	19,996	20.4%	1 years, 0 months
Proposed (3): VRF-Hydro	94,382	12,960	53,756	0	66,716	31,105	31.8%	1 years, 2 months

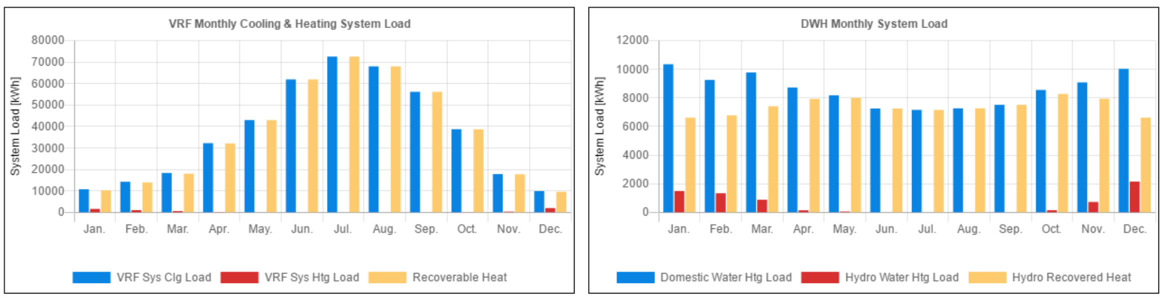
3) Results – Phoenix, AZ (2B)

Annual HVAC energy consumption and energy cost for Phoenix, AZ (Climate Zone 2B) were as follows:



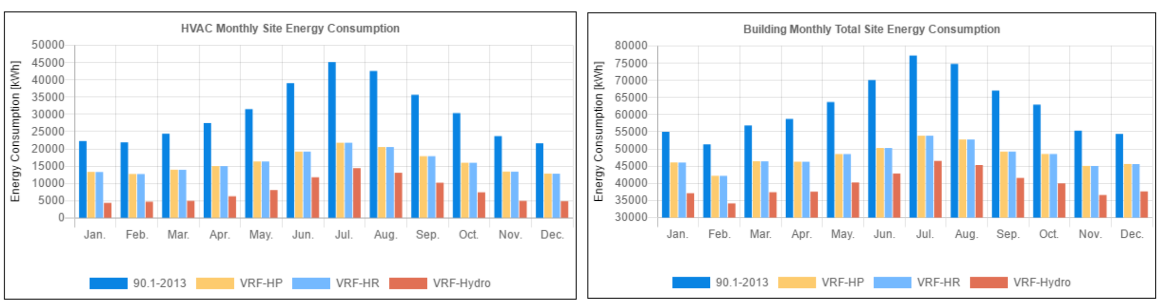
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 12: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 13: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 14: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 23.5%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [3]) was 36.7%.

Table 26: Phoenix Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	747,113	0.0	91,223	0	91,223	0	0
Proposed (1) : VRF-HP	574,687	0.0	70,169	0	70,169	21,053	23.1%
Proposed (2): VRF-HR	574,533	0.0	70,151	0	70,151	21,072	23.1%
Proposed (3) : VRF-Hydro	476,725	0.0	58,208	0	58,208	33,014	36.2%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 48.8%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 48.8%. When Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop, the HVAC energy cost savings increased by 75.9% compared to the ASHRAE Standard 90.1-2013 baseline. The simple payback period was about 1 year, 2 months compared to the ASHRAE Standard 90.1-2013 baseline.

Table 27: Phoenix Annual HVAC Energy Consumption and Energy Cost.

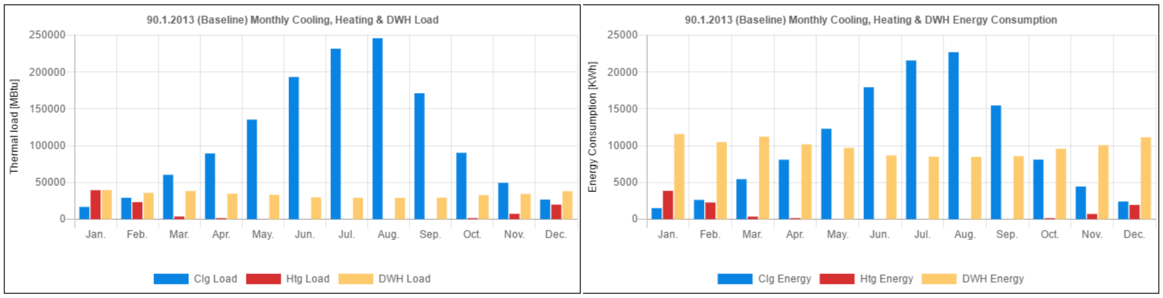
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	365,464	0.0	44,623	0	44,623	0	-
Proposed (1): VRF-HP	193,037	0.0	23,570	0	23,570	21,053	47.2%
Proposed (2): VRF-HR	192,884	0.0	23,551	0	23,551	21,072	47.2%
Proposed (3): VRF-Hydro	95,075	0.0	11,609	0	11,609	33,014	74.0%

Table 28: Phoenix Estimated HVAC + DHW Cost Analysis ($).

System	Initial Cost ($)	Annual Energy Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	60,360	12,960	91,223	0	104,183	0	-	-
Proposed (1): VRF-HP	74,184	12,960	70,169	0	83,129	21,054	20.2%	0 year 9 month
Proposed (2): VRF-HR	80,584	12,960	70,151	0	83,111	21,072	20.2%	1 year 0 month
Proposed (3) : VRF-Hydro	97,104	12,960	58,208	0	71,168	33,015	31.7%	1 year 2 month

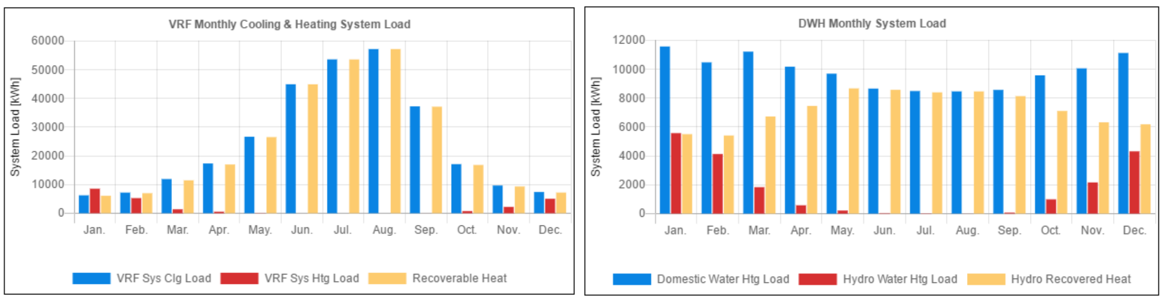
4) Results – Atlanta (3A)

Annual HVAC energy consumption and energy cost for Atlanta, GA (Climate Zone 3A) were as follows:



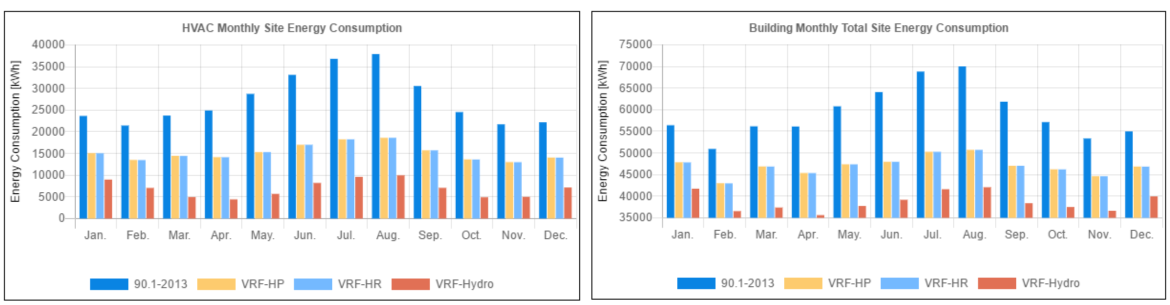
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 15: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 16: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 17: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 20.6%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 20.6%.

Table 29: Atlanta Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	710,564	0.0	76,031	0	76,031	0	0
Proposed (1): VRF-HP	564,167	0.0	60,366	0	60,366	15,664	20.6%
Proposed (2): VRF-HR	563,982	0.0	60,346	0	60,346	15,684	20.6%
Proposed (3): VRF-Hydro	464,402	0.0	49,691	0	49,691	26,339	34.6%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 44%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 45%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposal [3]), the HVAC energy cost savings increased by 75% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 1 year, 4 months.

Table 30: Atlanta Annual HVAC + DHW Energy Consumption and Energy Cost.

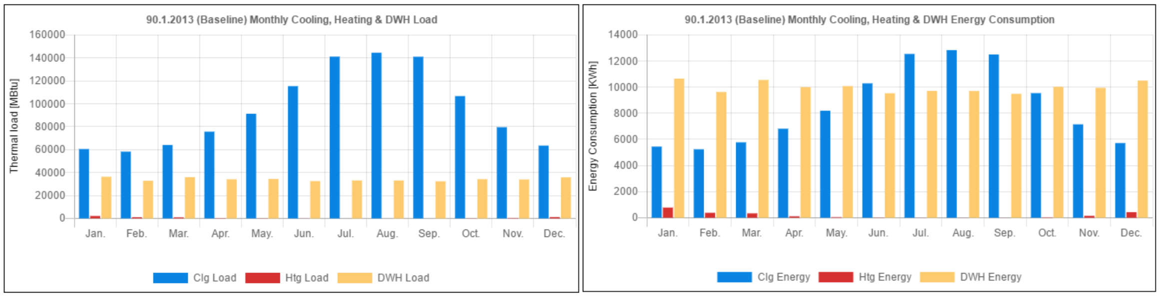
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	329,093	0.0	35,213	0	35,213	0	-
Proposed (1): VRF-HP	182,697	0.0	19,549	0	19,549	15,664	44%
Proposed (2): VRF-HR	182,512	0.0	19,529	0	19,529	15,684	45%
Proposed (3): VRF-Hydro	82,931	0.0	8,874	0	8,874	26,339	75%

Table 31: Atlanta Estimated HVAC + DHW Cost Analysis ($).

System	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	55,170	12,960	91,223	0	104,183	0	-	-
Proposed (1): VRF-HP	67,698	12,960	70,169	0	83,129	21,054	20%	0 years, 10 months
Proposed (2): VRF-HR	73,498	12,960	70,151	0	83,111	21,072	20%	1 years, 3 months
Proposed (3): VRF-Hydro	88,938	12,960	58,208	0	71,168	33,015	32%	1 years, 4 months

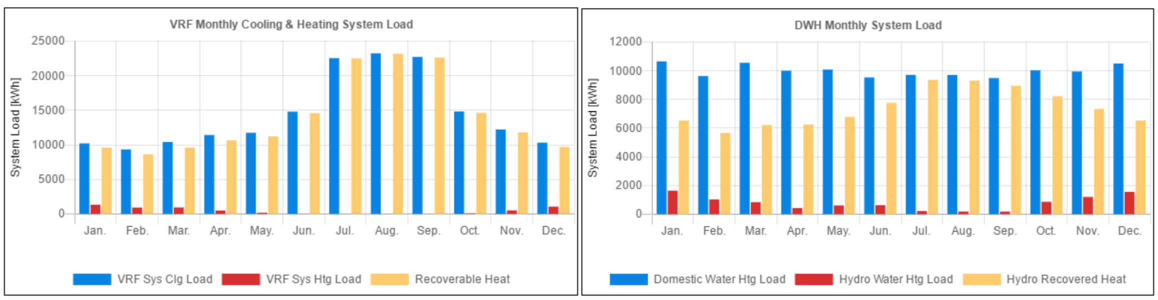
5) Results – Los Angeles (3B)

Annual HVAC energy consumption and energy cost for Los Angeles, CA (Climate Zone 3B) were as follows:



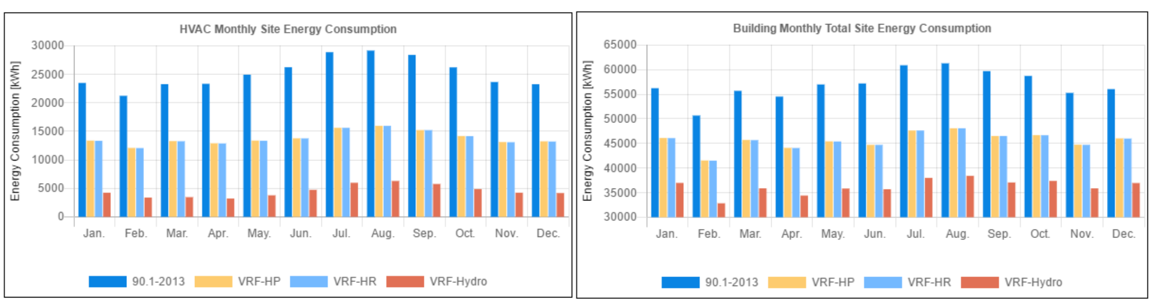
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 18: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 19: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 20: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 19.7%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 19.7%.

Table 32: Los Angeles Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	680,975	78.6	124,891	94	124,985	0	0
Proposed (1): VRF-HP	547,341	0.0	100,383	0	100,383	24,602	19.7%
Proposed (2): VRF-HR	547,092	0.0	100,337	0	100,337	24,648	19.7%
Proposed (3): VRF-Hydro	435,353	0.0	79,844	0	79,844	45,141	36.1%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 44%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 44%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposal [3]), the HVAC energy cost savings increased by 81% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 0 year, 8 months.

Table 33: Los Angeles Annual HVAC Energy Consumption and Energy Cost.

System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	302,054	78.6	55,397	94	55,490	0	-
Proposed (1): VRF-HP	168,420	0.0	30,888	0	30,888	24,602	44%
Proposed (2): VRF-HR	168,171	0.0	30,843	0	30,843	24,648	44%
Proposed (3): VRF-Hydro	56,432	0.0	10,350	0	10,350	45,141	81%

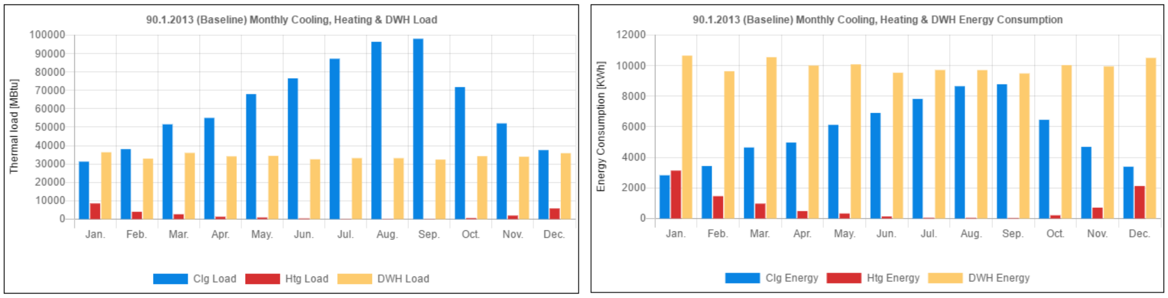
Table 34: Los Angeles Estimated HVAC + DHW Cost Analysis ($).

System	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	41,330	12,960	124,891	79	137,930	0	-	-
Proposed (1): VRF-HP	50,402	12,960	100,382	0	113,342	24,588	18%	0 years, 5 months
Proposed (2): VRF-HR	54,602	12,960	100,337	0	113,297	24,633	18%	0 years, 6 months

Proposed (3): VRF-Hydro	67,162	12,960	79,844	0	92,804	45,126	33%	0 years, 8 months

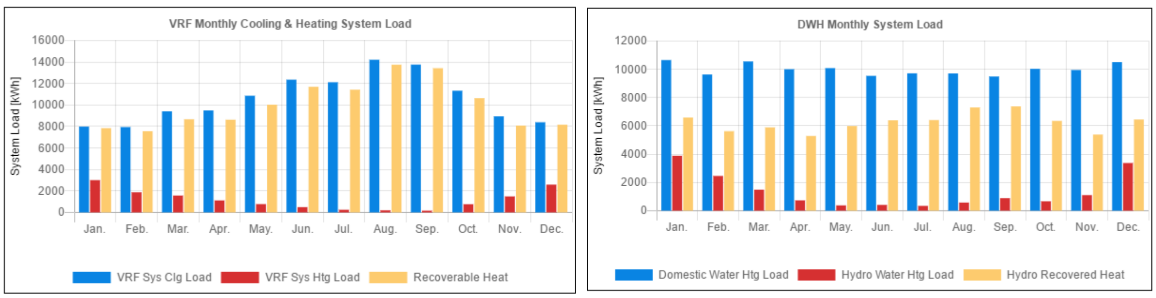
6) Results – San Francisco (3C)

Annual HVAC energy consumption and energy cost for San Francisco, CA (Climate Zone 3C) were as follows:



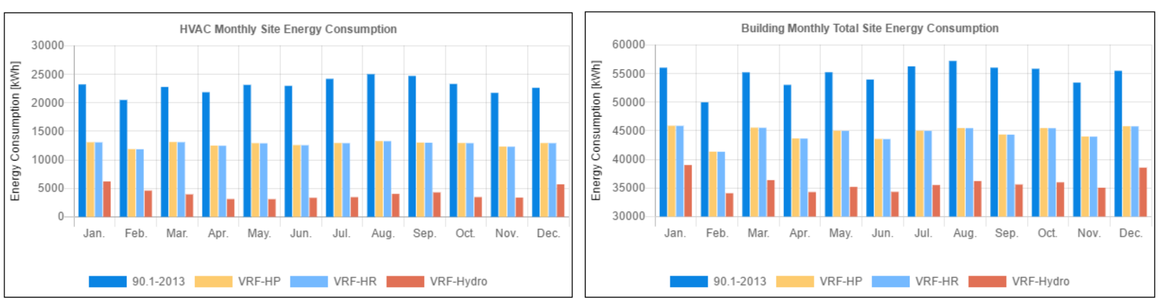
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 21: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 22: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 23: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 17.7%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 17.7%.

Table 35: San Francisco Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	647,955	330.1	118,835	393	119,228	0	0
Proposed (1): VRF-HP	535,127	0.0	98,142	0	98,142	21,085	17.7%
Proposed (2): VRF-HR	534,807	0.0	98,084	0	98,084	21,144	17.7%
Proposed (3): VRF-Hydro	430,190	0.0	78,897	0	78,897	40,331	33.8%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 41%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 41%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposal [3]), the HVAC energy cost savings increased by 79% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 0 years, 8 months.

Table 36: San Francisco Annual HVAC Energy Consumption and Energy Cost.

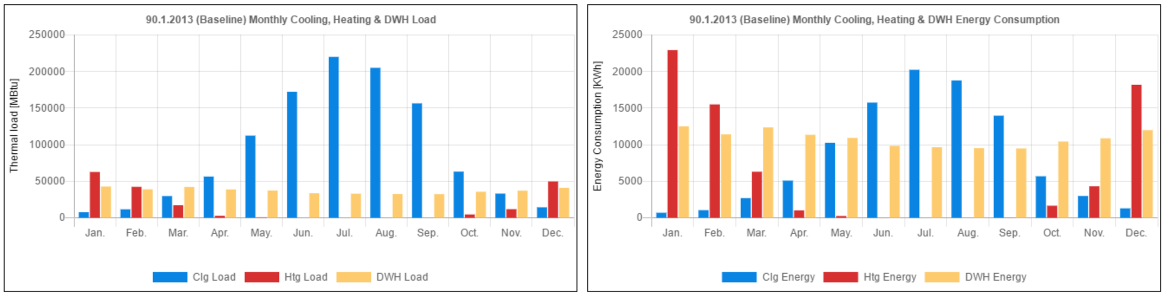
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	276,095	330.1	50,636	393	51,029	0	-
Proposed (1): VRF-HP	163,267	0.0	29,943	0	29,943	21,085	41%
Proposed (2): VRF-HR	162,947	0.0	29,884	0	29,884	21,144	41%
Proposed (3): VRF-Hydro	58,330	0.0	10,698	0	10,698	40,331	79%

Table 37: San Francisco Estimated HVAC + DHW Cost Analysis ($).

System	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	39,600	12,960	118,835	330	132,125	0	-	-
Proposed (1): VRF-HP	48,240	12,960	98,142	0	111,102	21,023	16%	0 years, 5 months
Proposed (2): VRF-HR	52,240	12,960	98,084	0	111,044	21,081	16%	0 years, 8 months
Proposed (3): VRF-Hydro	64,440	12,960	78,897	0	91,857	40,268	30%	0 years, 8 months

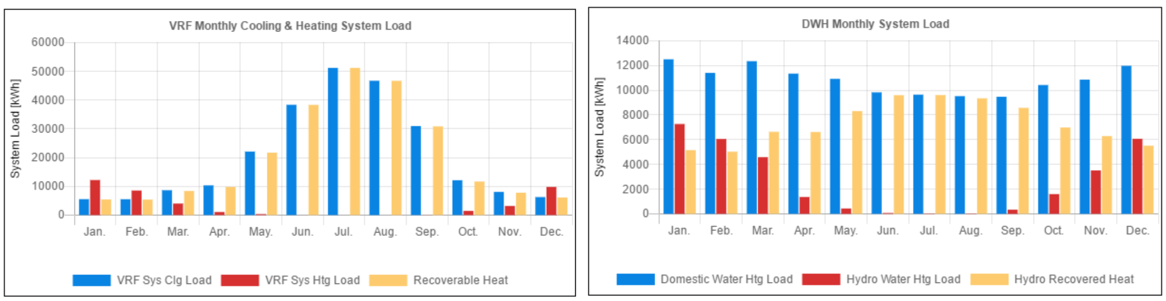
7) Results – Baltimore (4A)

Annual HVAC energy consumption and energy cost for Baltimore, MD (Climate Zone 4A) were as follows:



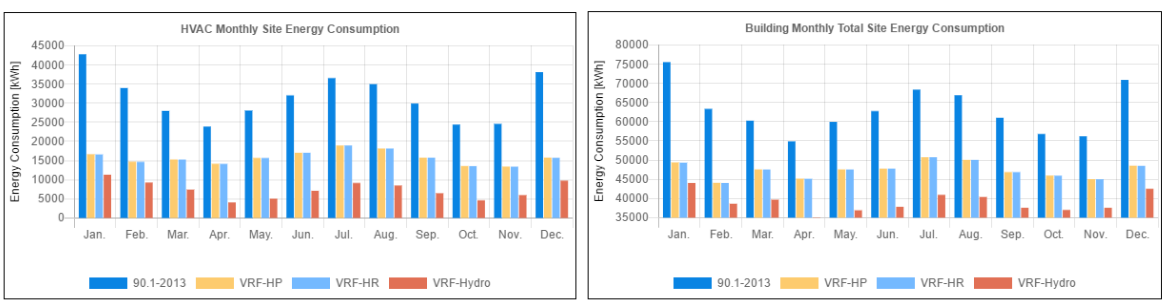
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 24: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads (b) Monthly Water Heating Load and Recovered Heat.

Figure 25: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 26: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 20%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 20%.

Table 38: Baltimore Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Std. 90.1-2013 (Baseline)	686,792	2,392.9	89,763	2,728	92,491	0	0
Proposed (1): VRF-HP	568,848	0.0	74,348	0	74,348	18,143	20%
Proposed (2): VRF-HR	568,550	0.0	74,309	0	74,309	18,182	20%
Proposed (3): VRF-Hydro	468,304	0.0	61,207	0	61,207	31,284	34%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 35%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]), was 35%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposed [3]), the HVAC energy cost savings increased by 60% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 1 year, 3 months.

Table 39: Baltimore Annual HVAC + DHW Energy Consumption and Energy Cost.

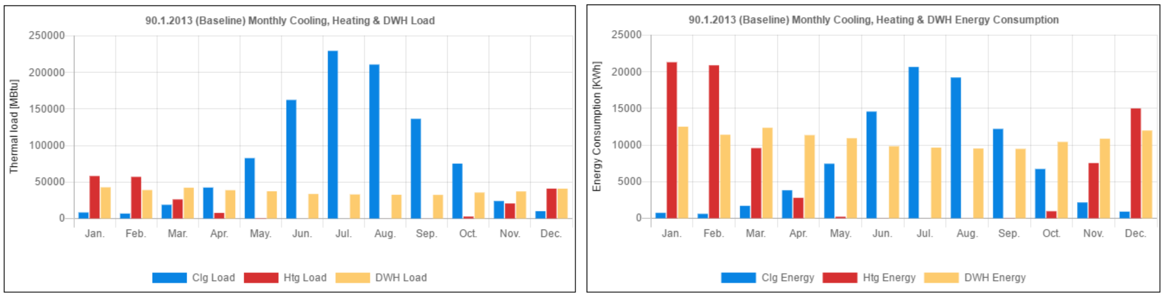
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	377,271	2,392.9	49,309	2,728	52,037	0	-
Proposed (1): VRF-HP	259,327	0.0	33,894	0	33,894	18,143	35%
Proposed (2): VRF-HR	259,029	0.0	33,855	0	33,855	18,182	35%
Proposed (3): VRF-Hydro	158,783	0.0	20,753	0	20,753	31,284	60%

Table 40: Baltimore Estimated HVAC + DHW Cost Analysis ($).

System Configuration	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	62,090	12,960	89,764	2,393	105,117	0	-	-
Proposed (1): VRF-HP	76,346	12,960	74,348	0	87,308	17,809	17%	0 year, 10 months
Proposed (2): VRF-HR	82,946	12,960	74,310	0	87,270	17,847	17%	1 year, 2 months
Proposed (3): VRF-Hydro	99,826	12,960	61,207	0	74,167	30,950	29%	1 year, 3 months

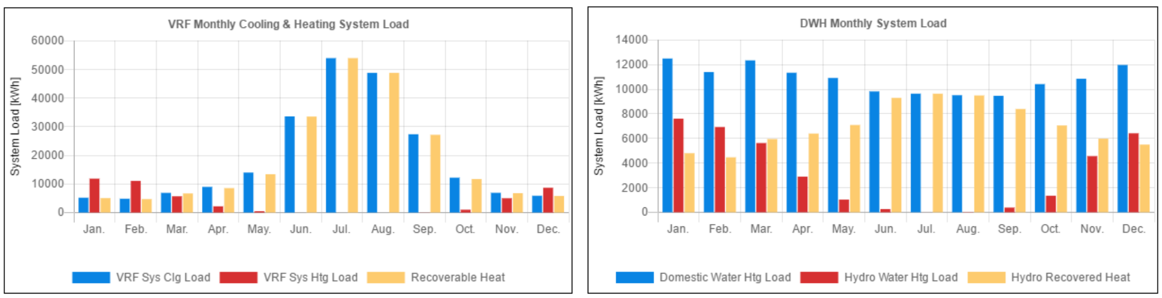
8) Results – New York (4A)

Annual HVAC energy consumption and energy cost for New York City, NY (Climate Zone 4A) were as follows:



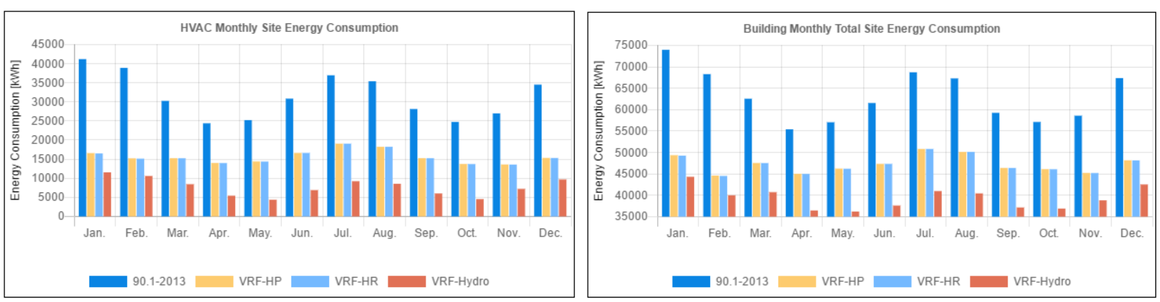
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 27: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads (b) Monthly Water Heating Load and Recovered Heat.

Figure 28: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 29: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 19%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 19%.

Table 41: New York City Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Std. 90.1-2013 (Baseline)	678,812	2,670.4	117,366	3,178	120,544	0	0
Proposed (1): VRF-HP	566,927	0.0	98,021	0	98,021	22,523	19%
Proposed (2): VRF-HR	566,584	0.0	97,962	0	97,962	22,582	19%
Proposed (3): VRF-Hydro	472,174	0.0	81,639	0	81,639	38,905	32%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 33%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]), was 33%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposed [3]), the HVAC energy cost savings increased by 57% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 0 years, 11 months.

Table 42: New York Annual HVAC + DHW Energy Consumption and Energy Cost.

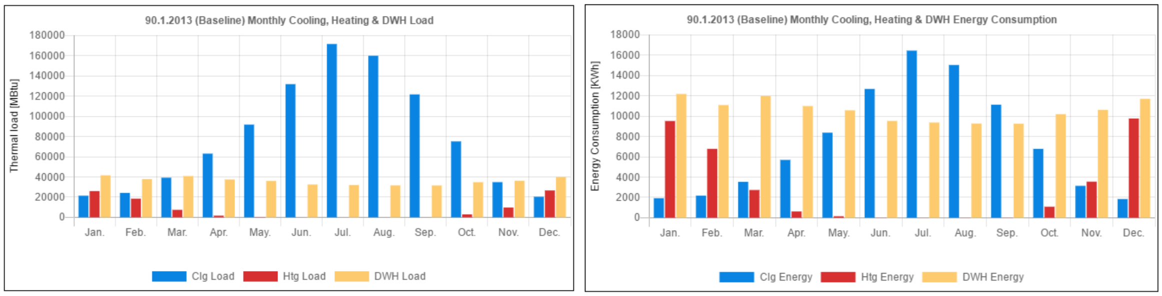
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	377,401	2,670.4	65,252	3,178	68,430	0	-
Proposed (1): VRF-HP	265,516	0.0	45,908	0	45,908	22,523	33%
Proposed (2): VRF-HR	265,173	0.0	45,848	0	45,848	22,582	33%
Proposed (3): VRF-Hydro	170,763	0.0	29,525	0	29,525	38,905	57%

Table 43: New York City Estimated HVAC + DHW Cost Analysis ($).

System Configuration	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	56,900	12,960	89,764	3,178	105,902	0	-	-
Proposed (1): VRF-HP	69,860	12,960	74,348	0	87,308	18,594	18%	0 years, 8 months
Proposed (2): VRF-HR	75,860	12,960	74,310	0	87,270	18,632	18%	0 years, 10 months
Proposed (3): VRF-Hydro	91,660	12,960	61,207	0	74,167	31,735	30%	0 years, 11 months

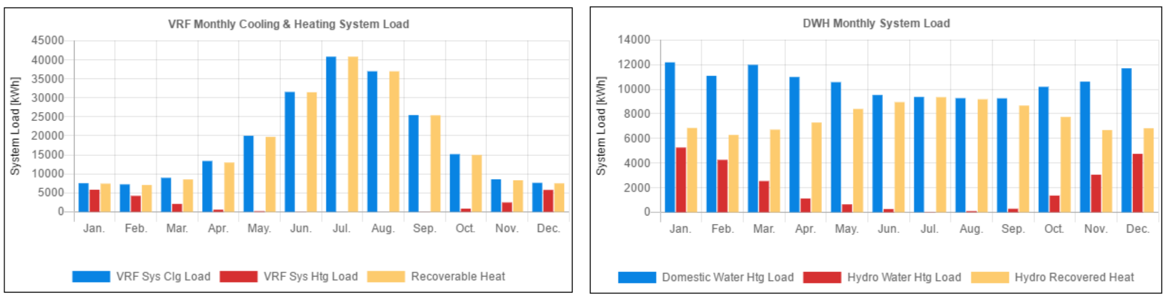
9) Results – Albuquerque (4B)

Annual HVAC energy consumption and energy cost for Albuquerque, NM (Climate Zone 4B) were as follows:



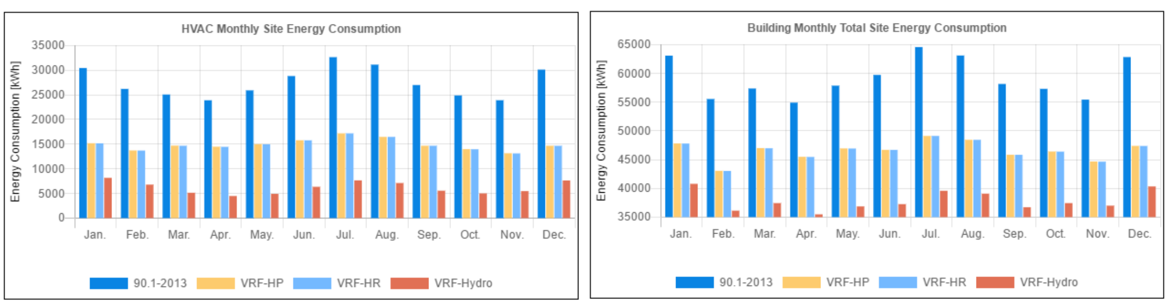
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 30: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads (b) Monthly Water Heating Load and Recovered Heat.

Figure 31: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 32: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 18%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 18%.

Table 44: Albuquerque Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Std. 90.1-2013 (Baseline)	675,699	1,169.4	82,503	889	83,392	0	0
Proposed (1): VRF-HP	558,938	0.0	68,246	0	68,246	15,145	18%
Proposed (2): VRF-HR	558,730	0.0	68,221	0	68,221	15,171	18%
Proposed (3): VRF-Hydro	472,174	0.0	57,652	0	57,652	25,739	31%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 37%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]), was 37%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposed [3]), the HVAC energy cost savings increased by 62% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 0 years, 11 months.

Table 45: Albuquerque Annual HVAC + DHW Energy Consumption and Energy Cost.

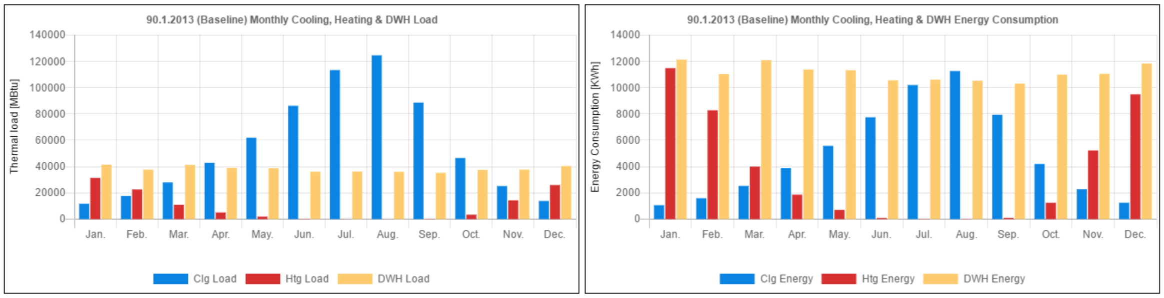
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	330,115	1,169.4	40,307	889	41,196	0	-
Proposed (1): VRF-HP	213,354	0.0	26,050	0	26,050	15,145	37%
Proposed (2): VRF-HR	213,146	0.0	26,025	0	26,025	15,171	37%
Proposed (3): VRF-Hydro	126,590	0.0	15,457	0	15,457	25,739	62%

Table 46: Albuquerque Estimated HVAC + DHW Cost Analysis ($).

System Configuration	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	41,330	12,960	82,503	889	96,352	0	-	-
Proposed (1): VRF-HP	50,402	12,960	68,246	0	81,206	15,146	16%	0 years, 8 months
Proposed (2): VRF-HR	54,602	12,960	68,221	0	81,181	15,171	16%	0 years, 11 months
Proposed (3): VRF-Hydro	67,162	12,960	55,451	0	68,411	27,941	29%	0 years, 11 months

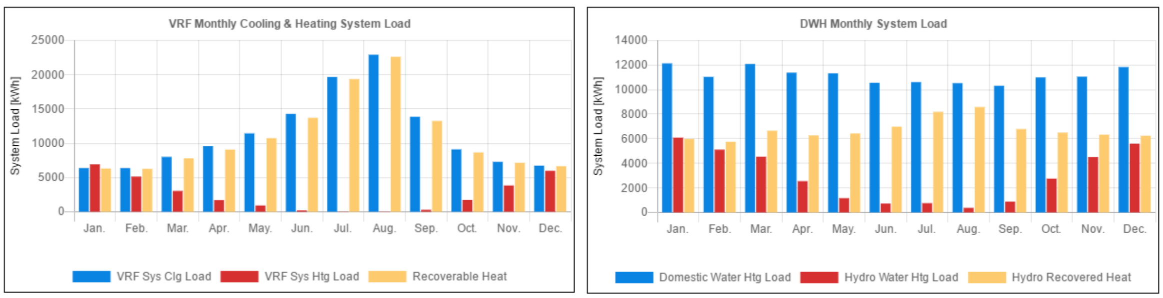
10) Results – Seattle (4C)

Annual HVAC energy consumption and energy cost for Seattle, WA (Climate Zone 4C) were as follows:



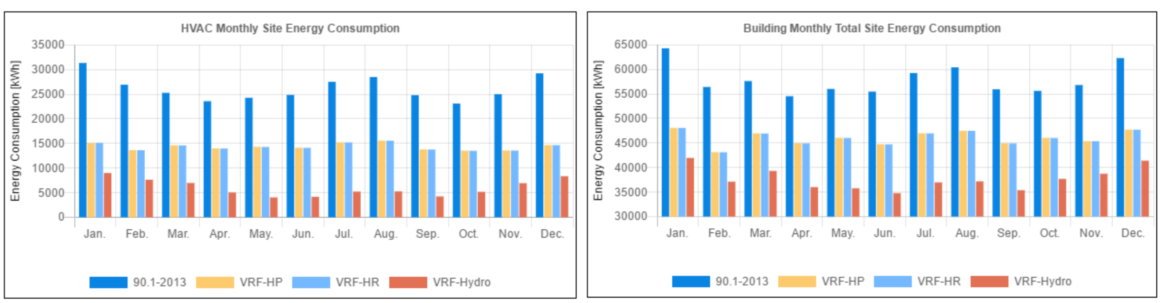
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 33: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads (b) Monthly Water Heating Load and Recovered Heat.

Figure 34: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 35: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the Small Hotel building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 17%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 17%.

Table 47: Seattle Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Std. 90.1-2013 (Baseline)	652,351	1,451.5	60,734	1,437	62,171	0	0
Proposed [(1): VRF-HP	552,563	0.0	51,444	0	51,444	10,727	17%
Proposed (2): VRF-HR	552,308	0.0	51,420	0	51,420	10,751	17%
Proposed (3): VRF-Hydro	452,308	0.0	42,110	0	42,110	20,061	32%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 35%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]), was 35%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposed [3]), the HVAC energy cost savings increased by 65% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 1 year, 5 months.

Table 48: Seattle Annual HVAC + DHW Energy Consumption and Energy Cost.

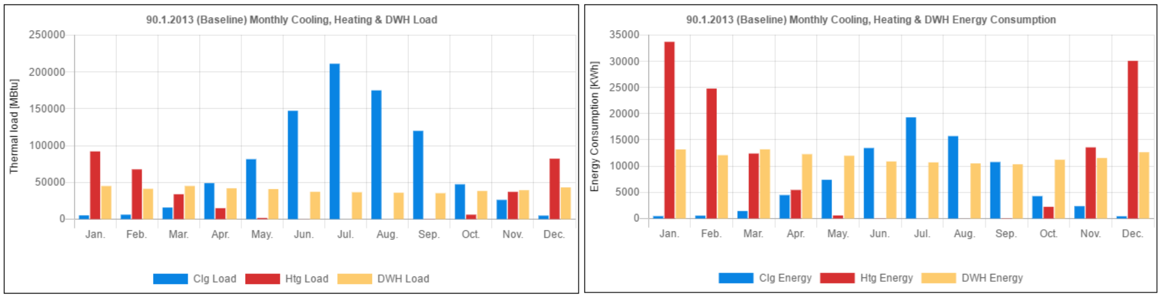
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	314,558	1,451.5	29,286	1,437	30,723	0	-
Proposed [(1): VRF-HP	214,770	0.0	19,995	0	19,995	10,727	35%
Proposed (2): VRF-HR	214,515	0.0	19,971	0	19,971	10,751	35%
Proposed (3): VRF-Hydro	114,515	0.0	10,661	0	10,661	20,061	65%

Table 49: Seattle Estimated HVAC + DHW Cost Analysis ($).

System Configuration	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	44,790	12,960	60,734	1,437	75,131	0	-	-
Proposed [(1): VRF-HP	54,726	12,960	51,444	0	64,404	10,727	14%	0 years, 11 months
Proposed (2): VRF-HR	59,326	12,960	51,420	0	64,380	10,751	14%	1 year, 5 months
Proposed (3): VRF-Hydro	72,606	12,960	42,110	0	55,070	20,061	27%	1 year, 5 months

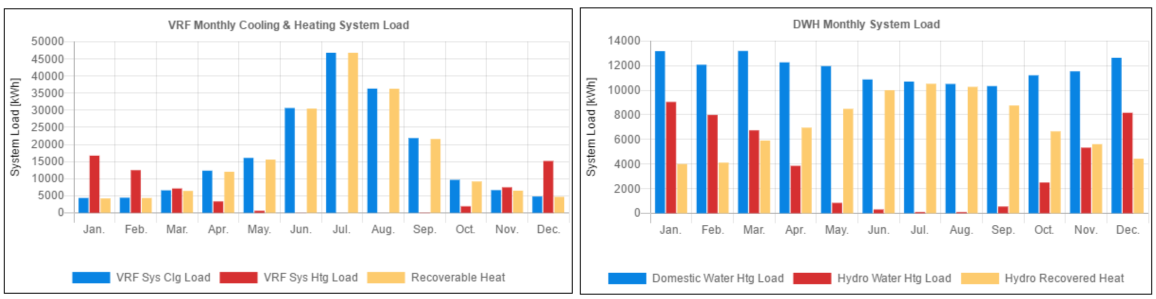
11) Results – Chicago (5A)

Annual HVAC energy consumption and energy cost for Chicago, IL (Climate Zone 5A) were as follows:



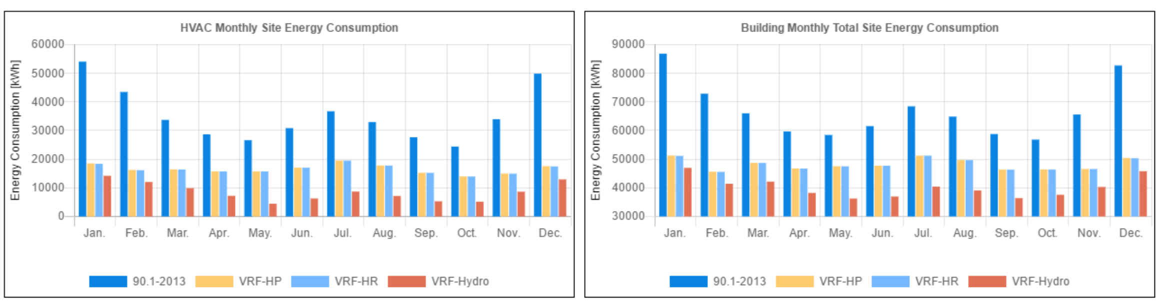
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 36: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 37: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 38: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 18%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 18%.

Table 50: Chicago Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	679,425	4,192.1	82,822	3,312	86,134	0	0
Proposed [(1): VRF-HP	578,131	0.0	70,474	0	70,474	15,659	18%
Proposed (2): VRF-HR	577,702	0.0	70,422	0	70,422	15,712	18%
Proposed (3): VRF-Hydro	481,405	0.0	58,683	0	58,683	27,450	32%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 29%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 29%. When the Multi V is a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposed [3]), the HVAC energy cost savings increased by 50% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 1 year, 4 months.

Table 51: Chicago Annual HVAC + DHW Energy Consumption and Energy Cost.

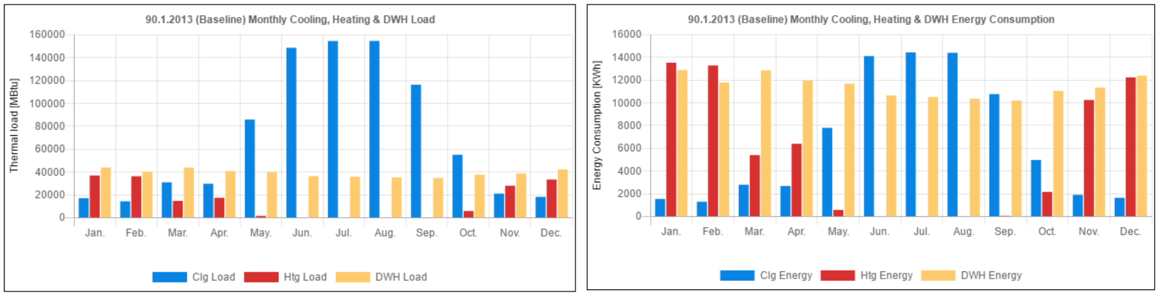
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	422,667	4,192.1	51,523	3,312	54,835	0	-
Proposed [(1): VRF-HP	321,374	0.0	39,176	0	39,176	15,659	29%
Proposed (2): VRF-HR	320,944	0.0	39,123	0	39,123	15,712	29%
Proposed (3): VRF-Hydro	224,647	0.0	27,385	0	27,385	27,450	50%

Table 52: Chicago Estimated HVAC + DHW Cost Analysis ($).

System	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline : ASHRAE Std. 90.1-2013	58,630	12,960	82,822	3,312	99,094	0	-	-
Proposed [(1): VRF-HP	72,022	12,960	70,474	0	83,434	15,660	16%	0 years, 11 months
Proposed (2): VRF-HR	78,222	12,960	70,422	0	83,382	15,712	16%	1 year, 3 months
Proposed (3): VRF-Hydro	94,382	12,960	58,683	0	71,643	27,451	28%	1 year, 4 months

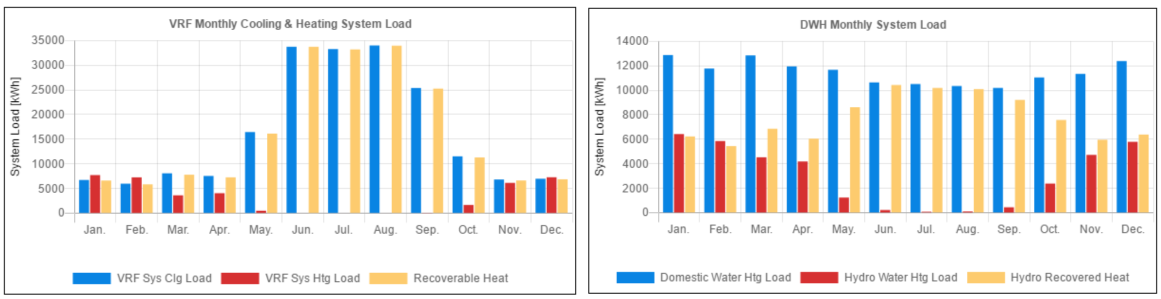
12) Results – Boulder (5B)

Annual HVAC energy consumption and energy cost for Boulder, CO (Climate Zone 5B) were as follows:



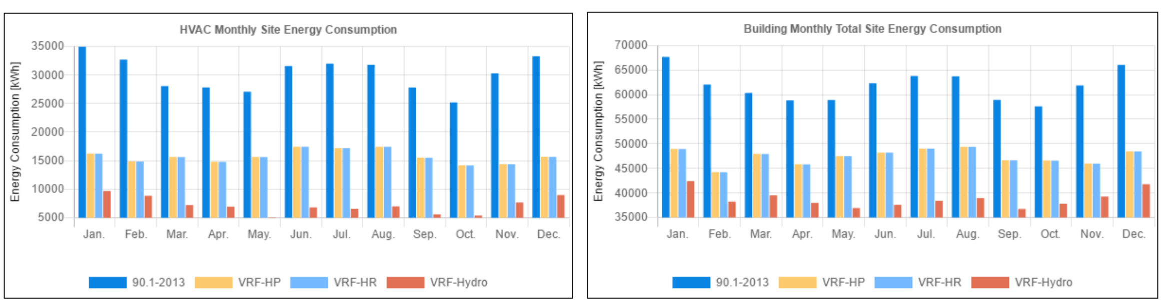
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 39: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 40: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 41: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 18%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 18%.

Table 53: Boulder Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline ASHRAE Std. 90.1-2013	678,198	2,180.5	80,638	1,635	82,273	0	0
Proposed [(1): VRF-HP	568,721	0.0	67,621	0	67,621	14,652	18%
Proposed (2): VRF-HR	568,504	0.0	67,595	0	67,595	14,678	18%
Proposed (3): VRF-Hydro	465,451	0.0	55,342	0	55,342	26,931	33%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 33%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 33%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposed [3]), the HVAC energy cost savings increased by 60% compared to the ASHRAE Standard 90.1-2013 baseline, and the simple payback period was about 1 year, 0 months.

Table 54: Boulder Annual HVAC + DHW Energy Consumption and Energy Cost.

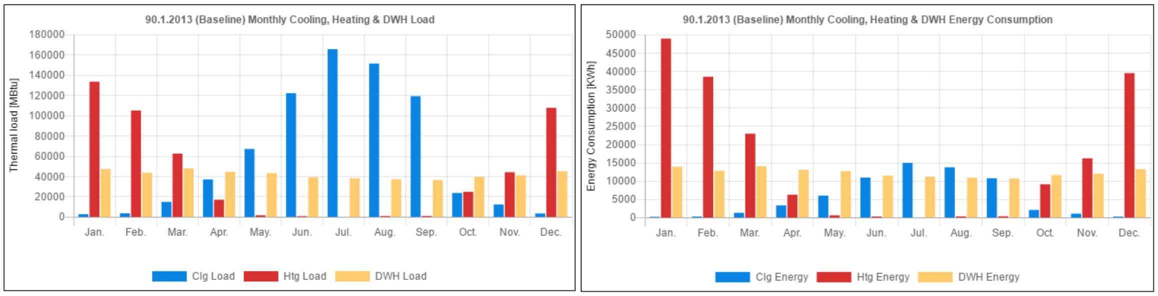
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	362,324	2,180.5	43,080	1,635	44,716	0	-
Proposed [(1): VRF-HP	252,847	0.0	30,064	0	30,064	14,652	33%
Proposed (2): VRF-HR	252,630	0.0	30,038	0	30,038	14,678	33%
Proposed (3): VRF-Hydro	149,577	0.0	17,785	0	17,785	26,931	60%

Table 55: Boulder Estimated HVAC + DHW Cost Analysis ($).

System	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	41,330	12,960	80,638	1,635	95,233	0	-	-
Proposed [(1): VRF-HP	50,402	12,960	67,621	0	80,581	14,652	15%	0 years, 8 months
Proposed (2): VRF-HR	54,602	12,960	67,595	0	80,555	14,678	15%	0 years, 11 months
Proposed (3): VRF-Hydro	67,162	12,960	55,342	0	68,302	26,931	28%	1 year, 0 months

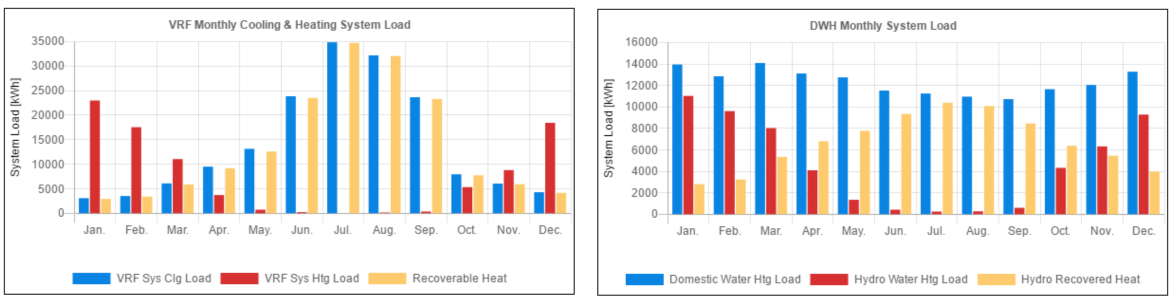
13) Results – Minneapolis (6A)

Annual HVAC energy consumption and energy cost for Minneapolis, MN (Climate Zone 6A) were as follows:



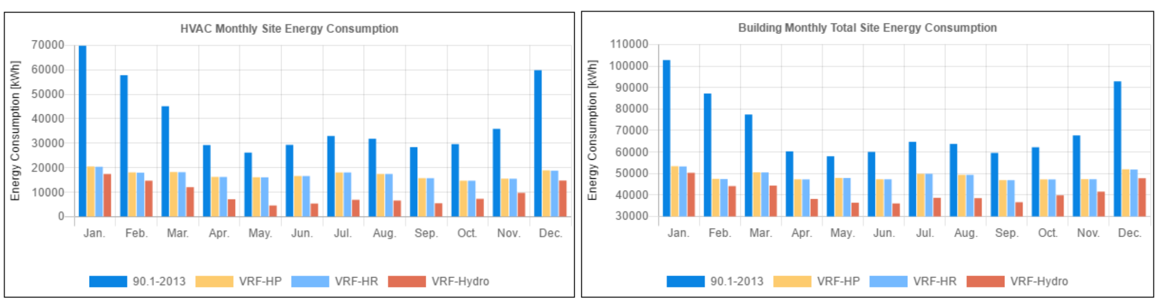
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 42: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 43: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 44: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 19%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 19%.

Table 56: Minneapolis Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	672,708	6,265.3	72,854	5,263	78,117	0	0
Proposed [(1): VRF-HP	586,407	0.0	63,508	0	63,508	14,609	19%
Proposed (2): VRF-HR	585,837	0.0	63,446	0	63,446	14,671	19%
Proposed (3): VRF-Hydro	492,126	0.0	53,297	0	53,297	24,820	32%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 26%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 26%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposed [3]), the HVAC energy cost savings increased by 44% compared to the ASHRAE 90.1-2013 Standard baseline, and the simple payback period was about 1 year, 5 months.

Table 57: Minneapolis Annual HVAC + DHW Energy Consumption and Energy Cost.

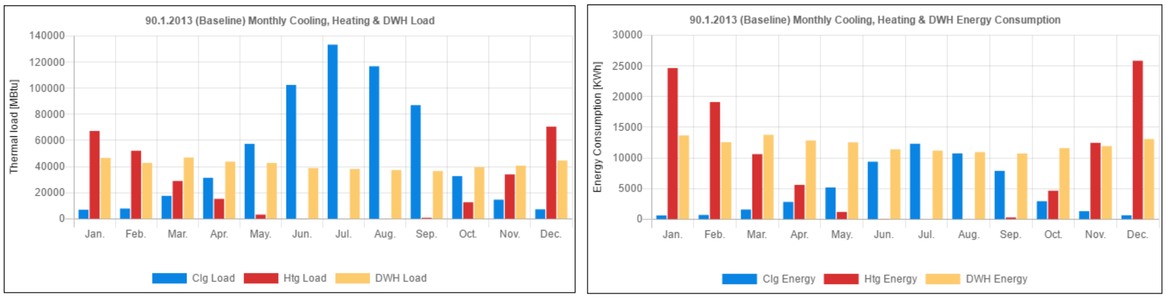
System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	476,178	6,265.3	51,570	5,263	56,833	0	-
Proposed [(1): VRF-HP	389,877	0.0	42,224	0	42,224	14,609	26%
Proposed (2): VRF-HR	389,307	0.0	42,162	0	42,162	14,671	26%
Proposed (3): VRF-Hydro	295,596	0.0	32,013	0	32,013	24,820	44%

Table 58: Minneapolis Estimated HVAC + DHW Cost Analysis ($).

System Configuration	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	56,900	12,960	72,854	5,263	91,077	0	-	-
Proposed [(1): VRF-HP	69,860	12,960	63,508	0	76,468	14,609	16%	0 years, 11 months
Proposed (2): VRF-HR	75,860	12,960	63,446	0	76,406	14,671	16%	1 year, 4 months
Proposed (3): VRF-Hydro	91,660	12,960	53,297	0	66,257	24,820	27%	1 year, 5 months

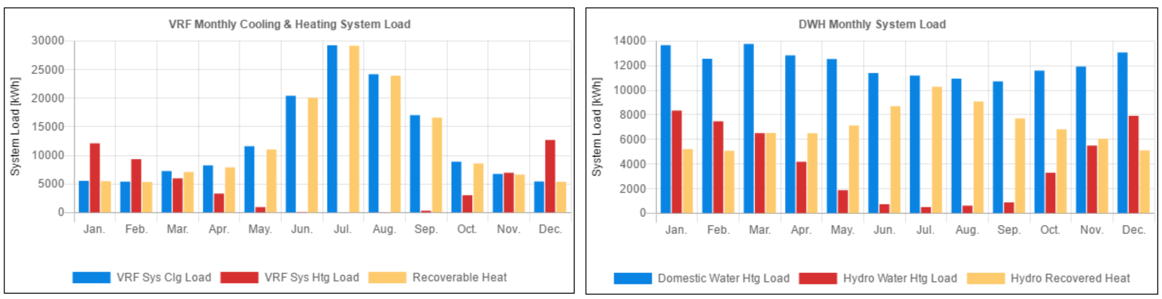
14) Results – Helena (6B)

Annual HVAC energy consumption and energy cost for Helena, MT (Climate Zone 6B) were as follows:



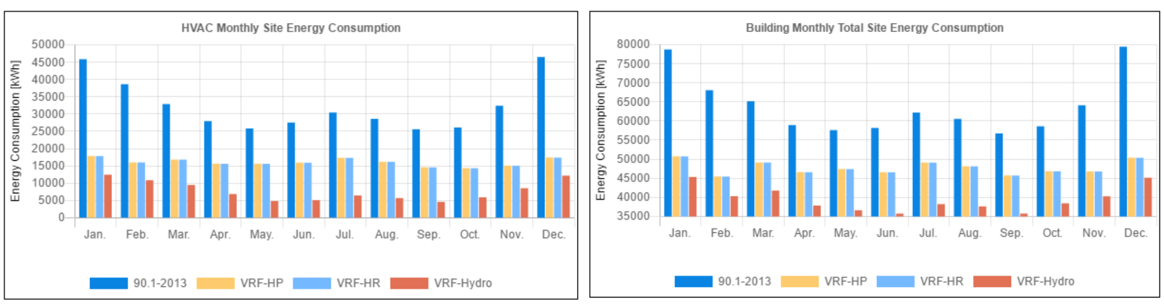
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 45: Monthly Baseline Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly VRF Cooling, Heating, and DHW Loads. (b) Monthly Water Heating Load and Recovered Heat.

Figure 46: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



(a) Monthly Cooling, Heating, and DHW Energy Consumptions. (b) Monthly Building Energy Consumptions.

Figure 47: Baseline Monthly Cooling, Heating, and DHW Energy and Building Energy Consumptions.

The following tables summarize the building energy usage and cost savings for the different systems. Compared to ASHRAE Standard 90.1-2013 baseline, the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 17%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 17%.

Table 59: Helena Annual Building Energy Consumption and Energy Cost.

System	Annual Energy		Annual Energy Cost ($)			Annual Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	663,594	3,566.8	84,874	2,996	87,870	0	0
Proposed [(1): VRF-HP	572,876	0.0	73,271	0	73,271	14,599	17%
Proposed (2): VRF-HR	572,638	0.0	73,241	0	73,241	14,629	17%
Proposed (3): VRF-Hydro	473,056	0.0	60,504	0	60,504	27,366	31%

Compared to ASHRAE Standard 90.1-2013 baseline, the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 28%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 28%. When the Multi V was a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposed [3]), the HVAC energy cost savings increased by 52% compared to the ASHRAE 90.1-2013 Standard baseline (PSZ-AC/HP), and the simple payback period was about 1 year, 0 months.

Table 60: Helena Annual HVAC + DHW Energy Consumption and Energy Cost.

System	Annual HVAC Energy		Annual HVAC Energy Cost ($)			Annual HVAC Energy Cost Saving	
	Electricity (kWh)	Natural Gas (Therm)	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio
Baseline: ASHRAE Std. 90.1-2013	388,094	3,566.8	49,637	2,996	52,633	0	-
Proposed [(1): VRF-HP	297,376	0.0	38,034	0	38,034	14,599	28%
Proposed (2): VRF-HR	297,138	0.0	38,004	0	38,004	14,629	28%
Proposed (3): VRF-Hydro	197,555	0.0	25,267	0	25,267	27,366	52%

Table 61: Helena Estimated HVAC + DHW Cost Analysis ($).

System Configuration	Initial Cost ($)	Annual Cost ($)				Annual Energy Cost Saving		Payback Period
		Maintenance	Electricity	Natural Gas	Total	Saving Amount ($)	Cost Saving Ratio	
Baseline: ASHRAE Std. 90.1-2013	43,060	12,960	84,874	2,996	100,830	0	-	-
Proposed [(1): VRF-HP	52,564	12,960	73,271	0	86,231	14,599	14%	0 years, 9 months
Proposed (2): VRF-HR	56,964	12,960	73,241	0	86,201	14,629	15%	1 year, 0 months
Proposed (3): VRF-Hydro	69,884	12,960	60,504	0	73,464	27,366	27%	1 year, 0 months

Appendix B. Building Loads, Energy, and Energy Cost (NZEB)

1) Results – Miami, FL (1A)

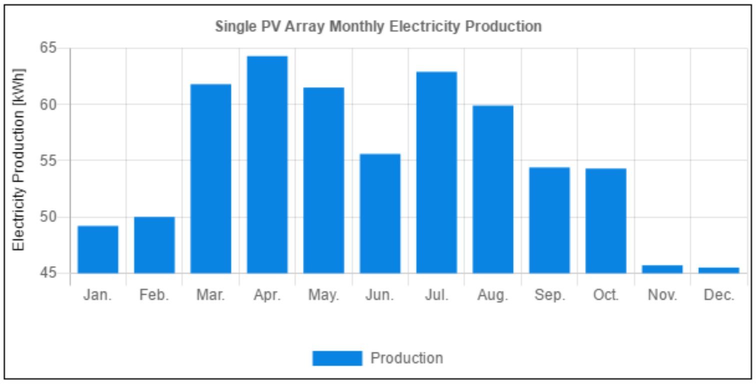


Figure 48: Single PV Array Monthly Electricity Production in Miami, FL.

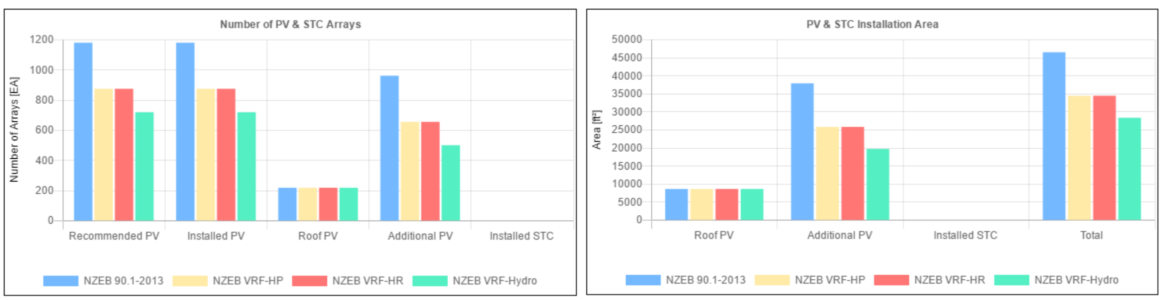


Figure 49: Number of PV Arrays and Required Installation Area in Miami, FL.

According to the energy consumption of the entire building, the LG NeON 2 Commercial PV panels were required to achieve a NZE in an ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 1,181. The number of PV arrays required by the NZEB Proposed (3) application has been reduced to 720, which was 61% of the NZE baseline building.

Table 62: Required PV Module and PV Initial Cost for Achieving NZE: Miami, FL.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB BASELINE : 90.1-2013	484.2	1181	865,525	100%	VS Baseline
NZEB Proposed (1): VRF-HP	358.8	875	641,368	74.1%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	358.8	875	641,368	74.1%	
NZEB Proposed [(3): VRF-Hydro	295.2	720	527,681	61.0%	

Table 63: Total Initial Cost to Achieve NZE: Miami, FL.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	58,630	0	58,630	-	-
NZEB Baseline: 90.1-2013	58,630	865,525	924,155	100%	VS Baseline
NZEB Proposed (1): VRF-HP	72,022	641,368	713,390	77.2%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	78,222	641,368	719,590	77.9%	
NZEB Proposed (3): VRF-Hydro	94,382	527,681	622,063	67.3%	

As shown in Table 64, the initial cost of $924,155 and the annual cost of $22,160 were required to achieve a building based on Standard 90.1-2013 with net energy zero, with an estimated payback period of about 10 years, 3 months. By applying Proposed (3) to the NZE Standard 90.1-2013 building, saving 39.1% of building energy (HVAC energy savings of approximately 75.9%) can reduce the required PV module installation area by about 39%, and thus, the payback period for the NZE building of NZE can be achieved in about 6 years, 5 months.

Table 64: Initial and Annual Cost Analysis to Achieve NZE: Miami, FL.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	58,630	12,960	94,128	107,088	0	0	0	-
NZEB Baseline: 90.1-2013	924,155	22,160	0	22,160	84,928	79.3%	10 years, 3 months	VS Baseline
NZEB: Proposed (1): VRF-HP	713,390	19,776	0	19,776	87,312	81.5%	7 years, 6 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	719,590	19,776	0	19,776	87,312	81.5%	7 years, 6 months	
NZEB Proposed (3): VRF-Hydro	622,063	18,569	0	18,569	88,519	82.7%	6 years, 5 months	

2) Results – Houston, TX (2A)

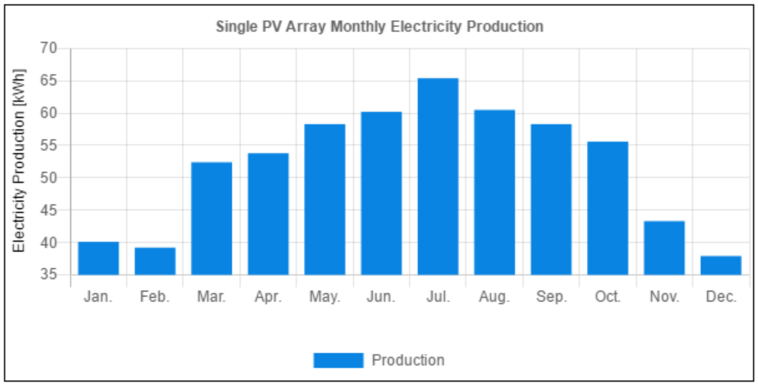


Figure 50: Single PV Array Monthly Electricity Production in Houston, TX.

According to the energy consumption of the entire Small Hotel building, LG NeON 2 Commercial PV panels were required to achieve NZE in an ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 484. The number of PV arrays required by the NZEB Proposed (3) application was reduced to 307, which is 63.4% of the NZE baseline building.

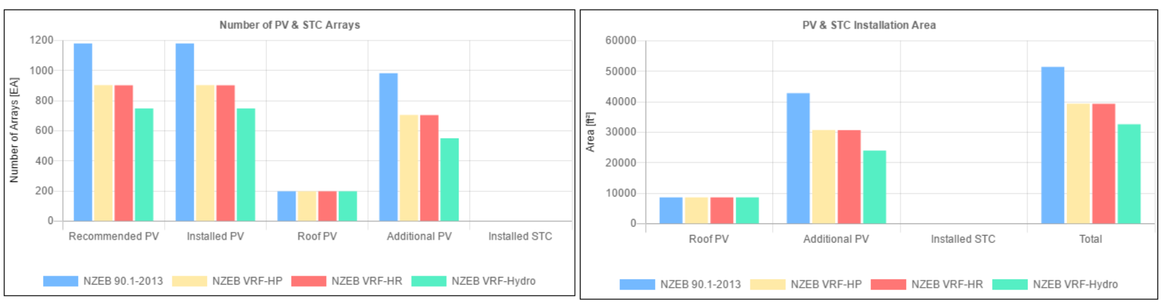


Figure 51: Number of PV Arrays and Required Installation Area in Houston, TX.

Table 65: Required PV Module and PV Initial Cost for Achieving NZE: Houston, TX.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	483.8	1180	864,810	100%	-
NZEB Proposed (1): VRF-HP	370.2	903	661,746	76.5%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	369.8	902	661,031	76.4%	
NZEB Proposed (3): VRF-Hydro	306.7	748	548,237	63.4%	

Table 66: Total Initial Cost to Achieve NZE: Houston, TX.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	58,630	0	58,630	-	-
NZEB Baseline: 90.1-2013	58,630	864,810	923,440	100%	-
NZEB Proposed (1): VRF-HP	72,022	661,746	733,768	79.5%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	78,222	661,031	739,253	80.1%	
NZEB Proposed [(3): VRF-Hydro	94,382	548,237	642,619	69.6%	

As shown in Table 67, the initial cost of $923,440 and the annual cost of $22,152 were required to achieve a building based on Standard 90.1-2013 with net energy zero, and the payback period was estimated to take about 11 years, 5 months. By applying the Proposed (3) the NZEB Baseline : ASHRAE 90.1-2013 building, saving 23.7% of the building energy (HVAC energy savings of approximately 75.9%), can reduce the required PV module installation area by about 36.6%, and thus, the payback period of net zero building achievement can be achieved in about 7 years, 5 months.

Table 67: Initial and Annual Cost Analysis to Achieve NZE: Houston, TX.

Case	Initial Cost ($)	Annual Energy Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	58,630	12,960	84,861	97,821	0	0	0	-
NZEB Baseline: 90.1-2013	923,440	22,152	0	22,152	75,669	77.4%	11 years, 5 months	-
NZEB Proposed (1): VRF-HP	733,768	19,994	0	19,994	77,827	79.6%	8 years, 9 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	739,253	19,987	0	19,987	77,834	79.6%	8 years, 9 months	
NZEB Proposed (3): VRF-Hydro	642,619	18,787	0	18,787	79,034	80.8%	7 years, 5 months	

3) Results – Phoenix, AZ (2B)

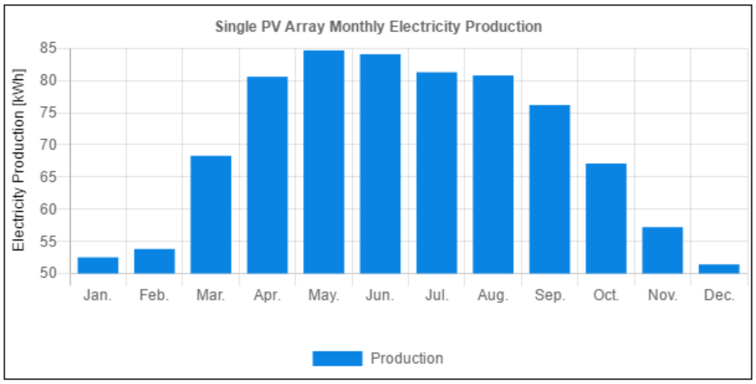


Figure 52: Single PV Array Monthly Electricity Production in Phoenix, AZ.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in an ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 892. The number of PV arrays required by the NZEB Proposed (3) application was reduced to 569, which is 63.8% of the NZE baseline building.

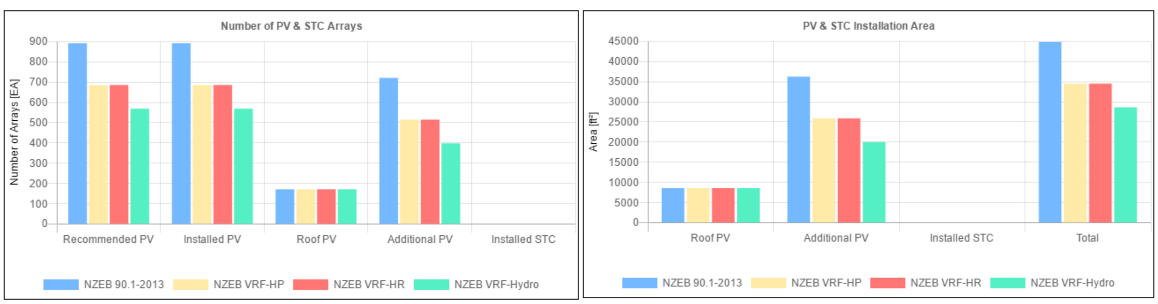


Figure 53: Number of PV Arrays and Required Installation Area in Phoenix, AZ.

Table 68: Required PV Module and PV Initial Cost for Achieving NZE: Phoenix, AZ.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	365.7	892	653,702	100%	-
NZEB Proposed (1): VRF-HP	281.3	686	502,834	76.9%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	281.3	686	502,834	76.9%	
NZEB Proposed (3): VRF-Hydro	233.3	569	417,032	63.8%	

Table 69: Total Initial Cost to Achieve NZE: Phoenix, AZ.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	60,360	0	60,360	-	-
NZEB Baseline: 90.1-2013	60,360	653,702	714,062	100%	-
NZEB Proposed (1): VRF-HP	74,184	502,834	577,018	80.8%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	80,584	502,834	583,418	81.7%	
NZEB Proposed (3): VRF-Hydro	97,104	417,032	514,136	72.0%	

As shown in Table 70, the initial cost of $714,062 and the annual cost of $19,909 were required to achieve a building based on Standard 90.1-2013 with net energy zero, and the payback period was estimated to take about 7 years, 10 months. By applying the Proposed [3] to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 31.7% of the building energy,(HVAC energy savings of approximately 74%), can reduce the required PV module installation area by about 36.2%, and thus, the payback period of net zero building achievement can be achieved in about 5 years, 3 months.

Table 70: Initial and Annual Cost Analysis to Achieve NZE: Phoenix, AZ.

Case	Initial Cost ($)	Annual Energy Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	60,360	12,960	91,223	104,183	0	0	0	-
NZEB Baseline: 90.1-2013	714,062	19,909	0	19,909	84,274	80.9%	7 years, 10 months	-
NZEB Proposed (1): VRF-HP	577,018	18,304	0	18,304	85,879	82.4%	6 years, 0 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	583,418	18,304	0	18,304	85,879	82.4%	6 years, 2 months	
NZEB Proposed (3): VRF-Hydro	514,136	17,393	0	17,393	86,790	83.3%	5 years, 3 months	

4) Results – Atlanta (3A)

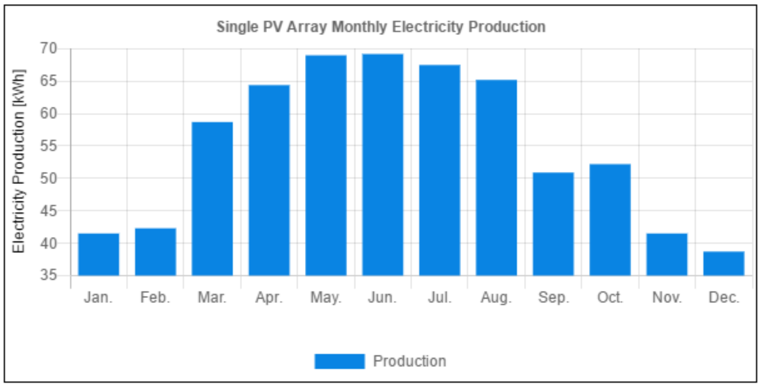


Figure 54: Single PV Array Monthly Electricity Production in Atlanta, GA.

According to the energy consumption of the entire building, LG NeON 2 Commercial 180kWp PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 450. The number of PV arrays required by the NZEB Proposed (3) application was reduced to 310, which was 68.8% of the NZE baseline building.

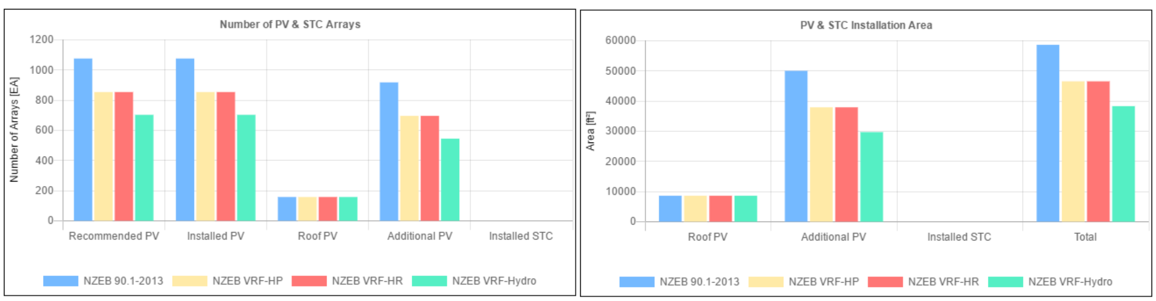


Figure 55: Number of PV Arrays and Required Installation Area in Atlanta, GA.

Table 71: Required PV Module and PV Initial Cost for Achieving NZE: Atlanta, GA.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	441.2	1,076	788,661	100%	-
NZEB Proposed (1): VRF-HP	350.1	854	625,816	79%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	350.1	854	625,816	79%	
NZEB Proposed (3): VRF-Hydro	288.2	703	515,168	65%	

Table 72: Total Initial Cost to Achieve NZE: Atlanta, GA.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline : ASHRAE Std. 90.1-2013	55,170	0	55,170	-	-
NZEB Baseline: 90.1-2013	55,170	788,661	843,831	100%	-
NZEB Proposed (1)VRF-HP	67,698	625,816	693,514	82%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	73,498	625,816	699,314	83%	
NZEB Proposed (3): VRF-Hydro	88,938	515,168	604,106	72%	

As shown in Table 73, it was calculated that the initial cost of $843,831 and the annual cost of $19,909 were required to achieve a building based on ASHRAE Standard 90.1-2013 with net zero, and the payback period was estimated to take about 11 years, 9 months. By applying the Proposed (3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 32% of the building energy (HVAC energy saving of approximately 75%), can reduce the required PV module installation area by about 34.7%, and thus, the payback period of net zero building achievement can be achieved in about 9 years.

Table 73: Initial and Annual Cost Analysis to Achieve NZE: Atlanta, GA.

Case	Initial Cost ($)	Annual Energy Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	55,170	12,960	91,223	104,183	0	0	0	-
NZEB Baseline: 90.1-2013	843,831	19,909	0	19,909	84,274	81%	11 years, 9 months	-
NZEB Proposed (1): VRF-HP	693,514	18,304	0	18,304	85,879	82%	9 years, 3 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	699,314	18,304	0	18,304	85,879	82%	9 years, 4 months	
NZEB Proposed (3): VRF-Hydro	604,106	17,393	0	17,393	86,790	83%	7 years 10 months	

5) Results – Los Angeles (3B)

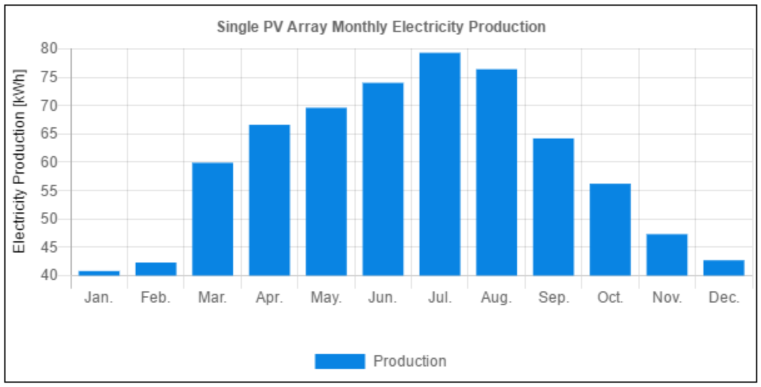


Figure 56: Single PV Array Monthly Electricity Production in Los Angeles, CA.

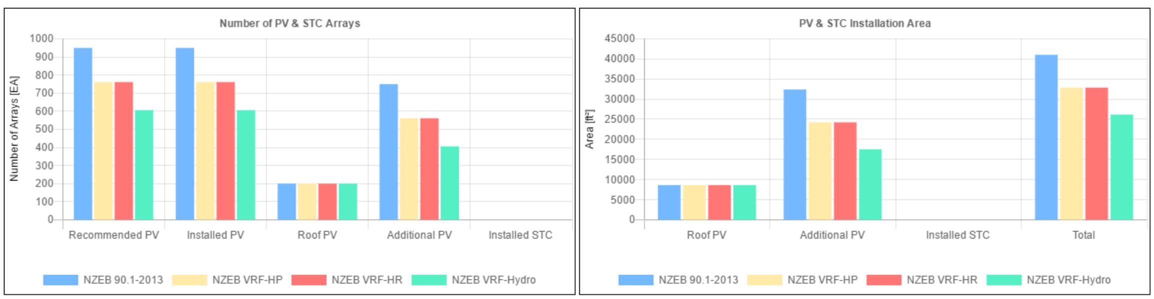


Figure 57: Number of PV Arrays and Required Installation Area in Los Angeles, CA.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 950. The number of arrays required by Proposed (3) application was reduced to 606, which was 64% of the NZE baseline building.

Table 74: Required PV Module and PV Initial Cost for Achieving NZE: Los Angeles, CA.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	389.5	950	696,245	100%	-
NZEB Proposed (1):VRF-HP	312	761	557,711	80%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	312	761	557,711	80%	
NZEB Proposed (3): VRF-Hydro	248.5	606	444,203	64%	

Table 75: Total Initial Cost to Achieve NZE: Los Angeles, CA.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	41,330	0	41,330	-	-
NZEB Baseline: 90.1-2013	41,330	696,245	737,575	100%	-
NZEB Proposed (1): VRF-HP	50,402	557,711	608,113	82%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	54,602	557,711	612,313	83%	
NZEB Proposed (3): VRF-Hydro	67,162	444,203	511,365	69%	

As shown in Table 76, it was calculated that the initial cost of $737,575 and the annual cost of $20,361 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 5 years, 11 months. By applying the Proposed (3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 33% of the building energy, i.e. HVAC energy saving 81%, can reduce the required PV module installation area by about 36%, and thus, the payback period of net zero building achievement can be achieved in about 3 years, 11 months.

Table 76: Initial and Annual Cost Analysis to Achieve NZE: Los Angeles, CA.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	41,330	12,960	124,970	137,930	0	0	0	-
NZEB Baseline: 90.1-2013	737,575	20,361	0	20,361	117,569	85%	5 years, 11 months	-
NZEB Proposed (1): VRF-HP	608,113	18,888	0	18,888	119,042	86%	4 years, 3 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	612,313	18,888	0	18,888	119,042	86%	4 years, 4 months	
NZEB Proposed (3): VRF-Hydro	511,365	17,681	0	17,681	120,249	87%	3 years, 11 months	

6) Results – San Francisco (3C)

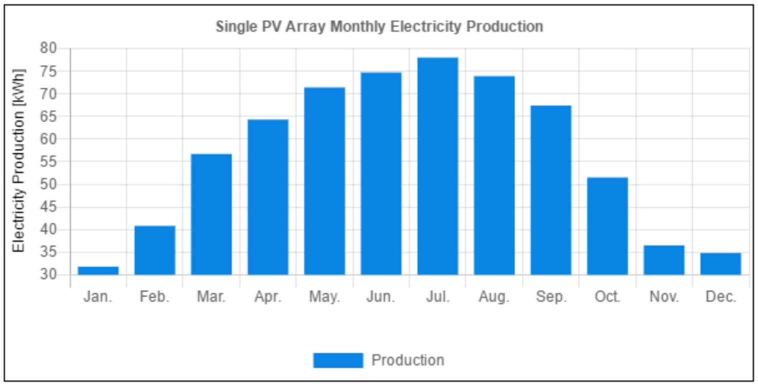


Figure 58: Single PV Array Monthly Electricity Production in San Francisco, CA.

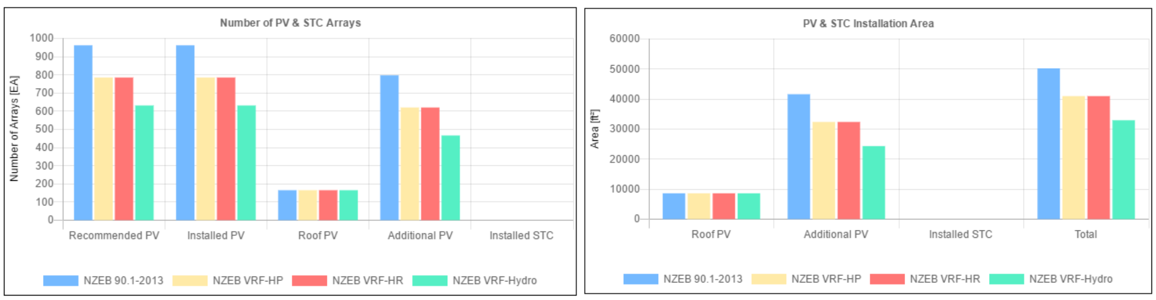


Figure 59: Number of PV Arrays and Required Installation Area in San Francisco, CA.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 962. The number of arrays required by Proposed (3) application was reduced to 631, which was 66% of the NZE baseline building.

Table 77: Required PV Module and PV Initial Cost for Achieving NZE: San Francisco, CA.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	394.4	962	705,004	100%	-
NZEB Proposed (1): VRF-HP	321.8	785	575,229	82%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	321.8	785	575,229	82%	
NZEB Proposed (3): VRF-Hydro	258.7	631	462,436	66%	

Table 78: Total Initial Cost to Achieve NZE: San Francisco, CA.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	39,600	0	39,600	-	-
NZEB Baseline: 90.1-2013	39,600	705,004	744,604	100%	-
NZEB Proposed (1): VRF-HP	48,240	575,229	623,469	84%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	52,240	575,229	627,469	84%	
NZEB Proposed (3): VRF-Hydro	64,440	462,436	526,876	71%	

As shown in Table 79, it was calculated that the initial cost of $744,604 and the annual cost of $20,454 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 6 years, 4 months. By applying the Proposed (3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 30% of the building energy (HVAC energy saving of approximately 79%), can reduce the required PV module installation area by about 34%, and thus, the payback period of net zero building achievement can be achieved in about 4 years, 4 months.

Table 79: Initial and Annual Cost Analysis to Achieve NZE: San Francisco, CA.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	39,600	12,960	119,165	132,125	0	0	0	-
NZEB Baseline: 90.1-2013	744,604	20,454	0	20,454	111,671	85%	6 years, 4 months	-
NZEB Proposed (1): VRF-HP	623,469	19,075	0	19,075	113,050	86%	5 years, 3 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	627,469	19,075	0	19,075	113,050	86%	5 years, 3 months	
NZEB Proposed (3): VRF-Hydro	526,876	17,876	0	17,876	114,249	86%	4 years, 4 months	

7) Results – Baltimore (4A)

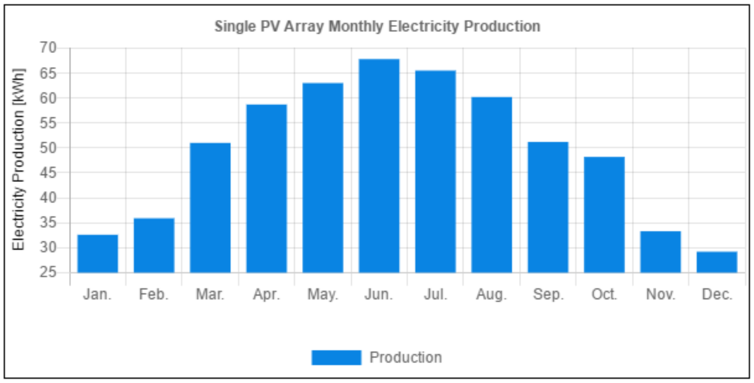


Figure 60: Single PV Array Monthly Electricity Production in Baltimore, MD.

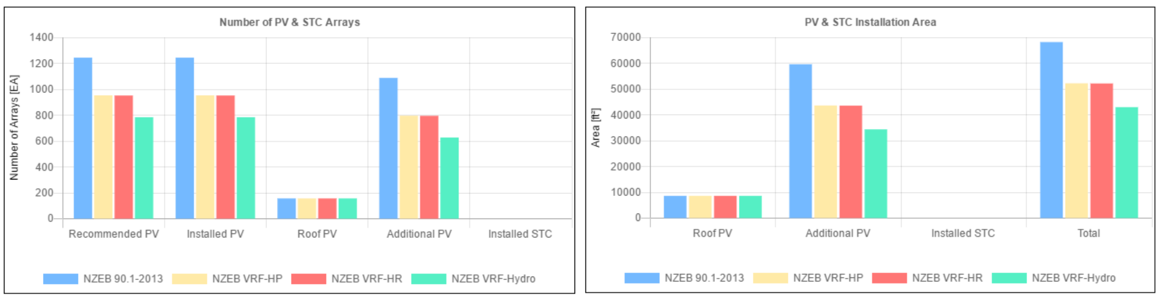


Figure 61: Number of PV Arrays and Required Installation Area in Baltimore, MD.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 1,246. The number of PV arrays required by the NZEB Proposed (3) application was reduced to 785, which was 63% of the NZE baseline building.

Table 80: Required PV Module and PV Initial Cost for Achieving NZE: Baltimore, MD.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	510.9	1,246	913,252	100%	-
NZEB Proposed [1](1): VRF-HP	391.1	954	699,105	77%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	390.7	953	698,390	76%	
NZEB Proposed (3): VRF-Hydro	321.8	785	575,229	63%	

Table 81: Total Initial Cost to Achieve NZE: Baltimore, MD.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	62,090	0	62,090	-	-
NZEB Baseline: 90.1-2013	62,090	913,252	975,342	100%	-
NZEB Proposed (1):: VRF-HP	76,346	699,105	775,451	80%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	82,946	698,390	781,336	80%	
NZEB Proposed (3): VRF-Hydro	99,826	575,229	675,055	69%	

As shown in Table 82, it was calculated that the initial cost of $975,342 and the annual cost of $22,666 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 11 years, 0 months. By applying the Proposed (3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 29% of the building energy (HVAC energy savings of approximately 60%), can reduce the required PV module installation area by about 37%, and thus, the payback period of net zero building achievement can be achieved in about 7 years, 2 months.

Table 82: Initial and Annual Cost Analysis to Achieve NZE: Baltimore, MD.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio		
Baseline: ASHRAE Std. 90.1-2013	62,090	12,960	92,157	105,117	0	0	0	-
NZEB Baseline: 90.1-2013	975,342	22,666	0	22,666	82,451	78%	11 years, 0 months	-
NZEB Proposed (1): VRF-HP	775,451	20,392	0	20,392	84,725	81%	8 years, 5 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	781,336	20,384	0	20,384	84,733	81%	8 years, 6 months	
NZEB Proposed (3): VRF-Hydro	675,055	19,075	0	19,075	86,042	82%	7 years, 2 months	

8) Results – New York (4A)

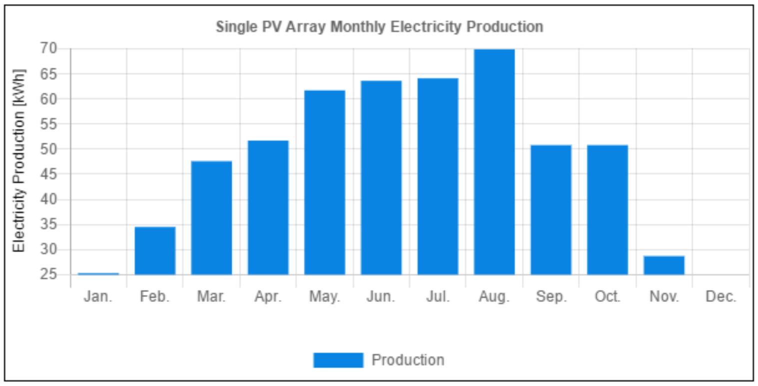


Figure 62: Single PV Array Monthly Electricity Production in New York City, NY.

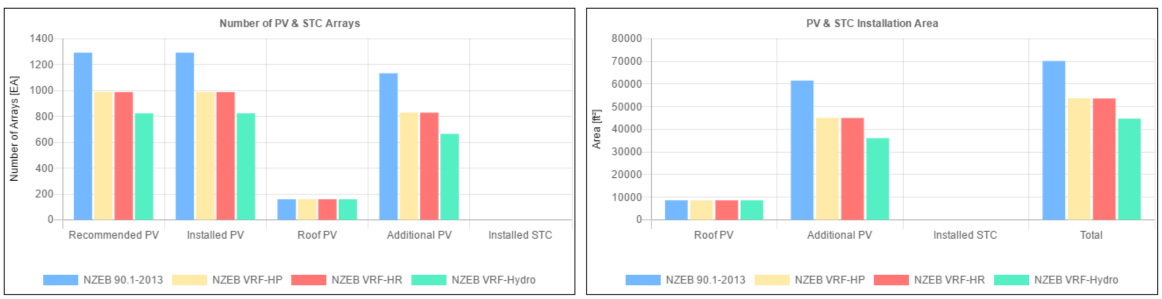


Figure 63: Number of PV Arrays and Required Installation Area in New York City, NY.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 1,293. The number of PV arrays required by the NZEB Proposed (3)] application was reduced to 824, which was 64% of the NZE baseline building.

Table 83: Required PV Module and PV Initial Cost for Achieving NZE: New York City, NY.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	530.1	1,293	947,573	100%	-
NZEB Proposed (1): VRF-HP	405.5	989	724,846	76%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2):VRF-HR	405.1	988	724,131	76%	
NZEB Proposed (3): VRF-Hydro	337.8	824	603,830	64%	

Table 84: Total Initial Cost to Achieve NZE: New York City, NY.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	56,900	0	56,900	-	-
NZEB Baseline: 90.1-2013	56,900	947,573	1,004,473	100%	-
NZEB Proposed (1): VRF-HP	69,860	724,846	794,706	79%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	75,860	724,131	799,991	80%	
NZEB Proposed (3): VRF-Hydro	91,660	603,830	695,490	69%	

As shown in Table 85, it was calculated that the initial cost of $1,004,473 and the annual cost of $23,033 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 8 years, 8 months. By applying the Proposed [3] to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 30% of the building energy (HVAC energy savings of approximately 57%), can reduce the required PV module installation area by about 36%, and thus, the payback period of net zero building achievement can be achieved in about 5 years, 8 months.

Table 85: Initial and Annual Cost Analysis to Achieve NZE: New York City, NY.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio		
Baseline: ASHRAE Std. 90.1-2013	56,900	12,960	92,942	105,902	0	0	0	-
NZEB Baseline: 90.1-2013	1,004,473	23,033	0	23,033	82,869	78%	8 years,8 months	-
NZEB Proposed (1): VRF-HP	794,706	20,664	0	20,664	85,238	80%	6 years, 6 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	799,991	20,657	0	20,657	85,245	80%	6 years, 8 months	
NZEB Proposed (3): VRF-Hydro	695,490	19,379	0	19,379	86,523	82%	5 years, 8 months	

9) Results – Albuquerque (4B)

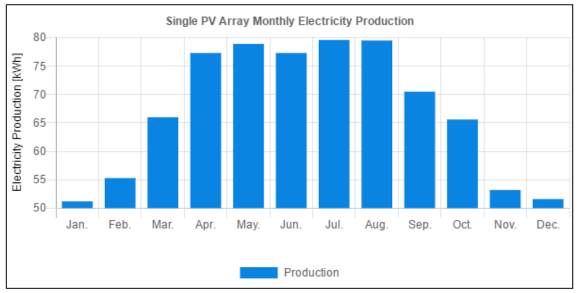


Figure 64: Single PV Array Monthly Electricity Production in Albuquerque, NM.

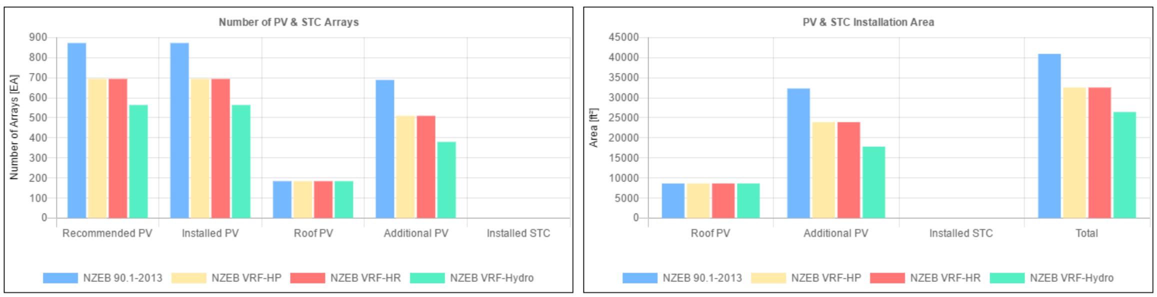


Figure 65: Number of PV Arrays and Required Installation Area in Albuquerque, NM.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 873. The number of PV arrays required by the NZEB Proposed (3) application was reduced to 564, which is 65% of the NZE baseline building.

Table 86: Required PV Module and PV Initial Cost for Achieving NZE: Albuquerque, NM.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	357.9	873	639,759	100%	-
NZEB Proposed (1): VRF-HP	284.5	694	508,554	79%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2):VRF-HR	284.5	694	508,554	79%	
NZEB Proposed (3): VRF-Hydro	231.2	564	413,278	65%	

Table 87: Total Initial Cost to Achieve NZE: Albuquerque, NM.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	41,330	0	41,330	-	-
NZEB Baseline: 90.1-2013	41,330	639,759	681,089	100%	-
NZEB Proposed)1): VRF-HP	50,402	508,554	558,956	82%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	54,602	508,554	563,156	83%	
NZEB Proposed [3] (3): VRF-Hydro	67,162	413,278	480,440	71%	

As shown in Table 88, it was calculated that the initial cost of $681,089 and the annual cost of $19,761 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 8 years, 5 months. By applying the Proposed [3(3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 29% of the building energy (HVAC energy savings of approximately 62%), can reduce the required PV module installation area by about 35%, and thus, the payback period of net zero building achievement can be achieved in about 5 years, 8 months.

Table 88: Initial and Annual Cost Analysis to Achieve NZE: Albuquerque, NM.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio		
Baseline: ASHRAE Std. 90.1-2013	41,330	12,960	83,392	96,352	0	0	0	-
NZEB Baseline:90.1-2013	681,089	19,761	0	19,761	76,591	79%	8 years, 5 months	-
NZEB Proposed (1): VRF-HP	558,956	18,366	0	18,366	77,986	81%	6 years, 8 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed)2): VRF-HR	563,156	18,366	0	18,366	77,986	81%	6 years, 9 months	
NZEB Proposed (3): VRF-Hydro	480,440	17,354	0	17,354	78,998	82%	5 years, 8 months	

10) Results – Seattle (4C)

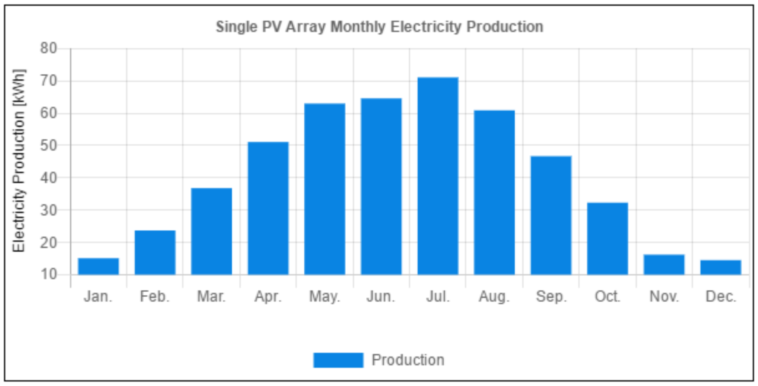


Figure 66: Single PV Array Monthly Electricity Production in Seattle, WA.

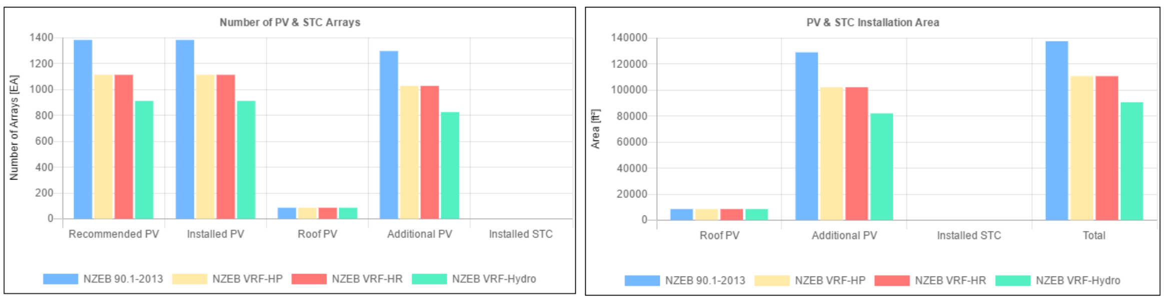


Figure 67: Number of PV Arrays and Required Installation Area in Seattle, WA.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of PV panel arrays necessary was 873. The number of PV arrays required by the NZEB Proposed (3) application was reduced to 564, which was 65% of the NZE baseline building.

Table 89: Required PV Module and PV Initial Cost for Achieving NZE: Seattle, WA.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	567.4	1,384	1,014,248	100%	-
NZEB Proposed [1](1): VRF-HP	456.7	1,114	816,368	80%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	456.7	1,114	816,368	80%	
NZEB Proposed (3): VRF-Hydro	373.9	912	668,360	66%	

Table 90: Total Initial Cost to Achieve NZE: Seattle, WA.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	44,790	0	44,790	-	-
NZEB Baseline: 90.1-2013	44,790	1,014,248	1,059,038	100%	-
NZEB Proposed (1): VRF-HP	54,726	816,368	871,094	82%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	59,326	816,368	875,694	83%	
NZEB Proposed (3): VRF-Hydro	72,606	668,360	740,966	70%	

As shown in Table 85, it was calculated that the initial cost of $1,059,038 and the annual cost of $23,741 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 19 years, 9 months. By applying the Proposed (3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 27% of the building energy (HVAC energy savings of approximately 70%), can reduce the required PV module installation area by about 34%, and thus, the payback period of net zero building achievement can be achieved in about 12 years, 8 months.

Table 91: Initial and Annual Cost Analysis to Achieve NZE: Seattle, WA.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio		
Baseline: ASHRAE Std. 90.1-2013	44,790	12,960	62,171	75,131	0	0	0	-
NZEB Baseline: 90.1-2013	1,059,038	23,741	0	23,741	51,390	68%	19 years, 9 months	-
NZEB Proposed (1): VRF-HP	871,094	21,638	0	21,638	53,493	71%	15 years, 5 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	875,694	21,638	0	21,638	53,493	71%	15 years, 6 months	
NZEB Proposed (3): VRF-Hydro	740,966	20,065	0	20,065	55,066	73%	12 years, 8 months	

11) Results – Chicago (5A)

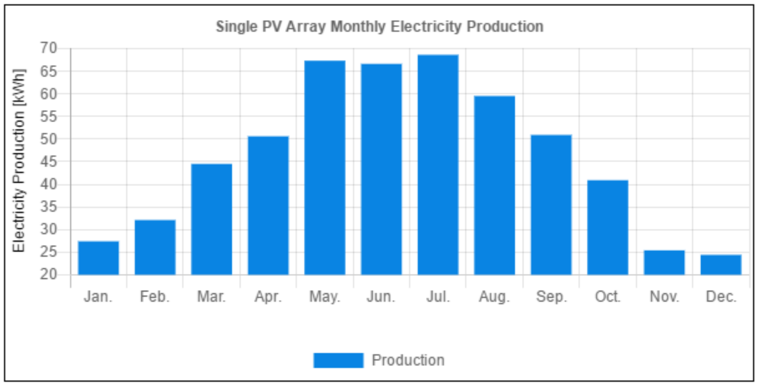


Figure 68: Single PV Array Monthly Electricity Production in Chicago, IL.

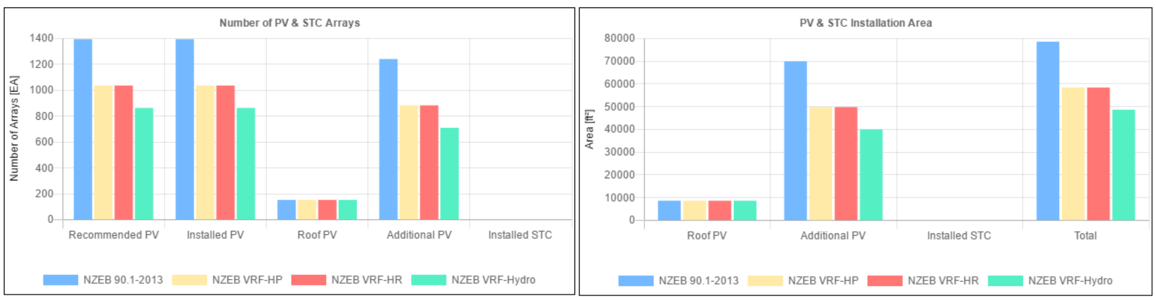


Figure 69: Number of PV Arrays and Required Installation Area in Chicago, IL.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building, and the number of PV panel arrays necessary was 1,394. The number of arrays required by the Proposal (3) application was been reduced to 863, which was 62% of the NZE baseline building.

Table 92: Required PV Module and PV Initial Cost for Achieving NZE: Chicago, IL.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	571.5	1,394	1,021,577	100%	-
NZEB Proposed (1): VRF-HP	424.8	1,036	759,345	74%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	424.8	1,036	759,345	74%	
NZEB Proposed (3): VRF-Hydro	353.8	863	632,430	62%	

Table 93: Total Initial Cost to Achieve NZE: Chicago, IL.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	58,630	0	58,630	-	-
NZEB Baseline: 90.1-2013	58,630	1,021,577	1,080,207	100%	-
NZEB Proposed (1): VRF-HP	72,022	759,345	831,367	77%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	78,222	759,345	837,567	78%	
NZEB Proposed (3): VRF-Hydro	94,382	632,430	726,812	67%	

As shown in Table 94, it was calculated that the initial cost of $1,080,207 and the annual cost of $23,819 were required to achieve a building based on ASHRAE Standard 90.1-2013 with net zero, and the payback period was estimated to take about 13 years, 8 months. By applying the Proposed (3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 28% of the building energy (HVAC energy savings of approximately 50%), can reduce the required PV module installation area by about 38%, and thus, the payback period of net zero building achievement can be achieved in about 8 years, 5 months.

Table 94: Initial and Annual Cost Analysis to Achieve NZE: Chicago, IL.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	58,630	12,960	86,134	99,094	0	0	0	-
NZEB Baseline: 90.1-2013	1,080,207	23,819	0	23,819	75,275	76%	13 years, 8 months	-
NZEB Proposed (1): VRF-HP	831,367	21,030	0	21,030	78,064	79%	9 years, 11 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	837,567	21,030	0	21,030	78,064	79%	10 years, 0 months	
NZEB Proposed (3): VRF-Hydro	726,812	19,683	0	19,683	79,411	80%	8 years, 5 months	

12) Results – Boulder (5B)

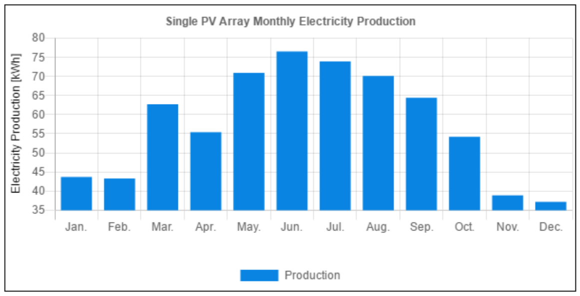


Figure 70: Single PV Array Monthly Electricity Production in Boulder, CO.

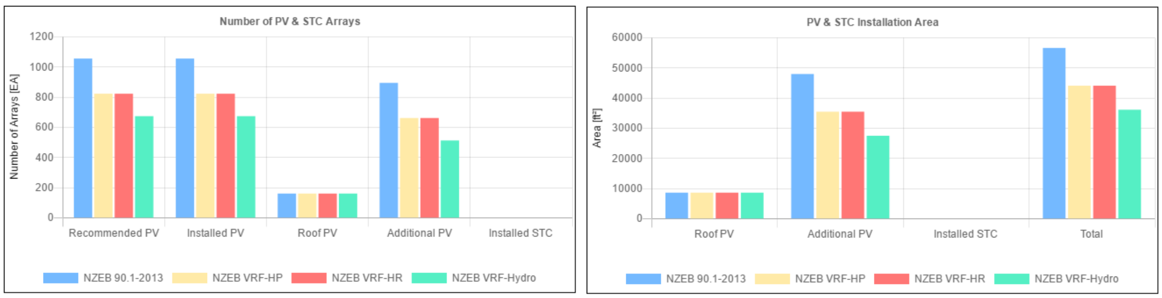


Figure 71: Number of PV Arrays and Required Installation Area in Boulder, CO.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building, and the number of PV panel arrays necessary was 1,056. The number of arrays required by the Proposal (3) application was been reduced to 674, which was 64% of the NZE baseline building.

Table 95: Required PV Module and PV Initial Cost for Achieving NZE: Boulder, CO.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	433	1,056	774,003	100%	-
NZEB Proposed (1): VRF-HP	337.4	823	603,115	78%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	337.4	823	603,115	78%	
NZEB Proposed (3): VRF-Hydro	276.3	674	493,896	64%	

Table 96: Total Initial Cost to Achieve NZE: Boulder, CO.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	41,330	0	41,330	-	-
NZEB Baseline: 90.1-2013	41,330	774,003	815,333	100%	-
NZEB Proposed (1): VRF-HP	50,402	603,115	653,517	80%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	54,602	603,115	657,717	81%	
NZEB Proposed (3): VRF-Hydro	67,162	493,896	561,058	69%	

As shown in Table 97, it was calculated that the initial cost of $815,333 and the annual cost of $21,186 were required to achieve a building based on ASHRAE Standard 90.1-2013 with net zero, and the payback period was estimated to take about 10 years, 6 months. By applying the Proposed (3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 28% of the building energy (HVAC energy savings of approximately 60%), can reduce the required PV module installation area by about 38%, and thus, the payback period of net zero building achievement can be achieved in about 6 years, 9 months.

Table 97: Initial and Annual Cost Analysis to Achieve NZE: Boulder, CO.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	41,330	12,960	82,273	95,233	0	0	0	-
NZEB Baseline: 90.1-2013	815,333	21,186	0	21,186	74,047	78%	10 years, 6 months	-
NZEB Proposed (1): VRF-HP	653,517	19,371	0	19,371	75,862	80%	8 years, 2 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	657,717	19,371	0	19,371	75,862	80%	8 years, 2 months	
NZEB Proposed (3): VRF-Hydro	561,058	18,211	0	18,211	77,022	81%	6 years, 9 months	

13) Results – Minneapolis (6A)

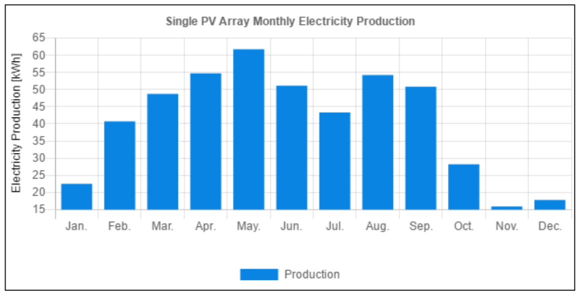


Figure 72: Single PV Array Monthly Electricity Production in Minneapolis, MN.

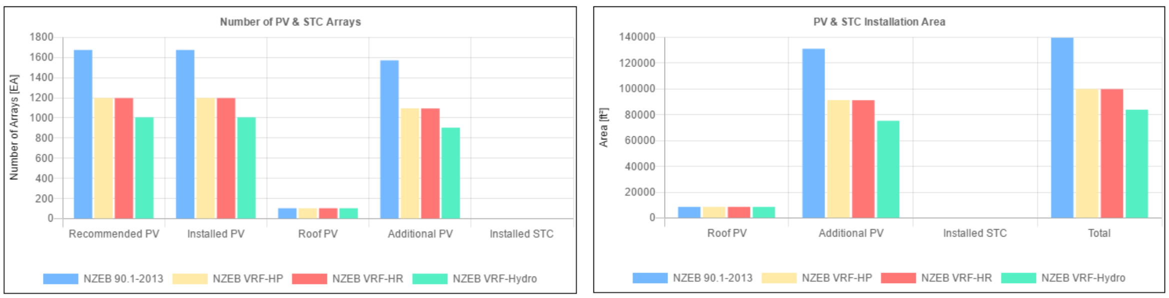


Figure 73: Number of PV Arrays and Required Installation Area in Minneapolis, MN.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building, and the number of PV panel arrays necessary was 1,675. The number of PV arrays required by the NZEB Proposed [3] was reduced to 1006, which was 60% of the NZE baseline building.

Table 98: Required PV Module and PV Initial Cost for Achieving NZE: Minneapolis, MN.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	686.8	1,675	1,227,680	100%	-
NZEB Proposed (1): VRF-HP	491.2	1,198	878,038	72%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	490.8	1,197	877,323	71%	
NZEB Proposed (3): VRF-Hydro	412.5	1,006	737,359	60%	

Table 99: Total Initial Cost to Achieve NZE: Minneapolis, MN.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	56,900	0	56,900	-	-
NZEB Baseline: 90.1-2013	56,900	1,227,680	1,284,580	100%	-
NZEB Proposed (1): VRF-HP	69,860	878,038	947,898	74%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	75,860	877,323	953,183	74%	
NZEB Proposed (3): VRF-Hydro	91,660	737,359	829,019	65%	

As shown in Table 100, it was calculated that the initial cost of $1,284,580 and the annual cost of $26,008 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 18 years, 11 months. By applying the Proposed (3) to the NZEB Baseline building, saving 27.0% of the building energy (HVAC energy savings of approximately 44%), can reduce the required PV module installation area by about 39.9%, and thus, the payback period of net zero building achievement can be achieved in about 11 years, 0 months.

Table 100: Initial and Annual Cost Analysis to Achieve NZE: Minneapolis, MN.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	56,900	12,960	78,117	91,077	0	0	0	-
NZEB Baseline: 90.1-2013	1,284,580	26,008	0	26,008	65,069	71%	18 years, 11 months	-
NZEB Proposed (1): VRF-HP	947,898	22,292	0	22,292	68,785	76%	13 years, 0 months	VS NZEB ASHR Baseline AE 90.1 -2013
NZEB Proposed (2): VRF-HR	953,183	22,285	0	22,285	68,792	76%	13 years, 0 months	
NZEB Proposed (3): VRF-Hydro	829,019	20,797	0	20,797	70,280	77%	11 years, 0 months	

14) Results – Helena (6B)

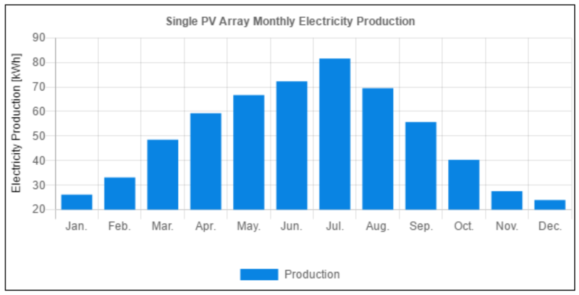


Figure 74: Single PV Array Monthly Electricity Production in Helena, MT.

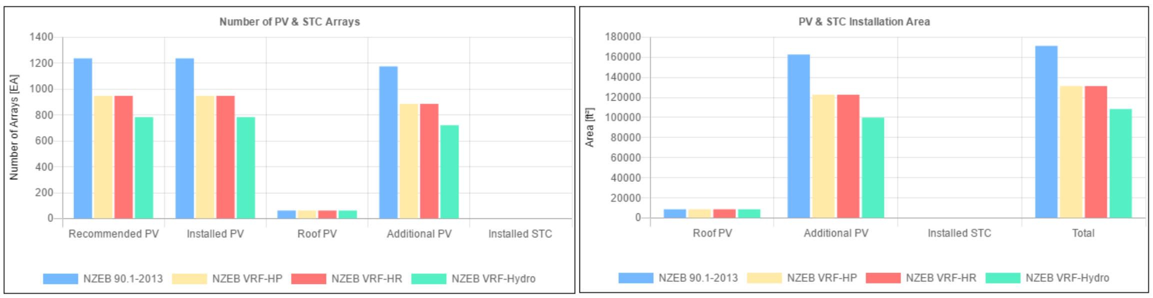


Figure 75: Number of PV Arrays and Required Installation Area in Helena, MT.

According to the energy consumption of the entire building, LG NeON 2 Commercial PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building, and the number of PV panel arrays necessary was 1,237. However, the hotel building has a roof area of 10,800.0 ft², and a single PV panel requires a footprint of 138.5 ft², so the roof can accommodate approximately 62 PV panels. Therefore, the NZEB Baseline building requires an additional installation area of 162,748 ft² in addition to the roof space to install the entire PV panel. The number and the installation area of PV arrays required by the NZEB Proposed (3) were reduced to 783, which was 63% of the NZE baseline building.

Table 101: Required PV Module and PV Initial Cost for Achieving NZE: Helena, MT.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	0	0	0	-	-
NZEB Baseline: 90.1-2013	507.2	1,237	906,638	100%	-
NZEB Proposed (1): VRF-HP	388.7	948	694,815	77%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	388.7	948	694,815	77%	
NZEB Proposed (3): VRF-Hydro	321	783	573,799	63%	

Table 102: Total Initial Cost to Achieve NZE: Helena, MT.

Case	HVAC Cost ($)	PV Cost ($)	Total Cost ($)	Cost Ratio	Note
Baseline: ASHRAE Std. 90.1-2013	43,060	0	43,060	-	-
NZEB Baseline: 90.1-2013	43,060	906,638	949,698	100%	-
NZEB Proposed (1): VRF-HP	52,564	694,815	747,379	79%	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	56,964	694,815	751,779	79%	
NZEB Proposed (3): VRF-Hydro	69,884	573,799	643,683	68%	

As shown in Table 103, it was calculated that the initial cost of $949,698 and the annual cost of $22,596 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 11 years, 9 months. By applying the NZEB Proposed (3) to the NZEB Baseline: ASHRAE 90.1-2013 building, saving 27% of the building energy (HVAC energy savings of approximately 52%), can reduce the required PV module installation by about 37%, and thus, the payback period of net zero building achievement can be achieved in about 7 years, 0 months.

Table 103: Initial and Annual Cost Analysis to Achieve NZE: Helena, MT.

Case	Initial Cost ($)	Annual Cost ($)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Baseline: ASHRAE Std. 90.1-2013	43,060	12,960	87,870	100,830	0	0	0	-
NZEB Baseline: 90.1-2013	949,698	22,596	0	22,596	78,234	78%	11 years, 9 months	-
NZEB Proposed (1): VRF-HP	747,379	20,345	0	20,345	80,485	80%	8 years, 10 months	VS NZEB Baseline ASHRAE 90.1 -2013
NZEB Proposed (2): VRF-HR	751,779	20,345	0	20,345	80,485	80%	8 years, 11 months	
NZEB Proposed (3): VRF-Hydro	643,683	19,060	0	19,060	81,770	81%	7 years, 0 months	

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