



**Building Energy Efficiency Analysis Stand-alone
Retail Building and LG Multi V™ VRF Systems
(Achieving Net Zero Energy)**

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Executive Summary

LG Electronics U.S.A., Inc. performed a stand-alone retail building's energy efficiency analysis that compared LG Variable Refrigerant Flow (VRF) systems with other conventional Heating, Ventilating, and Air Conditioning (HVAC) systems, reviewing performances in seven various climate zones: 1A - Miami, FL; 2A - Houston, TX; 3A - Atlanta, GA; 3B - Los Angeles, CA; 4A - New York, NY; 5A - Chicago, IL; and 6A - Minneapolis, MN. The HVAC energy analysis baseline followed was American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1.

In this 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 shows the annual HVAC and domestic water heating energy cost saving (%) and the payback period comparing LG VRF baseline HVAC systems.

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 (\$)	HVAC and Domestic Water Heating Energy Cost Savings by LG VRF + Hydro Kit (%)	Payback Period (year)
Miami, FL (1A)	11,639	64%	2 year 4 month
Houston, TX (2A)	10,114	65%	2 year 8 month
Atlanta, GA (3A)	4,284	33%	2 year 10 month
Los Angeles, CA (3B)	9,713	67%	1 year 11 month
New York, NY (4A)	11,696	64%	2 year 3 month
Chicago, IL (5A)	7,948	60%	3 year 4 month
Minneapolis, MN(6A)	6,987	54%	4 year 8 month
Average	8,911	58%	2 year 10 month

[*Compared to the baseline ASHRAE Standard 90.1-2013 PSZ -AC/HP.]

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

Stand-Alone Retail Buildings

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 University¹, is based on Department of Energy's (DOE) EnergyPlus™ and 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 studies the life cycle cost. Using LNZEP, LGE U.S. ACT performed building and HVAC and Domestic Hot Water (DHW) energy comparison analysis between the baseline systems and the proposed systems.

The study gathered the information of a stand-alone Retail from the DOE's commercial prototype building models².

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

To determine energy savings by using LG VRF, the building energy consumption was compared with other conventional cooling / heating systems.

Retail Building Construction and Energy Costs

The U.S. Environmental Protection Agency (EPA) report—*Sector Collaborative on Energy Efficiency Accomplishments and Next Steps: A Resource of the National Action Plan for Energy Efficiency*³ — has identified potential for energy savings up to 21% for supermarkets and up to 41% for retail stores. Approximately 657,000 retail buildings (stand-alone facilities, strip malls, and enclosed malls) in the U.S. consume more than \$20 billion of energy each year. Considering modern high-efficiency technologies, there is considerable potential to reduce energy consumption and operating costs. According to the retail industry's annual energy expenditure of \$20 billion, if energy savings of around 20% are possible, this represents an opportunity to save \$3 billion in energy cost. Depending on weather or building operating conditions, HVAC accounts for about 20 to 50% of energy consumption in average retail buildings. One of the most effective ways to reduce retail buildings' HVAC energy consumption is to install efficient HVAC units, and there are many energy efficiency options for HVAC equipment in retail buildings.

¹ <https://www.me.msstate.edu/people/faculty/heejin-cho/>

² http://www.energycodes.gov/development/commercial/prototype_models

³ <https://www.epa.gov/energy/national-action-plan-energy-efficiency>

Studied Model of Stand-Alone Retail Buildings

ASHRAE Standard 90.1 prototype building models were developed by Pacific Northwest National Laboratory (PNNL) in support of the U.S. DOE's Building Energy Codes Program. These prototype buildings were derived from DOE's Commercial Reference Building Models. This study reviewed the building and HVAC energy use of baseline and proposed systems by assigning multiple climate conditions to a 24,742 ft² stand-alone retail building as shown in the floor plan below.

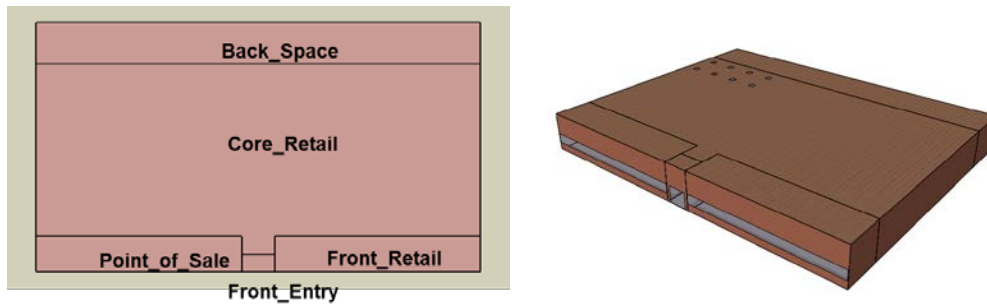


Figure 1: Floor Plan and Thermal Zones of the Stand-Alone Retail Building.

Space Cooling / Heating Systems for Stand-Alone Retail Buildings

Baseline: Packaged Single Control Zone (PSZ) Systems

Many retail buildings have met their space cooling and heating requirements through packaged units (often called rooftop units because many are located on the roof of a building). Packaged unit controls make managing heating, cooling and ventilation easier. They provide retail store owners and managers the ability to more effectively control indoor climate, making customers more comfortable and happy, which leads to higher profits. In this study, according to the ASHRAE Standard 90.1-2013 criteria (see Table 2), the baseline systems were determined as follows:

- System 3 - PSZ-AC with the minimum ASHRAE Standard 90.1-2013 requirements: Packaged single-zone rooftop air conditioners, combined with combustion furnaces and ductwork, are designed primarily for commercial buildings like stand-alone retail buildings to provide heating and cooling for a single room or zone. This system comprises more than half of all air conditioning units used by the building industry. 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 - PSZ-HP with the minimum ASHRAE Standard 90.1-2013 requirements on: Packaged single-zone heat pump with ductwork, are widely used in commercial applications like stand-alone retail buildings. PSZ-HP units include continuous indoor fan operation during occupancy and occupant ventilation air. The cooling coil is direct expansion, and the heating is furnished by an air-to-air heat pump.

Table 2: Baseline HVAC System Type List (ASHRAE Standard 90.1-2013).

Building Type	Climate Zones 3B, 3C And 4-8	Climate Zones 1-3A
Retail with One or Two Floors	System 3 - PSZ-AC	System 4 - PSZ-HP

Table 3: Baseline HVAC Systems.

Climate Zone	System No.	System Type	COP(Cooling)	COP or % (Heating)
1A_Miami_FL	System 4	PSZ-HP	3.80	3.30(Heat Pump)
2A_Houston, TX	System 4	PSZ-HP	3.80	3.30(Heat Pump)
3A_Atlanta, GA	System 4	PSZ-HP	3.80	3.30(Heat Pump)
3B_Los Angeles, CA	System 3	PSZ-AC	3.80	80%(gas furnace)
4A_New York City, NY	System 3	PSZ-AC	3.80	80%(gas furnace)
5A_Chicago, IL	System 3	PSZ-AC	3.80	80%(gas furnace)
6A_Minneapolis, MN	System 3	PSZ-AC	3.80	80%(gas furnace)

Proposed: Variable Refrigerant Flow (VRF) Systems

The proposed were 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, hotels, hospitals, schools, and stand-alone retail buildings. 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) Standard 1230. 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 4: Proposed HVAC Systems Efficiency Data (Outdoor Units).

System Type	Model Name	COP (Cooling)	COP (Heating)
VRF(HP/HR)	ARUM288B(D)TE5	4.5	4.3
	ARUM312B(D)TE5	4.4	4.2
	ARUM336B(D)TE5	4.3	4.1
	ARUM360B(D)TE5	4.3	4.2

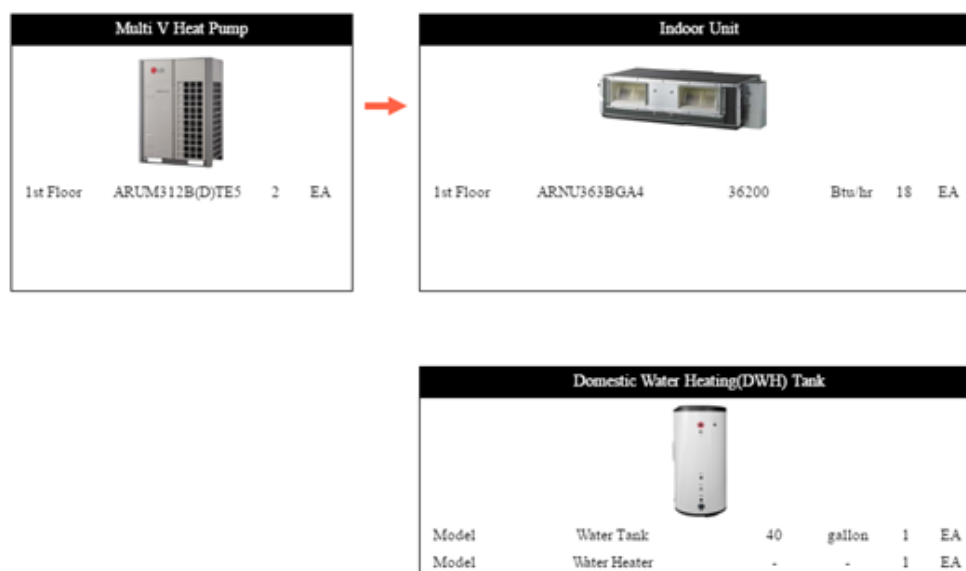


Figure 2: Proposed (1): VRF Heat Pump System and a Forty-Gallon Electric Water Heater.

The 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 forty-gallon electric water heat supplied hot water to the entire building.

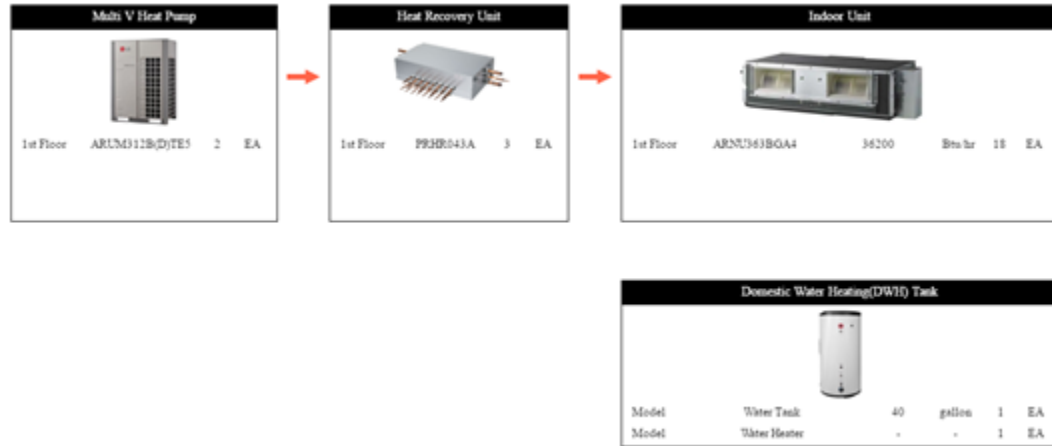


Figure 3: Proposed (2): VRF Heat Recovery System and a Forty-Gallon Electric Water Heater.

The Multi V heat recovery system (Figure 3) redistributes the energy discarded from the indoor unit zones to zones that require heating, so it will save energy through simultaneous heating and cooling, and provide comfort to individual zones. A single forty-gallon electric water heater supplied hot water to the entire building.

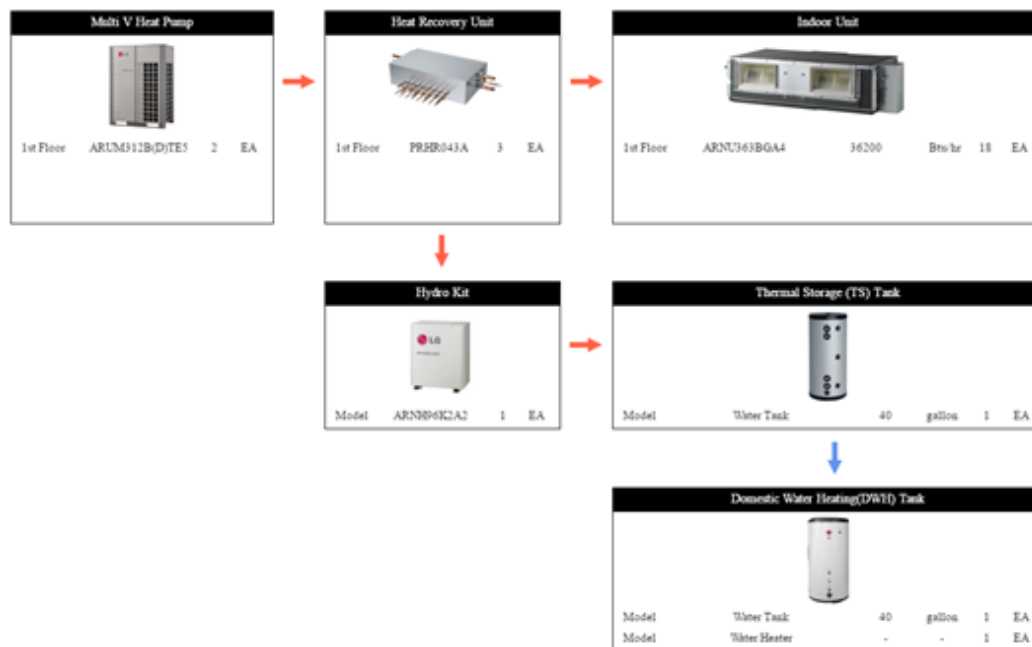


Figure 4: Proposed (3): VRF Heat Recovery System and Hydro Kit.

The Hydro Kit may be used in conjunction with Multi V systems. For the Proposed (3) system (Figure 4) the Hydro Kit uses a refrigerant-to-water heat exchanger to distribute hot thermal energy from the 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 carbon.

Building Envelope

Different values are required depending on the insulation of the building (exterior walls, roofs, windows, etc.). The insulation level according to the ASHRAE Standard 90.1-2013 minimum requirements is as follows.

Table 5: Building Envelope.

Exterior Walls	
Construction	Concrete Block Wall
	8 in. CMU + Wall Insulation+0.5 in. gypsum board
U-factor (Btu / h * ft ² * °F) and/or	Requirements in codes or standards
R-value (h * ft ² * °F / Btu)	Nonresidential; Walls, Above-Grade, Mass
Roof	
Construction	Built-up roof
	Roof membrane + roof insulation + metal decking
U-factor (Btu / h * ft ² * °F) and/or	Requirements in codes or standards
R-value (h * ft ² * °F / Btu)	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 * ft ² * °F)	Requirements in codes or standards
SHGC (all)	Nonresidential; Vertical Glazing
Visible transmittance	Same as above requirements
Operable area	2%
Foundation	
Foundation Type	Slab-on-grade floors (unheated)
Construction	6" concrete slab poured directly on to the earth with carpet
Thermal properties for ground level floor	Requirements in codes or standards
U-factor (Btu / h * ft ² * °F)	Nonresidential; Slab-on-Grade Floors, unheated
Interior Partitions	
Construction	0.5 in gypsum board + 0.5 in gypsum board
Dimensions	Based on floor plan and floor-to-floor height
Internal Mass	6 inches standard wood (16.6 lb/ft ²)
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

Interior Lighting

The baseline and proposed interior lighting followed the ASHRAE Standard 90.1 - 2013 of 1.26 W/ft² for stand-alone retail buildings.

Equipment Load

The baseline and the proposed building equipment loads followed the ASHRAE Standard 90.1-2013 of 0.95 W/ft².

Water Heater

In general, using natural gas is avoided in net zero energy building, so this study examined electric water heaters

Average Utility Rates

The electricity and natural gas rates⁴ were as follows:

Table 6: Average Utility Rates.

Weather Zone	1A	2A	3A	3B	4A	5A	6A
State	FL	TX	GA	CA	NY	IL	MN
City	Miami	Houston	Atlanta	Los Angeles	New York	Chicago	Minneapolis
Electricity (Cents/kWh)	11.99	11.51	10.7	18.34	17.29	12.19	10.83
Electricity CO ² Emission (lb/kWh)	1.11	1.17	1.11	0.51	0.55	0.92	1.11
Natural Gas (\$/Therm)	2.06	1.10	1.35	1.19	1.19	0.79	0.84
Natural Gas CO ² Emission (lb/therm)	13	13	13	13	13	13	13

⁴ Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State.

http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a.

Average Retail Price of Natural Gas Prices.

http://www.eia.gov/dnav/ng/ng_pri_sum_a_EPGO_PRS_DMcf_m.htm

What Is a Net Zero Energy (NZE) Building?

Net Zero Energy (NZE) buildings are efficient stand-alone retail buildings that produce renewable energy as consumed throughout the year. DOE defines NZE buildings as “a high-performance building so energy efficient all or most annual energy consumption can be offset with renewable energy.”⁵ 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 defines NZE HVAC applications for stand-alone retail buildings that can maximize HVAC and DHW energy savings.

• Design NZE Stand-Alone Retail Buildings

In terms of total cost, current NZE buildings can be more cost effective than standard efficiency buildings—if designed correctly. To achieve this, 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, 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.⁶

- Installation Cost: \$1,787.5/kWp
- Maintenance Cost: \$19.0/kWp



Figure 5: Solar Panel - LG NeON² Solar Panel (LG Electronics).⁷

⁵ <https://www.energy.gov/eere/buildings/zero-energy-ready-homes>

⁶ <https://www.energy.gov/eere/buildings/zero-energy-ready-homes>

⁷ <https://www.lg.com/us/business/neon%C2%AE-2/lg-lg400n2t-j5>

Table 7: LG Solar PV Specifications.⁸

	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 inch x 1.5748 inch	79.68 inch x 40.31 inch x 1.5748 inch	66.93 inch x 40 inch x 1.5748 inch

⁸ <https://www.lg.com/us/business/solar>

Energy Study Parameters

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

- Weather: 1A Miami, FL; 2A Houston, TX; 3A Atlanta, GA; 3B Los Angeles, CA; 4A New York, NY; 5A Chicago, IL; 6A Minneapolis, MN
- Building: Eight (18) zones, average 51 Tons cooling capacity, DHW (40 gallons, electric)

Table 8: HVAC System Type and Cost Data.

System Type		Climate Zones 3B, 3C AND 4-8	Climate Zones 1-3A
Baseline	Packaged Rooftop	System 3 - PSZ-AC	System 4 - PSZ-HP
	Installation Cost	865 \$/TONS	865 \$/TONS
	Maintenance Cost	0.3 \$/FT ²	0.3 \$/FT ²
	DWH Installation Cost (40 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	1081 \$/TONS	1081 \$/TONS
	Maintenance Cost	0.3 \$/FT ²	0.3 \$/FT ²
	DWH Installation Cost(40 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	1181 \$/TONS	1181 \$/TONS
	Maintenance Cost	0.3 \$/FT ²	0.3 \$/FT ²
	DWH Installation Cost(40 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	1361 \$/TONS	1361 \$/TONS
	Maintenance Cost	0.3 \$/FT ²	0.3 \$/FT ²
	DWH Installation Cost(40 Gallon Water Heater + 40 Gallon Thermal Storage (TS) Tank)	10 \$/GAL	10 \$/GAL

Building Energy and Life Cycle Cost Analysis Study Results

Summary – Building Energy and Energy Cost

The overall HVAC energy cost savings realized with the Multi V system was an average of 55% compared to the ASHRAE Standard 90.1-2013 PSZ system. This energy cost saving increases to an average of 58% when domestic hot water energy is saved through heat recovery (Hydro Kit), which also greatly contributes to lowering the initial investment cost for the NZE building.

Table 9: Annual ASHRAE 90.1-2013 Baseline System Energy and Energy Cost Summary.

Weather Zone		1A	2A	3A	3B	4A	5A	6A	Average
State		FL	TX	GA	CA	NY	IL	MN	
City		Miami	Houston	Atlanta	Los Angeles	New York City	Chicago	Minneapolis	
Thermal Peak Load (MBtu)	Cooling	490	517	467	360	493	486	477	470
	Heating	99	214	263	114	339	376	681	298
	DWH	7	7	8	7	8	9	9	8
HVAC Capacity (tons)	Cooling	52	52	48	38	52	52	64	51
	Heating	59	59	54	43	59	59	72	58
	DWH	0.6	0.6	0.8	0.7	0.8	0.9	0.9	0.8
Energy Consumption (kWh)	Cooling	145,428	123,755	98,358	71,990	80,955	79,035	72,759	96,040
	Heating	961	17,031	39,051	5,578	79,362	97,792	143,377	54,736
	DWH	5,296	5,296	6,119	6,215	6,768	7,317	7,724	6,391
Energy Cost(\$)	Cooling	17,437	14,244	10,524	13,203	13,997	9,634	7,880	12,417
	Heating	68	639	1,799	227	3,222	2,636	4,110	1,814
	DWH	635	610	655	1,140	1,170	892	837	848

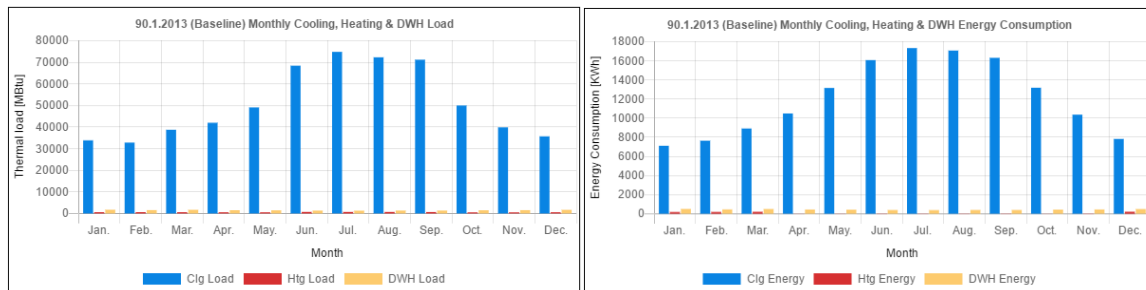
Table 10: HVAC Energy and Energy Cost Saving Summary.

	Baseline	Proposed (1): VRF-HP			Proposed (2): VRF-HR			Proposed (3): VRF-Hydro			
	HVAC Energy Cost (\$)	HVAC Energy Cost (\$)	Saving (\$)	%	HVAC Energy Cost (\$)	Saving (\$)	%	HVAC Energy Cost (\$)	Saving (\$)	%	Payback Period
Miami, FL (1A)	18,139	7,148	10,992	61%	10,992	7,148	39%	6,501	11,639	64%	2 year 4 month
Houston, TX (2A)	15,493	5,960	9,533	62%	9,533	5,960	38%	5,379	10,114	65%	2 year 8 month
Atlanta, GA (3A)	12,978	12,266	4,843	37%	8,135	4,843	37%	8,694	4,284	33%	2 year 10 month
Los Angeles, CA (3B)	14,569	5,976	8,593	59%	5,976	8,594	59%	4,856	9,713	67%	1 year 11 month
New York, NY (4A)	18,390	7,535	10,855	59%	7,533	10,857	59%	6,694	11,696	64%	2 year 3 month
Chicago, IL (5A)	13,162	5,788	7,375	56%	5,786	7,376	56%	5,215	7,948	60%	3 year 4 month
Minneapolis, MN (6A)	12,826	6,314	6,512	51%	6,312	6,514	51%	5,839	6,987	54%	4 year 8 month
Average	15,080	7,284	8,386	55%	7,752	7,327	49%	6,168	8,911	58%	2 year 10 month

1) Results – Miami, FL (1A)

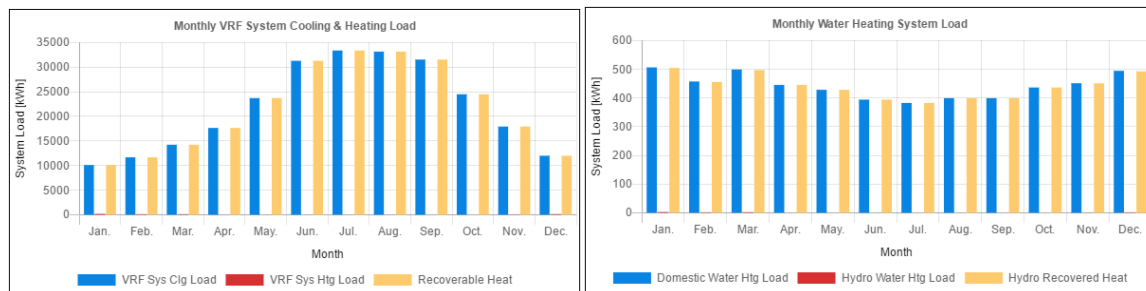
Miami has a tropical climate with hot, humid summers and short, warm winters. Year-to-year variations in solar radiation mean that some years the system will produce more or less energy than the typical year. Based on 30 years of historical weather data for Miami, FL, a fixed (open rack) PV system has a 90% possibility of generating at least 95% of a typical year's production. Similarly, it has a 10% chance of generating more than 104% the typical year's output. Annual HVAC energy consumption and energy cost for Miami, FL (Climate Zone 1A) were as follows:

• Non-NZE Buildings



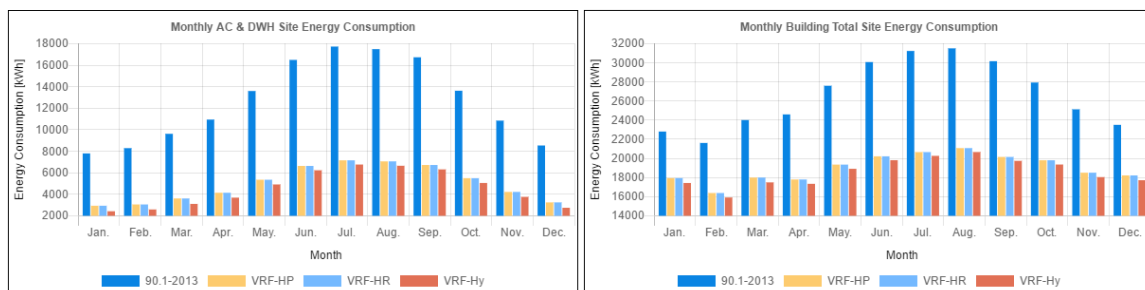
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

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



(b) 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 (PSZ-AC / HP), the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 28.8%. Additionally, the building energy cost savings using the Multi V heat recovery VRF system (Proposed [2]) was 28.8%.

Table 11: 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
Std. 90.1-2013 (Baseline)	319,192	32.8	38,271	68	38,339	0	0
VRF-HP : Proposed [1]	228,082	0.0	27,347	0	27,347	10,992	28.7%
VRF-HR : Proposed [2]	228,082	0.0	27,347	0	27,347	10,992	28.7%
VRF-Hydro	222,685	0.0	26,700	0	26,700	11,639	30.4%

Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 43%. Additionally, the HVAC energy cost savings using the Multi V heat recovery VRF system (Proposed [2]) was 43%. When the Multi V is a heat recovery system using the Hydro Kit with a domestic hot water loop, the HVAC energy cost savings increased by 45.5% compared to the ASHRAE Standard 90.1-2013 baseline (PSZ-AC/HP). Also, the simple payback period was about 2.3 years compared to the ASHRAE Standard 90.1-2013 baseline (PSZ-AC/HP).

Table 12: 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
Std. 90.1-2013 (Baseline)	150,724	32.8	18,072	68	18,139	0	-
VRF-HP : Proposed [1]	59,614	0.0	7,148	0	7,148	10,992	60.6%
VRF-HR : Proposed [2]	59,614	0.0	7,148	0	7,148	10,992	60.6%
VRF-Hydro	54,217	0.0	6,501	0	6,501	11,639	64.2%

Table 13: 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	
Std. 90.1-2013 (Baseline)	45,380	7,423	38,271	45,762	0	-	-
VRF-HP	56,612	7,423	27,347	34,770	10,992	24.0%	1 year 0 month
VRF-HR	61,812	7,423	27,347	34,770	10,992	24.0%	1 year 6 month
VRF-Hydro	71,572	7,423	26,700	34,123	11,639	25.4%	2 year 4 month

• Net Zero Energy (NZE) Buildings

Most NZE buildings can produce energy through use of solar panels (PV). 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 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 14: Selected PV Module Information.

PV Model	LG NeON R	-
Maximum Power	400	Wp
Peak Efficiency	0.205	-
Length of PV	6.6	ft
Width of PV	3.4	ft
Net Area	20.3	ft ²
PV Area	22.3	ft ²
Single PV Installation Area	39.4	ft ²

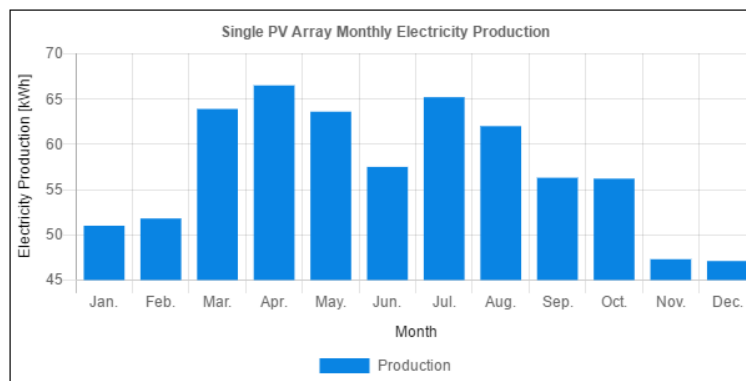


Figure 9: Single PV Array Monthly Electricity Production in Miami, FL.

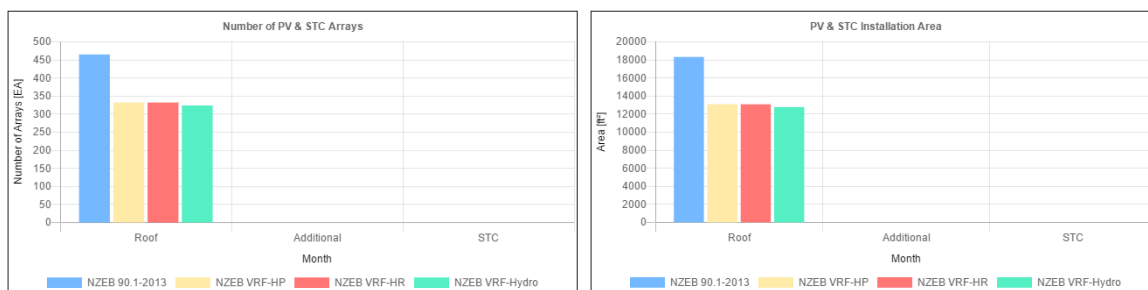


Figure 10: Number of PV Arrays and Required Installation Area in Miami, FL.

According to the energy consumption of the entire building, the LG NeON R PV panels were required to achieve a NZE in an ASHRAE Standard 90.1-2013 building; the number of arrays necessary was 556. The number of arrays required by the Proposed (3) application has been reduced to 387, which is 69.6% of the baseline NZE building.

Table 15: Required PV Module and PV Initial Cost for Achieving NZE: Miami, FL.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	0	0	0	-	-
NZEB 90.1-2013	197.4	556	352,817	100%	-
NZEB VRF-HP	140.9	397	251,833	71.4%	VS NZEB 90.1-2013
NZEB VRF-HR	140.9	397	251,833	71.4%	
NZEB VRF-Hydro	137.4	387	245,578	69.6%	

Table 16: Total Initial Cost to Achieve NZE: Miami, FL.

Case	HVAC Cost (\$)	PV Cost (\$)	Total Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	45,380	0	45,380	-	-
NZEB 90.1-2013	45,380	352,817	398,197	100%	-
NZEB VRF-HP	56,612	251,833	308,445	77.5%	VS NZEB 90.1-2013
NZEB VRF-HR	61,812	251,833	313,645	78.8%	
NZEB VRF-Hydro	71,572	245,578	317,150	79.6%	

As shown in Table 17, the initial cost of \$398,197 and the annual cost of \$11,173 were required to achieve a building based on Standard 90.1-2013 with net energy zero, with an estimated payback period of about 10 year 3 month. By applying Proposed (3) to the NZE Standard 90.1-2013 building, saving 25.4% of building energy, HVAC energy savings of approximately 64.2% can reduce the required PV module installation area by about 30.4%, and thus, the payback period for the NZE building of NZE can be achieved in about 7 year 8 month.

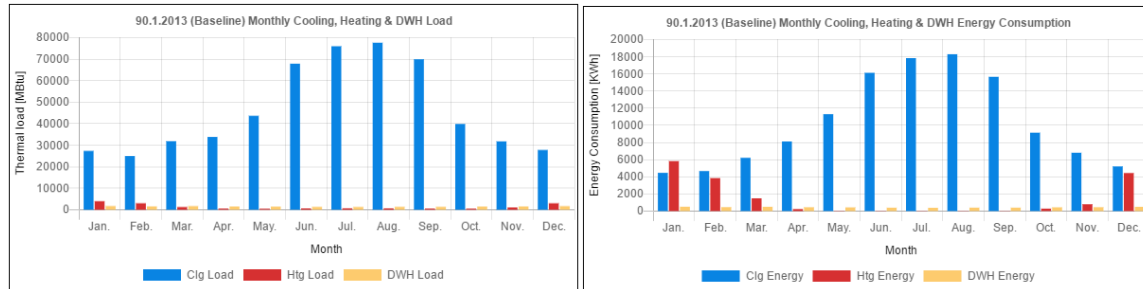
Table 17: Initial and Annual Cost Analysis to Achieve NZE: Miami, FL.

Case	Initial Cost (\$)	Annual Cost (\$)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Std. 90.1-2013 (Baseline)	45,380	7,423	38,339	45,762	0	0	0	-
NZEB 90.1-2013	398,197	11,173	0	11,173	34,589	75.6%	10 year 3 month	-
NZEB VRF-HP	308,445	10,100	0	10,100	35,662	77.9%	7 year 5 month	VS NZEB 90.1-2013
NZEB VRF-HR	313,645	10,100	0	10,100	35,662	77.9%	7 year 6 month	
NZEB VRF-Hydro	317,150	10,033	0	10,033	35,729	78.1%	7 year 8 month	

2) Results – Houston, TX (2A)

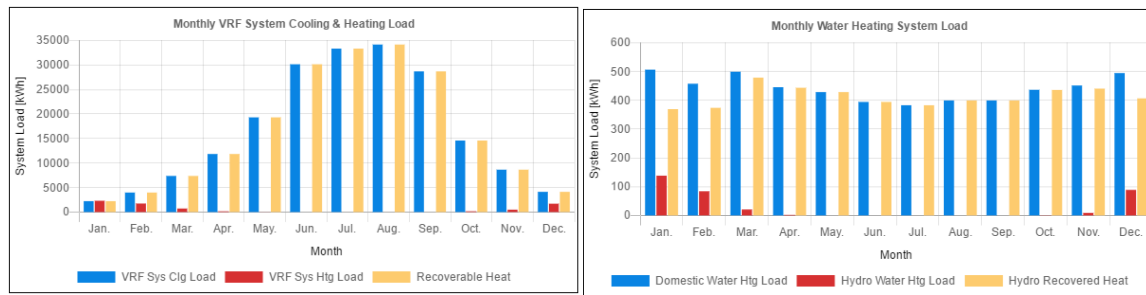
The climate in Houston is categorized as a humid, sub-tropical region, although it is highly affected by tropical regions. Year-to-year variations in solar radiation mean that some years the system will produce more or less energy than the typical year. Based on 30 years of historical weather data for Houston, TX, a fixed (open rack) PV system has a 90% likelihood of generating at least 97% of a typical year's production. Similarly, it has a 10% chance of generating more than 103% the typical year's output. Annual HVAC energy consumption and energy cost for Houston, TX (Climate Zone 2A) were as follows:

• Non-NZE Buildings



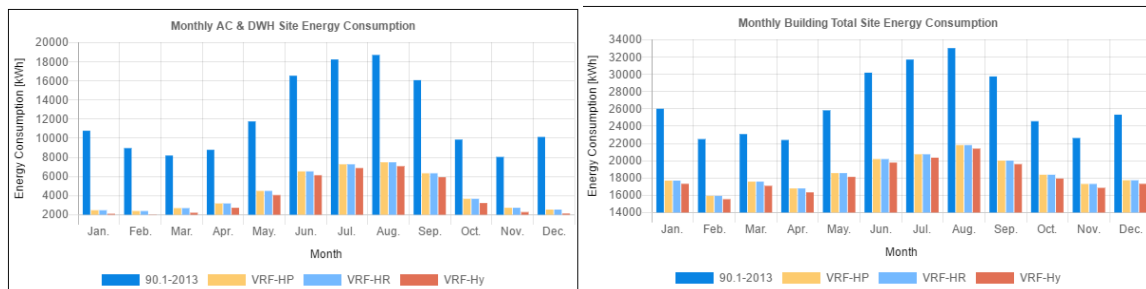
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 11: 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 12: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



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

Figure 13: 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 27.1%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [3]) was 28.8%.

Table 18: Houston Annual Building Energy Consumption and Energy Cost.

System	Annual HVAC Energy		Annual HVAC 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)	299,964	581.1	34,526	639	35,165	0	0
VRF-HP	222,698	0.0	25,633	0	25,633	9,533	27.1%
VRF-HR	222,694	0.0	25,632	0	25,632	9,533	27.1%
VRF-Hydro	217,647	0.0	25,051	0	25,051	10,114	28.8%

Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 61.5%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 61.5%. When Multi V is a heat recovery system using the Hydro Kit with a domestic hot water loop, the HVAC energy cost savings increased by 65.3% compared to the ASHRAE Standard 90.1-2013 baseline (PSZ-AC/HP). The simple payback period was about 2 year 8 month compared to the ASHRAE Standard 90.1-2013 baseline (PSZ-AC/HP).

Table 19: 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
Std. 90.1-2013 (Baseline)	129,051	581.1	14,854	639	15,493	0	-
VRF-HP	51,785	0.0	5,960	0	5,960	9,533	61.5%
VRF-HR	51,780	0.0	5,960	0	5,960	9,533	61.5%
VRF-Hydro	46,734	0.0	5,379	0	5,379	10,114	65.3%

Table 20: 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	
Std. 90.1-2013 (Baseline)	45,380	7,423	34,526	0	42,588	0	-	-
VRF-HP	56,612	7,423	25,633	0	33,056	9,532	22.4%	1 year 3 month
VRF-HR	61,812	7,423	25,633	0	33,056	9,532	22.4%	1 year 9 month
VRF-Hydro	71,572	7,423	25,051	0	32,474	10,114	23.7%	2 year 8 month

- NZE Buildings

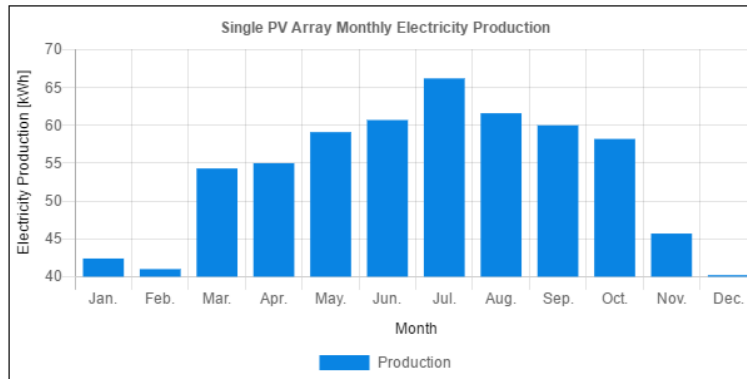


Figure 14: Single PV Array Monthly Electricity Production in Houston, TX.

According to the energy consumption of the entire building, LG NeON R PV panels were required to achieve NZE in an ASHRAE Standard 90.1-2013 building; the number of arrays necessary was 582. The number of arrays required by the Proposed (3) application was reduced to 404, which is 69.4% of the baseline NZE building.

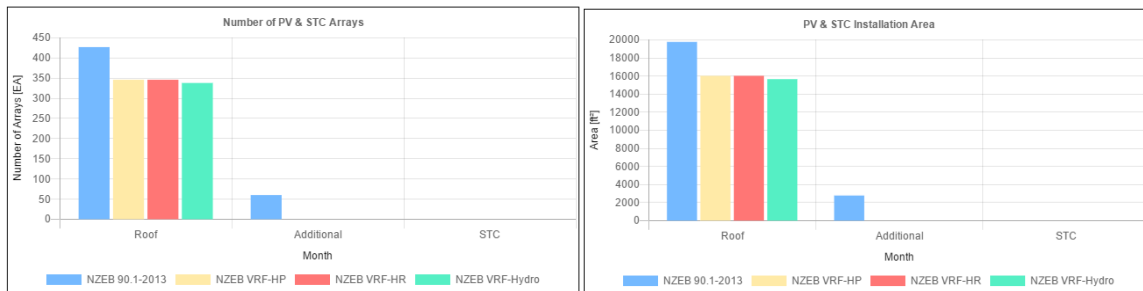


Figure 15: Number of PV Arrays and Required Installation Area in Houston, TX.

Table 21: Required PV Module and PV Initial Cost for Achieving NZE: Houston, TX.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	0	0	0	-	-
NZEB 90.1-2013	206.6	582	369,279	100%	-
NZEB VRF-HP	147	414	262,749	71.2%	VS NZEB 90.1-2013
NZEB VRF-HR	147	414	262,749	71.2%	
NZEB VRF-Hydro	143.4	404	256,314	69.4%	

Table 22: Total Initial Cost to Achieve NZE: Houston, TX.

Case	HVAC Cost (\$)	PV Cost (\$)	Total Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	45,380	0	45,380	-	-
NZEB 90.1-2013	45,380	369,279	414,659	100%	-
NZEB VRF-HP	56,612	262,749	319,361	77.0%	VS NZEB 90.1-2013
NZEB VRF-HR	61,812	262,749	324,561	78.3%	
NZEB VRF-Hydro	71,572	256,314	327,886	79.1%	

As shown in Table 23, the initial cost of \$414,659 and the annual cost of \$11,348 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 year 10 month. By applying the proposed (3) to the NZEB 90.1-2013 building, saving 23.7% of the building energy, i.e. HVAC energy saving 65.3%, can reduce the required PV module installation area by about 30.6%, and thus, the payback period of net zero building achievement can be achieved in about 8 year 9 month.

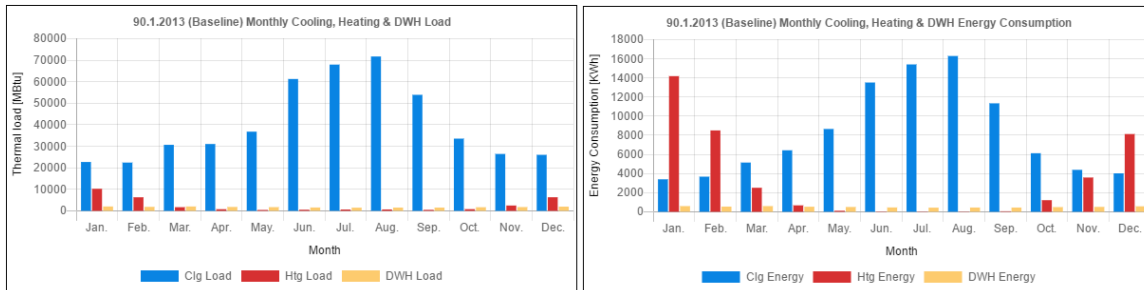
Table 23: Initial and Annual Cost Analysis to Achieve NZE: Houston, TX.

Case	Initial Cost (\$)	Annual Energy Cost (\$)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Std. 90.1-2013(Baseline)	45,380	7,423	35,165	42,588	0	0	0	-
NZEB 90.1-2013	414,659	11,348	0	11,348	31,240	73.4%	11 year 10 month	-
NZEB VRF-HP	319,361	10,215	0	10,215	32,373	76.0%	8 year 5 month	VS NZEB 90.1-2013
NZEB VRF-HR	324,561	10,215	0	10,215	32,373	76.0%	8 year 8 month	
NZEB VRF-Hydro	327,886	10,148	0	10,148	32,440	76.2%	8 year 9 month	

3) Results – Atlanta (3A)

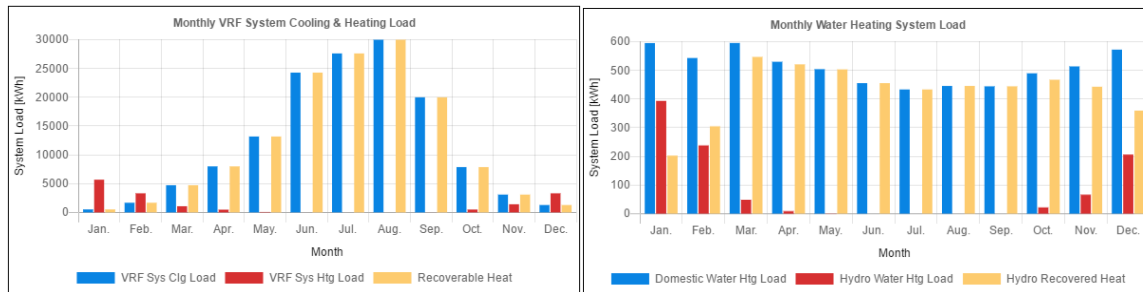
Atlanta is a humid, sub-tropical climate with the typical four seasons and precipitation throughout the year. The summer is hot and humid, there is an average of 48 freezing days in a year, and the temperature rarely drops to 0°F. Year-to-year variations in solar radiation mean that some years the PV system will produce more or less energy than the typical year. Based on 30 years of historical weather data for Atlanta, GA, a fixed (open rack) PV system has a 90% likelihood of generating at least 95% of a typical year's production. Similarly, it has a 10% chance of generating more than 102% the typical year's output. Annual HVAC energy consumption and energy cost for Atlanta, GA (Climate Zone 3A) were as follows:

- **Non-NZE Buildings**



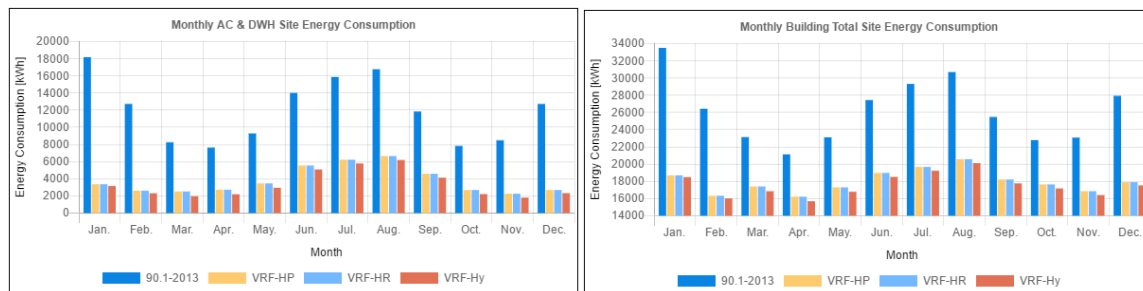
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 16: 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 17: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



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

Figure 18: 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 26.1%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 26.1%.

Table 24: 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
Std. 90.1-2013 (Baseline)	274,961	1,332.5	29,421	1,799	31,220	0	0
VRF-HP	215,750	0.0	23,085	0	23,085	8,135	26.1%
VRF-HR	215,744	0.0	23,085	0	23,085	8,135	26.1%
VRF-Hydro	210,522	0.0	22,526	0	22,526	8,694	27.8%

Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 62.7%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 62.7%. When the Multi V is a heat recovery system using the Hydro Kit with a domestic hot water loop (Proposal [3]), the HVAC energy cost savings increased by 67.0% compared to the ASHRAE Standard 90.1-2013 baseline (PSZ-AC/HP), and the simple payback period was about 2.8 years.

Table 25: 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
Std. 90.1-2013 (Baseline)	104,477	1,332.5	11,179	1,799	12,978	0	-
VRF-HP	45,266	0.0	4,843	0	4,843	8,135	62.7%
VRF-HR	45,260	0.0	4,843	0	4,843	8,135	62.7%
VRF-Hydro	40,038	0.0	4,284	0	4,284	8,694	67.0%

Table 26: 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	
Std. 90.1-2013 (Baseline)	41,920	7,423	29,421	0	38,643	0	-	-
VRF-HP	52,288	7,423	23,085	0	30,508	8,135	21.1%	1 year 4 month
VRF-HR	57,088	7,423	23,085	0	30,508	8,135	21.1%	1 year 11 month
VRF-Hydro	66,128	7,423	22,526	0	29,949	8,694	22.5%	2 year 10 month

- NZE Buildings

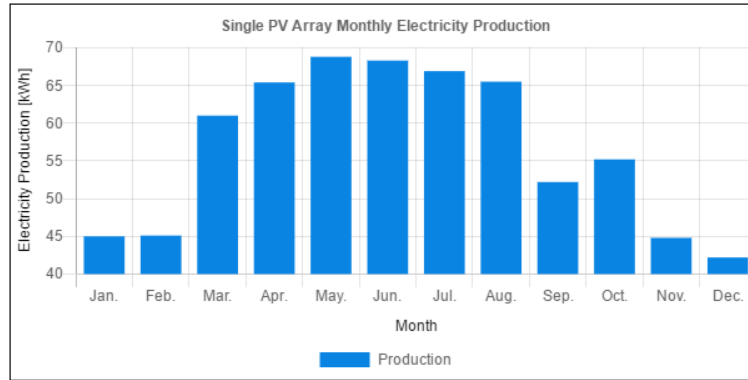


Figure 19: Single PV Array Monthly Electricity Production in Atlanta, GA.

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

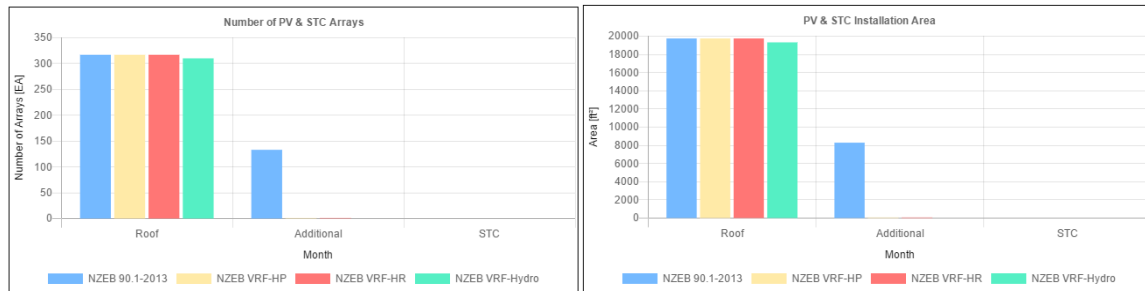


Figure 20: Number of PV Arrays and Required Installation Area in Atlanta, GA.

Table 27: Required PV Module and PV Initial Cost for Achieving NZE: Atlanta, GA.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	0	0	0	-	-
NZEB 90.1-2013	191	538	341,395	100%	-
NZEB VRF-HP	134.9	380	241,121	70.6%	VS NZEB 90.1-2013
NZEB VRF-HR	134.9	380	241,121	70.6%	
NZEB VRF-Hydro	131.4	370	234,865	68.8%	

Table 28: Total Initial Cost to Achieve NZE: Atlanta, GA.

Case	HVAC Cost (\$)	PV Cost (\$)	Total Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	41,920	0	41,920	-	-
NZEB 90.1-2013	41,920	341,395	383,315	100%	-
NZEB VRF-HP	52,288	241,121	293,409	76.5%	VS NZEB 90.1-2013
NZEB VRF-HR	52,288	241,121	293,409	76.5%	
NZEB VRF-Hydro	66,128	234,865	300,993	78.5%	

As shown in Table 29, it was calculated that the initial cost of \$383,315 and the annual cost of \$11,051 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 12 year 5 month. By applying the proposed (3) to the NZEB 90.1-2013 building, saving 22.5% of the building energy, i.e. HVAC energy saving 67%, can reduce the required PV module installation area by about 31.2%, and thus, the payback period of net zero building achievement can be achieved in about 9 years.

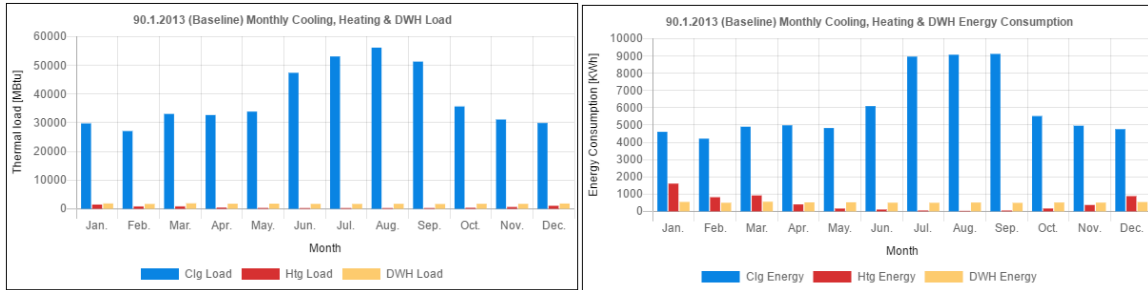
Table 29: Initial and Annual Cost Analysis to Achieve NZE: Atlanta, GA.

Case	Initial Cost (\$)	Annual Energy Cost (\$)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Std. 90.1-2013 (Baseline)	41,920	7,423	31,220	38,643	0	0	0	-
NZEB 90.1-2013	383,315	11,051	0	11,051	27,592	71.4%	12 year 5 month	-
NZEB VRF-HP	293,422	9,986	0	9,986	28,657	74.2%	8 year 10 month	VS NZEB 90.1-2013
NZEB VRF-HR	298,222	9,986	0	9,986	28,657	74.2%	8 year 11 month	
NZEB VRF-Hydro	300,916	9,986	0	9,986	28,657	74.2%	9 year 0 month	

4) Results – Los Angeles (3B)

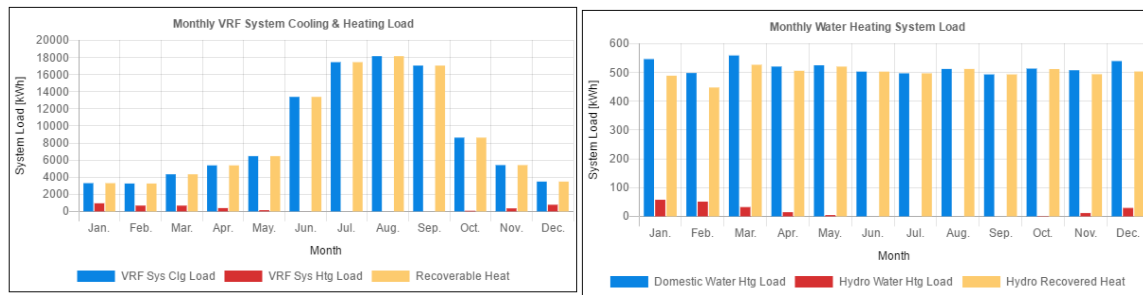
The climate in Los Angeles is classified as Mediterranean, a type of dry sub-tropical climate. It is temperate and mostly dry year round, but characterized by a change of precipitation in the rainy season in dry summer and winter. Year-to-year variations in solar radiation mean that in some years the system will produce more or less energy than the typical year. Based on 30 years of historical weather data for Los Angeles, CA, a fixed (open rack) PV system has a 90% likelihood of generating at least 95% of a typical year's production. Annual HVAC energy consumption and energy cost for Los Angeles, CA (Climate Zone 3B) were as follows:

- **Non-NZE Buildings**



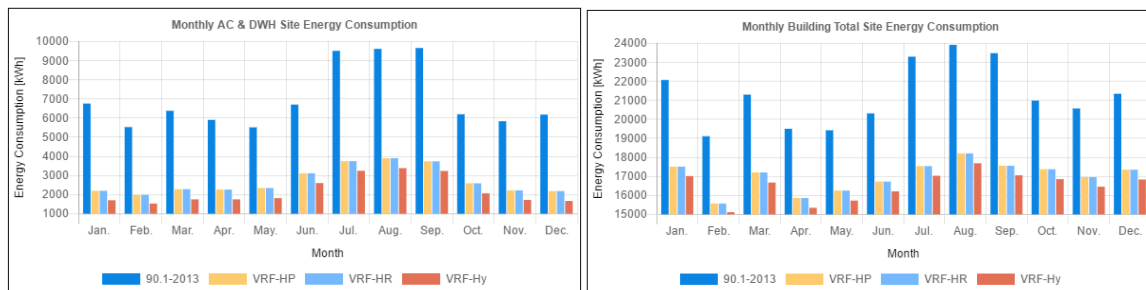
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

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 18.7%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 18.7%.

Table 30: 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
Std. 90.1-2013 (Baseline)	249,763	190.3	45,806	226	46,033	0	0
VRF-HP	204,141	0.0	37,439	0	37,439	8,593	18.7%
VRF-HR	204,140	0.0	37,439	0	37,439	8,594	18.7%
VRF-Hydro	198,038	0.0	36,320	0	36,320	9,713	21.1%

Table 31: 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
Std. 90.1-2013 (Baseline)	78,205	190.3	14,343	226	14,569	0	-
VRF-HP	32,583	0.0	5,976	0	5,976	8,593	59.0%
VRF-HR	32,582	0.0	5,976	0	5,976	8,594	59.0%
VRF-Hydro	26,480	0.0	4,856	0	4,856	9,713	66.7%

Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 59%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 59%. 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 66.7% compared to the ASHRAE Standard 90.1-2013 baseline (PSZ-AC/HP), and the simple payback period was about 1 year 11 month.

Table 32: 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	
Std. 90.1-2013 (Baseline)	31,540	7,423	45,807	227	53,457	0	-	-
VRF-HP	39,316	7,423	37,440	0	44,863	8,594	16.1%	0 year 11 month
VRF-HR	42,916	7,423	37,439	0	44,862	8,595	16.1%	1 year 4 month
VRF-Hydro	49,796	7,423	36,320	0	43,743	9,714	18.2%	1 year 11 month

- **NZE Buildings**

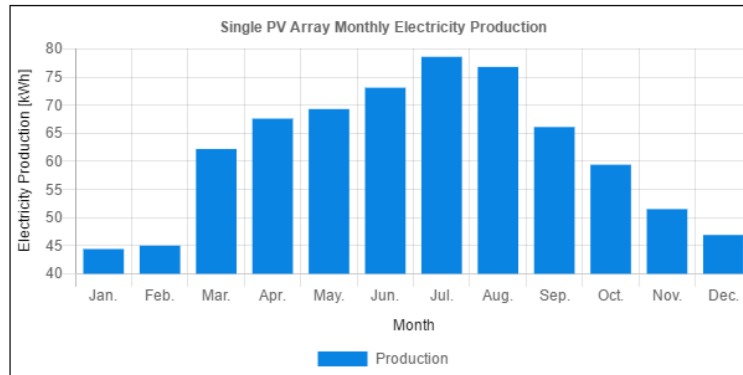


Figure 24: Single PV Array Monthly Electricity Production in Los Angeles, CA.

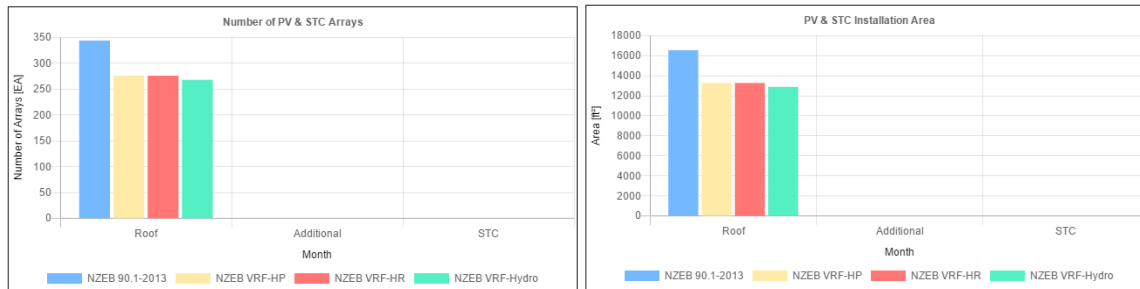


Figure 25: Number of PV Arrays and Required Installation Area in Los Angeles, CA.

According to the energy consumption of the entire building, LG NeON R PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of arrays necessary was 411. The number of arrays required by Proposed (3) application was reduced to 320, which is 77.9% of the baseline NZE building.

Table 33: 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
Std. 90.1-2013 (Baseline)	0	0	0	-	-
NZEB 90.1-2013	145.9	411	260,805	100%	-
NZEB VRF-HP	117.2	330	209,406	80.3%	VS NZEB 90.1-2013
NZEB VRF-HR	117.2	330	209,406	80.3%	
NZEB VRF-Hydro	113.6	320	203,060	77.9%	

Table 34: Total Initial Cost to Achieve NZE: Los Angeles, CA.

Case	HVAC Cost (\$)	PV Cost (\$)	Total Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	31,540	0	31,540	-	-
NZEB 90.1-2013	31,540	260,805	292,345	100%	-
NZEB VRF-HP	39,316	209,406	248,722	85.1%	VS NZEB 90.1-2013
NZEB VRF-HR	42,916	209,406	252,322	86.3%	
NZEB VRF-Hydro	49,796	203,060	252,856	86.5%	

As shown in Table 35, it was calculated that the initial cost of \$31,540 and the annual cost of \$53,457 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. By applying the proposed (3) to the NZEB 90.1-2013 building, saving 18.2% of the building energy, i.e. HVAC energy saving 66.7%, can reduce the required PV module installation area by about 22.1%, and thus, the payback period of net zero building achievement can be achieved in about 5 years.

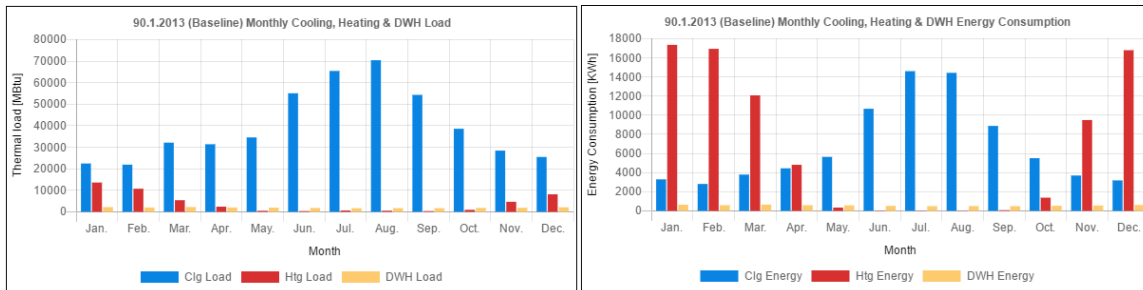
Table 35: Initial and Annual Cost Analysis to Achieve NZE: Los Angeles, CA.

Case	Initial Cost (\$)	Annual Cost (\$)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Std. 90.1-2013 (Baseline)	31,540	7,423	46,034	53,457	0	0	0	-
NZEB 90.1-2013	292,345	10,195	0	10,195	43,262	80.9%	6 year 0 month	-
NZEB VRF-HP	248,722	9,648	0	9,648	43,809	82.0%	4 year 11 month	VS NZEB 90.1-2013
NZEB VRF-HR	252,322	9,648	0	9,648	43,809	82.0%	5 year 0 month	
NZEB VRF-Hydro	252,856	9,581	0	9,581	43,876	82.1%	5 year 0 month	

5) Results – New York (4A)

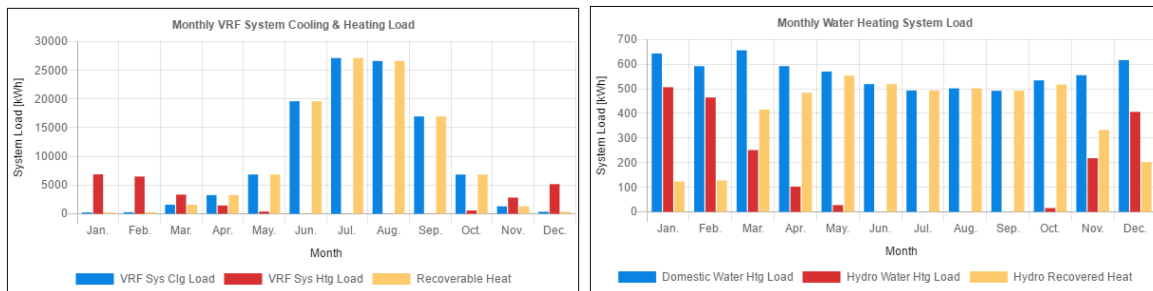
The summer climate in New York City, NY lies in a warm, humid sub-tropical zone. Typical winter temperatures are above the freezing temperatures, but average temperatures drop below zero in January and February. Year-to-year variations in solar radiation mean that for some years, the PV system will produce more or less energy than the typical year. Based on 30 years of historical weather data for New York City, NY a fixed (roof mount) PV system has a 90% likelihood of generating at least 96% of a typical year's production. Similarly, it has a 10% chance of generating more than 103% the typical year's output. Annual HVAC energy consumption and energy cost for New York City, NY (Climate Zone 4A) were as follows:

- **Non-NZE Buildings**



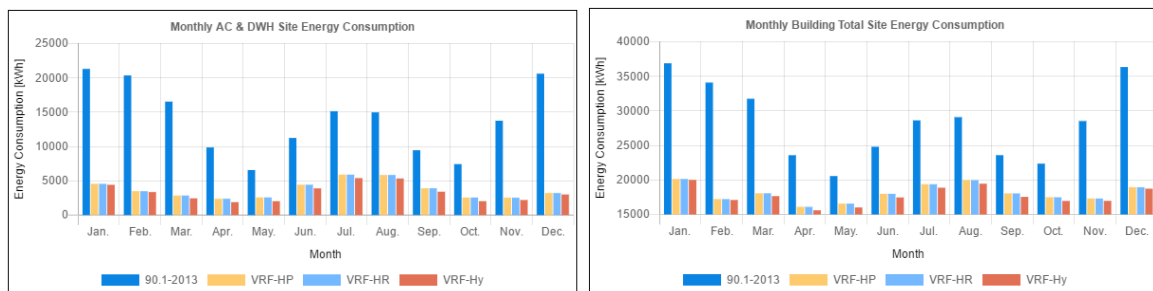
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 26: 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 27: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



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

Figure 28: 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 22.5%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 22.5%.

Table 36: 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)	260,731	2,707.9	45,080	3,222	48,303	0	0
VRF-HP	216,407	0	37,417	0	37,417	10,855	22.5%
VRF-HR	216,394	0	37,415	0	37,415	10,857	22.5%
VRF-Hydro	211,542	0	36,576	0	36,576	11,696	24.2%

Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 59%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]), was 59%. 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 63.6% compared to the ASHRAE Standard 90.1-2013 baseline (PSZ-AC/HP), and the simple payback period was about 2.2 years.

Table 37: 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
Std. 90.1-2013 (Baseline)	87,723	2,707.9	15,167	3,222	18,390	0	-
VRF-HP	43,398	0	7,504	0	7,504	10,855	59.0%
VRF-HR	43,386	0	7,501	0	7,501	10,857	59.0%
VRF-Hydro	38,534	0	6,663	0	6,663	11,696	63.6%

Table 38: 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	
Std. 90.1-2013 (Baseline)	45,380	7,423	45,080	3,222	55,725	0	-	-
VRF-HP	56,612	7,423	37,417	0	44,871	10,854	19.5%	1 year 0 month
VRF-HR	61,812	7,423	37,417	0	44,871	10,854	19.5%	1 year 6 month
VRF-Hydro	71,572	7,423	36,576	0	44,030	11,695	21.0%	2 year 3 month

- NZE Buildings

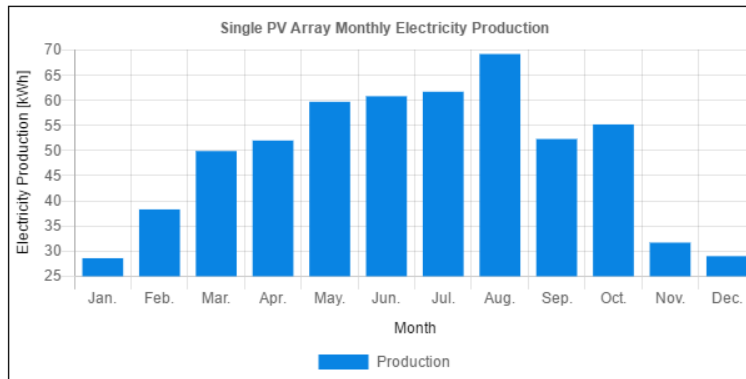


Figure 29: Single PV Array Monthly Electricity Production in New York City, NY.

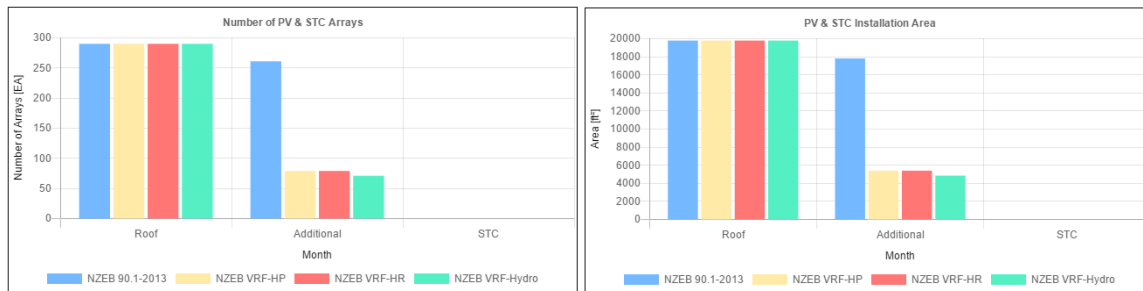


Figure 30: Number of PV Arrays and Required Installation Area in New York City, NY.

According to the energy consumption of the entire building, LG NeON R PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building; the number of arrays necessary was 659. The number of arrays required by the Proposed (3) application was reduced to 431, which is 65.4% of the baseline NZE building.

Table 39: 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
Std. 90.1-2013 (Baseline)	0	0	0	-	-
NZEB 90.1-2013	233.9	659	418,177	100%	-
NZEB VRF-HP	156.6	441	279,842	66.9%	VS NZEB 90.1-2013
NZEB VRF-HR	156.6	441	279,842	66.9%	
NZEB VRF-Hydro	153	431	273,496	65.4%	

Table 40: Total Initial Cost to Achieve NZE: New York City, NY.

Case	HVAC Cost (\$)	PV Cost (\$)	Total Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	45,380	0	45,380	-	-
NZEB 90.1-2013	45,380	418,177	463,557	100%	-
NZEB VRF-HP	56,612	279,842	336,454	72.6%	VS NZEB 90.1-2013
NZEB VRF-HR	61,812	279,842	341,654	73.7%	
NZEB VRF-Hydro	71,572	273,496	345,068	74.4%	

As shown in Table 41, it was calculated that the initial cost of \$277,500 and the annual cost of \$9,921 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 5.6 years. By applying the proposed (3) to the NZEB 90.1-2013 building, saving 24.2% of the building energy, i.e. HVAC energy saving 63.6%, can reduce the required PV module installation area by about 34.6%, and thus, the payback period of net zero building achievement can be achieved in about 6 year 8 month.

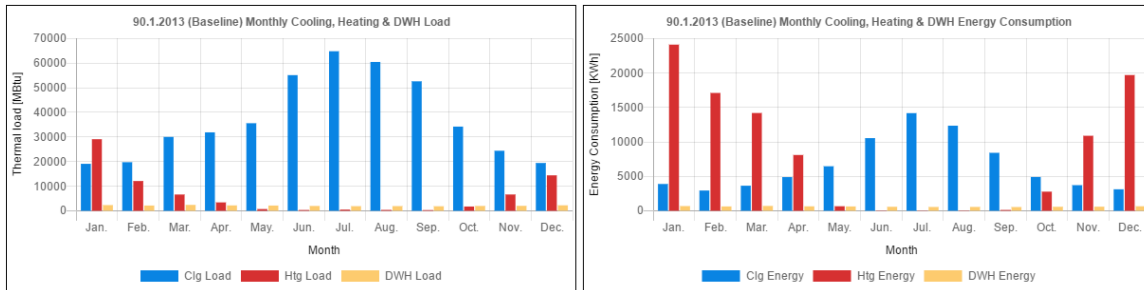
Table 41: Initial and Annual Cost Analysis to Achieve NZE: New York City, NY.

Case	Initial Cost (\$)	Annual Cost (\$)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio		
Std. 90.1-2013 (Baseline)	45,380	7,423	48,302	55,725	0	0	0	-
NZEB 90.1-2013	463,557	11,868	0	11,868	43,857	78.7%	9 year 6 month	-
NZEB VRF-HP	336,454	10,397	0	10,397	45,328	81.3%	6 year 5 month	VS NZEB 90.1-2013
NZEB VRF-HR	341,654	10,397	0	10,397	45,328	81.3%	6 year 6 month	
NZEB VRF-Hydro	345,068	10,330	0	10,330	45,395	81.5%	6 year 8 month	

6) Results – Chicago (5A)

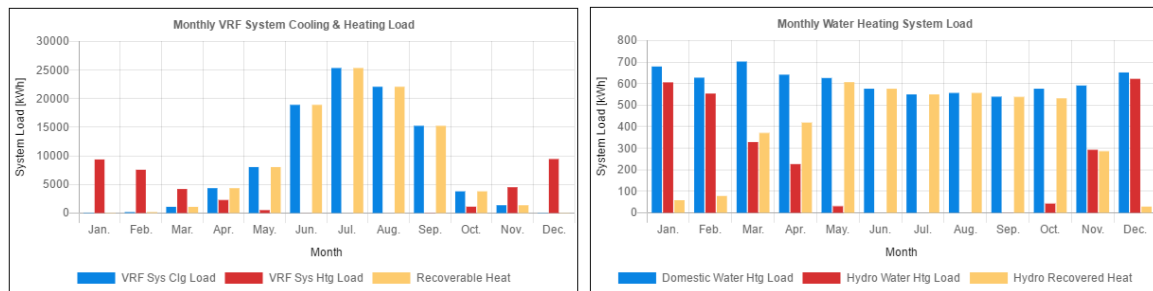
Chicago's weather is categorized as continental humid, and with all four seasons distinctly represented: wet springs; hot, humid summers; mild autumns; and cold winters. Year-to-year variations in solar radiation mean that some years the system will produce more or less energy than the typical year. Based on 30 years of historical weather data for Chicago, IL, a fixed (open rack) PV system has a 90% likelihood of generating at least 96% of a typical year's production. Similarly, it has a 10% chance of generating more than 104% the typical year's output. Annual HVAC energy consumption and energy cost for Chicago, IL (Climate Zone 5A) were as follows:

• Non-NZE Buildings



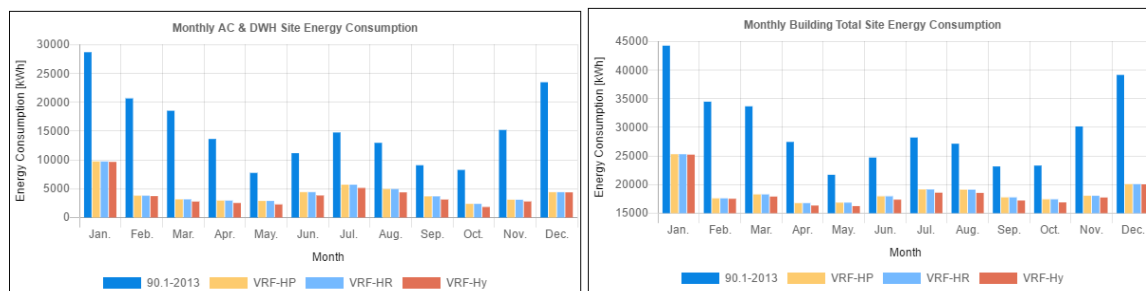
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

Figure 31: 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 32: Monthly Proposed Cooling, Heating, and DHW Loads and Energy Consumptions.



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

Figure 33: 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 21.5%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 21.5%.

Table 42: 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
Std. 90.1-2013 (Baseline)	259,666.4	3,336.8	31,653	2,636	34,289	0	0
VRF-HP	219,787.0	0	26,792	0	26,792	7,375	21.5%
VRF-HR	219,775.8	0	26,791	0	26,791	7,376	21.5%
VRF-Hydro	215,086.3	0	26,219	0	26,219	7,948	23.2%

Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 56.0%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 56.0%. 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 60.4% compared to the ASHRAE Standard 90.1-2013 baseline (PSZ-AC/HP), and the simple payback period was about 3.3 years.

Table 43: 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
Std. 90.1-2013 (Baseline)	86,352	3,336.8	10,526	2,636	13,162	0	-
VRF-HP	46,473	0	5,665	0	5,665	7,375	56.0%
VRF-HR	46,461	0	5,664	0	5,664	7,376	56.0%
VRF-Hydro	41,772	0	5,092	0	5,092	7,948	60.4%

Table 44: 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	
Std. 90.1-2013 (Baseline)	45,380	7,423	31,653	2,636	41,712	0	-	-
VRF-HP	56,612	7,423	26,792	0	34,338	7,374	17.7%	1 year 6 month
VRF-HR	61,812	7,423	26,791	0	34,337	7,375	17.7%	2 year 3 month
VRF-Hydro	71,572	7,423	26,219	0	33,765	7,947	19.1%	3 year 4 month

- NZE Buildings

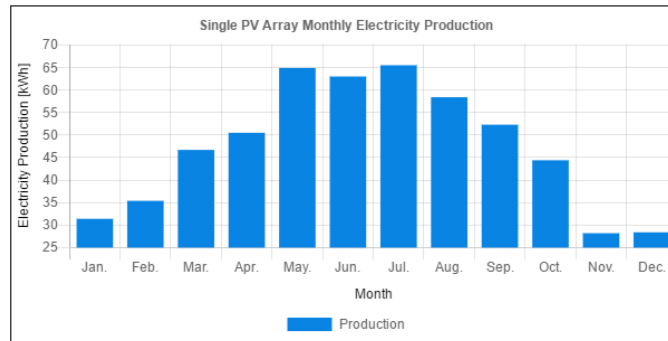


Figure 34: Single PV Array Monthly Electricity Production in Chicago, IL.

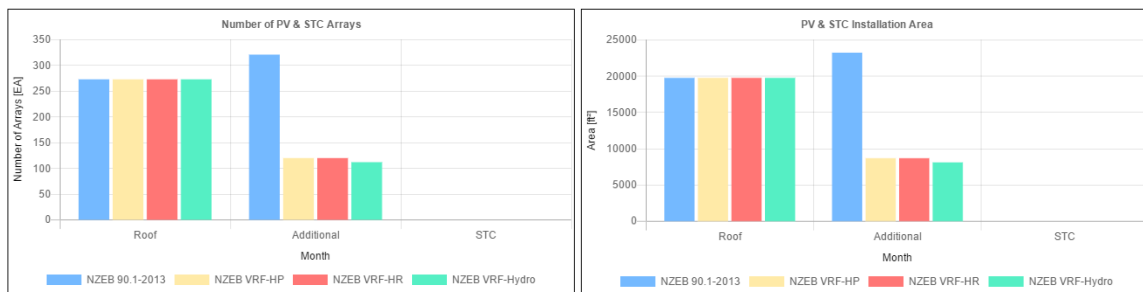


Figure 35: Number of PV Arrays and Required Installation Area in Chicago, IL.

According to the energy consumption of the entire building, LG NeON R PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building, and the number of arrays necessary was 710. The number of arrays required by the Proposal (3) application was been reduced to 460, which is 64.8% of the baseline NZE building.

Table 45: Required PV Module and PV Initial Cost for Achieving NZE: Chicago, IL.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	0	0	0	-	-
NZEB 90.1-2013	252	710	450,539	100%	-
NZEB VRF-HP	166.8	470	298,244	66.2%	VS NZEB 90.1-2013
NZEB VRF-HR	166.8	470	298,244	66.2%	
NZEB VRF-Hydro	163.3	460	291,899	64.8%	

Table 46: Total Initial Cost to Achieve NZE: Chicago, IL.

Case	HVAC Cost (\$)	PV Cost (\$)	Total Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	45,380	0	45,380	-	-
NZEB 90.1-2013	45,380	450,539	495,919	100%	-
NZEB VRF-HP	56,612	298,244	354,856	71.6%	VS NZEB 90.1-2013
NZEB VRF-HR	61,812	298,244	360,056	72.6%	
NZEB VRF-Hydro	71,572	291,899	363,471	73.3%	

As shown in Table 47, it was calculated that the initial cost of \$495,919 and the annual cost of \$12,212 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 15 year 4 month. By applying the proposed (3) to the NZEB 90.1-2013 building, saving 25.2% of the building energy, i.e. HVAC energy saving 60.4%, can reduce the required PV module installation area by about 35.2%, and thus, the payback period of net zero building achievement can be achieved in about 10 year 3 month.

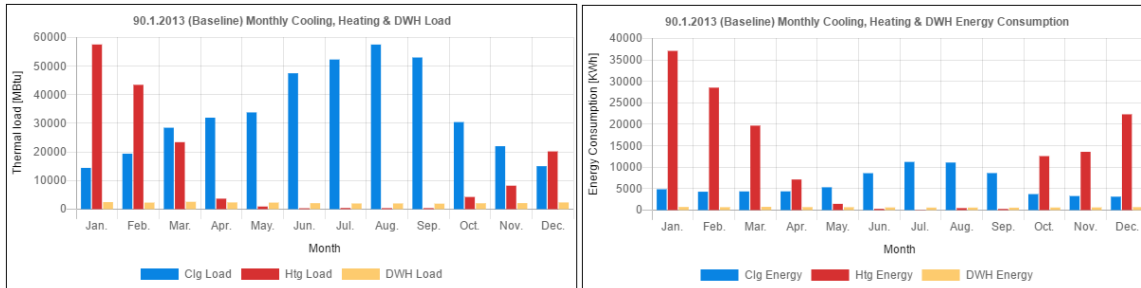
Table 47: Initial and Annual Cost Analysis to Achieve NZE: Chicago, IL.

Case	Initial Cost (\$)	Annual Cost (\$)					Payback Period	Note
		Maintenance	Energy Cost	Total Cost	Saving	Saving Ratio (%)		
Std. 90.1-2013 (Baseline)	45,380	7,423	34,289	41,712	0	0	0	-
NZEB 90.1-2013	495,919	12,212	0	12,212	29,500	70.7%	15 year 4 month	-
NZEB VRF-HP	354,856	10,593	0	10,593	31,119	74.6%	9 year 11 month	VS NZEB 90.1-2013
NZEB VRF-HR	360,056	10,593	0	10,593	31,119	74.6%	10 year 2 month	
NZEB VRF-Hydro	363,471	10,525	0	10,525	31,187	74.8%	10 year 3 month	

7) Results – Minneapolis (6A)

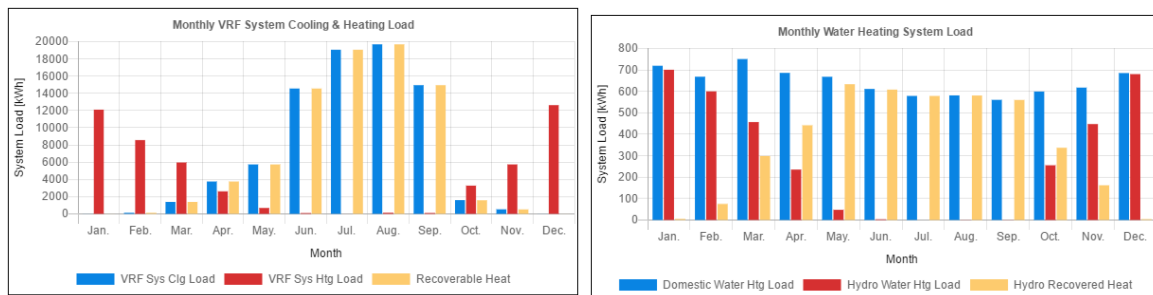
In Minneapolis, the summers are warm and wet; the winters are freezing, snowy, and windy; and it is partly cloudy year round. During the course of the year, the temperature typically varies from 9°F to 83°F and is rarely below -11°F or above 92°F. Based on 30 years of historical weather data for Minnesota, a fixed (open rack) PV system has a 90% likelihood of generating at least 95% of a typical year's production. Similarly, it has a 10% chance of generating more than 102% the typical year's output. Annual HVAC energy consumption and energy cost for Minneapolis, MN (Climate Zone 6A) were as follows:

• Non-NZE Buildings



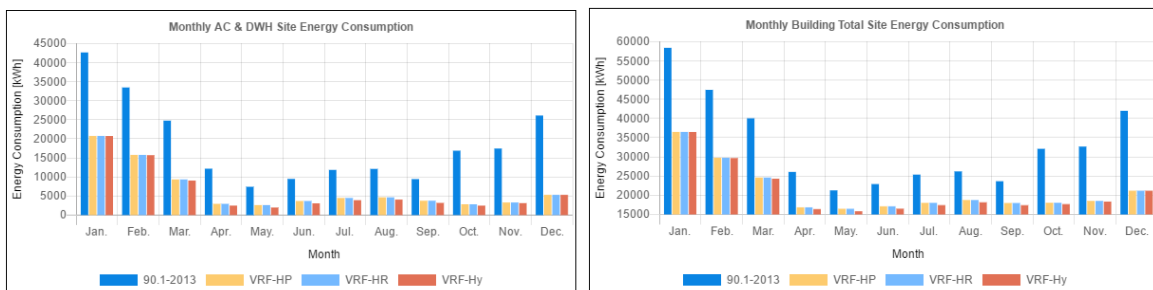
(a) Monthly Cooling, Heating, and DHW Loads. (b) Monthly Cooling, Heating, and DHW Energy Consumptions.

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 Standards 90.1-2013 baseline (PSZ-AC / HP), the building energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 20.5%. Additionally, the building energy cost savings using the heat recovery VRF system (Proposed [2]) was 20.5%.

Table 48: 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
Std. 90.1-2013 (Baseline)	254,844.2	4,892.2	27,600	4,110	31,710.0	0	0
VRF-HP	225,009.4	0	24,369	0	24,369	6,513.0	20.5%
VRF-HR	224,995.7	0	24,367	0	24,367	6,515.0	20.5%
VRF-Hydro	220,629.2	0	23,894	0	23,894	6,988.0	22.0%

Compared to ASHRAE Standard 90.1-2013 baseline (PSZ-AC / HP), the HVAC + DHW energy cost savings using the Multi V heat pump VRF system (Proposed [1]) was 50.8%. Additionally, the HVAC energy cost savings using the heat recovery VRF system (Proposed [2]) was 50.8%. 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 54.5% compared to the ASHRAE 90.1-2013 Standard baseline (PSZ-AC/HP), and the simple payback period was about 4 year 8 month.

Table 49: 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
Std. 90.1-2013 (Baseline)	80,483	4,892.2	8,716	4,110	12,826	0	-
VRF-HP	50,648	986.2	5,485	0	5,485	6,512	50.8%
VRF-HR	50,634	986.2	5,484	0	5,484	6,514	50.8%
VRF-Hydro	46,268	986.2	5,011	0	5,011	6,987	54.5%

Table 50: 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	
Std. 90.1-2013 (Baseline)	55,760	7,423	27,600	4,110	39,133	0	-	-
VRF-HP	69,584	7,423	24,369	0	32,620	6,513	16.6%	2 year 2 month
VRF-HR	75,984	7,423	24,367	0	32,618	6,515	16.6%	3 year 2 month
VRF-Hydro	87,904	7,423	23,894	0	32,145	6,988	17.9%	4 year 8 month

- NZE Buildings

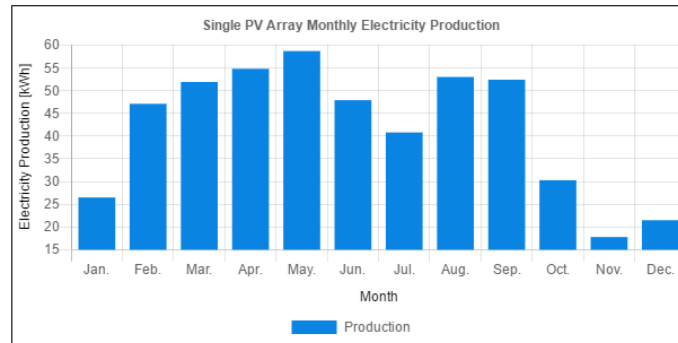


Figure 39: Single PV Array Monthly Electricity Production in Minneapolis, MN.

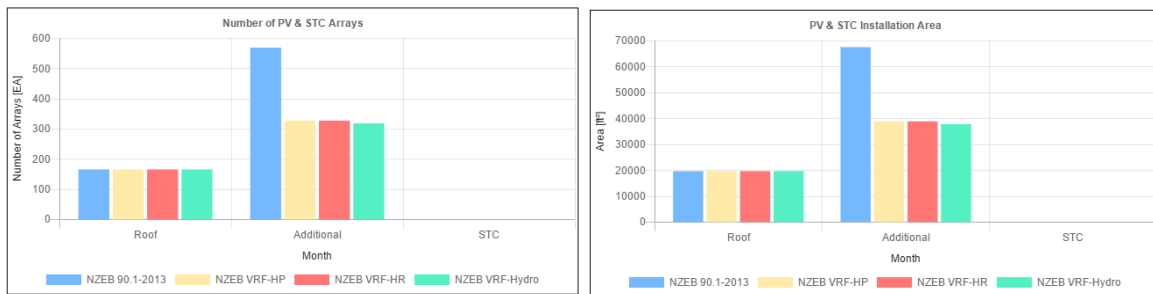


Figure 40: Number of PV Arrays and Required Installation Area in Minneapolis, MN.

According to the energy consumption of the entire building, LG NeON R PV panels were required to achieve NZE in the ASHRAE Standard 90.1-2013 building, and the number of arrays necessary was 879. The number of arrays required by the Proposed (3) was reduced to 580, which is 66% of the baseline NZE building.

Table 51: Required PV Module and PV Initial Cost for Achieving NZE: Minneapolis, MN.

Case	Capacity (kWp)	Number of Arrays (EA)	Initial Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	0	0	0	-	-
NZEB 90.1-2013	312	879	557,780	100%	-
NZEB VRF-HP	209.8	591	375,026	67.2%	VS NZEB 90.1-2013
NZEB VRF-HR	209.8	591	375,026	67.2%	
NZEB VRF-Hydro	205.9	580	368,046	66.0%	

Table 52: Total Initial Cost to Achieve NZE: Minneapolis, MN.

Case	HVAC Cost (\$)	PV Cost (\$)	Total Cost (\$)	Cost Ratio	Note
Std. 90.1-2013 (Baseline)	55,760	0	55,760	-	-
NZEB 90.1-2013	55,760	557,780	613,540	100%	-
NZEB VRF-HP	69,584	375,026	444,610	72.5%	VS NZEB 90.1-2013
NZEB VRF-HR	75,984	375,026	451,010	73.5%	
NZEB VRF-Hydro	87,904	368,046	455,950	74.3%	

As shown in Table 53, it was calculated that the initial cost of \$613,540 and the annual cost of \$13,352 were required to achieve a building based on 90.1-2013 with net zero, and the payback period was estimated to take about 21 year 8 month. By applying the proposed (3) to the NZEB 90.1-2013 building, saving 29.0% of the building energy, i.e. HVAC energy saving 54.5%, can reduce the required PV module installation area by about 34.0%, and thus, the payback period of net zero building achievement can be achieved in about 14 year 5 month.

Table 53: 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 (%)		
Std. 90.1-2013 (Baseline)	55,760	7,423	31,710	39,133	0	0	0	-
NZEB 90.1-2013	613,540	13,352	0	13,352	25,781	65.9%	21 year 8 month	-
NZEB VRF-HP	444,610	11,409	0	11,409	27,724	70.8%	14 year 0 month	VS NZEB 90.1-2013
NZEB VRF-HR	451,010	11,409	0	11,409	27,724	70.8%	14 year 3 month	
NZEB VRF-Hydro	455,950	11,335	0	11,335	27,798	71.0%	14 year 5 month	

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