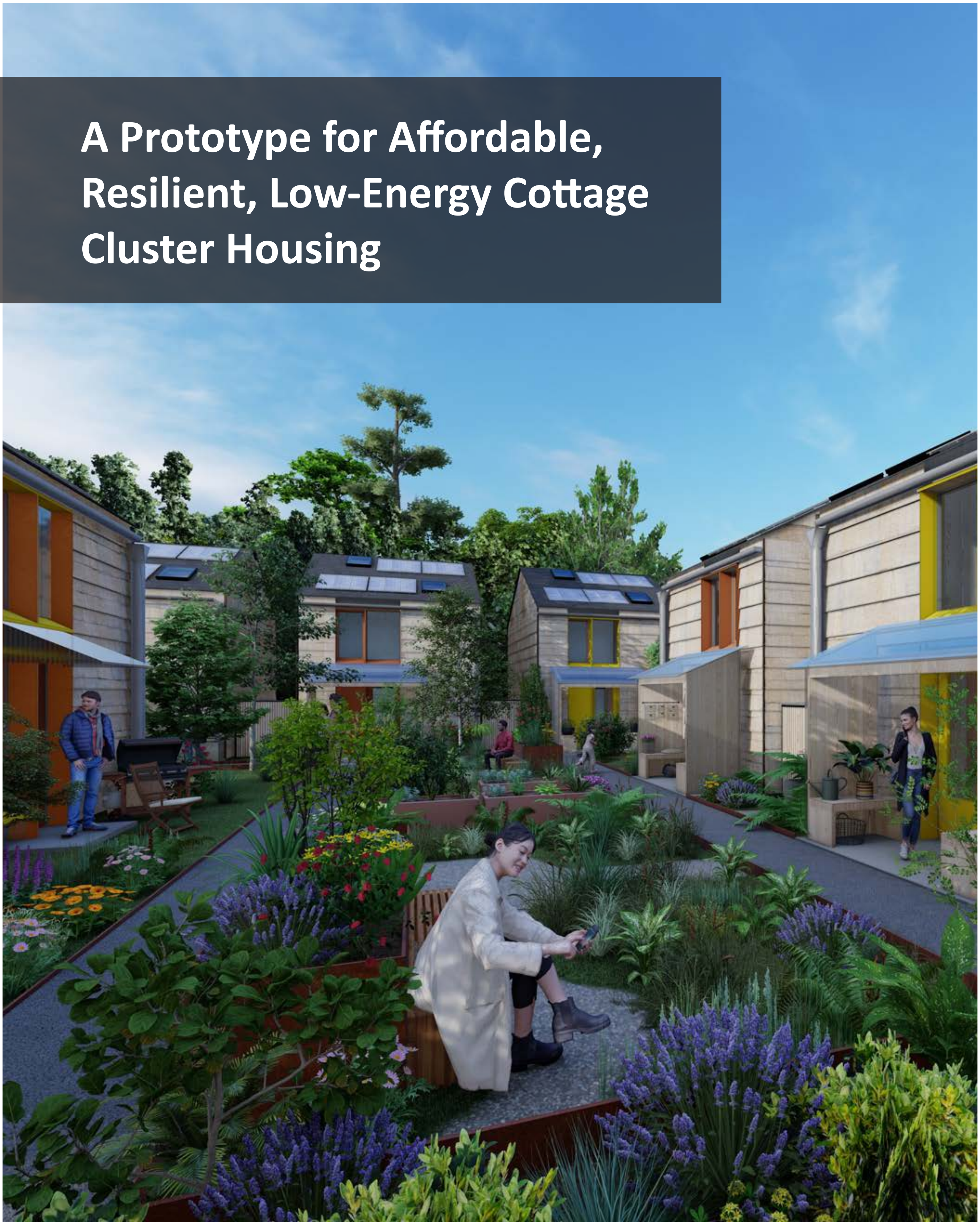
A Prototype for Affordable, Resilient, Low-Energy Cottage Cluster Housing



AUTHORS AND ACKNOWLEDGEMENTS

The research was led by Jessy Ledesma, of HomeWork Development, as part of an Energy Trust Net Zero Fellowship. The real estate development team is led by HomeWork Development, with support from Sister City under their multi-site Shortstack development collaboration, and from Wild Hair Development. All three firms are female-owned developers focused on building new models for attainable housing in the Portland metro region.

- Jessy Ledesma,
  Founder and Principal of HomeWork Development (Net Zero Fellow)
- Anna Mackay,
  Founder and Principal of Sister City
- Jennifer Dillan,
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A team from the University of Oregon Department of Architecture Energy Studies in Buildings Laboratory prepared the initial site energy and HVAC concepts, energy model, MPP window design, MPP window mock-up and performance testing that comprises the bulk of the research conducted for the Net Zero Fellowship. Thank you to:

- Mark Fretz (PI)
- Alen Mahic
- Dale Northcutt
- Simone O'Halloran (concept renderings)
- Judith Sheine (Co-PI)
- Jason Stenson

PAE Engineers conducted an initial feasibility assessment of the research and provided valuable input on mechanical, electrical and plumbing system design, as well as solar microgrid sizing and cost information. Thank you to:

- Craig Collins
- Andrew Comstock
- Karina Hershberg
- Erica Ross

TallWood Design Institute provided valuable initial design research and input related to prototyping the mass timber homes. Thank you to:

- Mark Gerig
- Phill Mann
- Iain Macdonald
- Judith Sheine

Energy Design provided initial solar photovoltaic design and Elemental Energy provided an in-depth solar photovoltaic feasibility analysis and siting design. Thank you to:

- Vince McClellan, Energy Design
- Zach Parrot, Elemental Energy

DISCLAIMER

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CONFLICT OF INTEREST STATEMENT FOR MARK FRETZ

I receive research funding from Shortstack Housing, LLC. and HomeWork Development to research and develop prototypical 2-bed and 3-bed panelized modular mass timber housing units. Shortstack Housing, LLC. may use a vacant lot I own with my spouse to use as a location for a development employing prototype units developed from this research. The sponsored project research funds would be used to inform the development of the prototype, but my property would only be used as a model for costs and code considerations. No actual work from the sponsored project would be done on my property.

DEFINITIONS

Solar microgrid:
While the technical definition of a solar microgrid often refers to a small-scale power grid that can operate independently or collaboratively with other power grids (usually a public utility), for this project the term refers to a central, inter-connected community solar photovoltaic (solar PV) system.

Workforce affordable:
For the purposes of this research, workforce affordable is defined as housing affordable to households earning 60%–100% area median income (AMI), although the broader definition often scales up to 120% AMI.

Area median income levels projected for 2023 include the below household income limits and anticipated for-sale prices for a 2-bedroom cottage cluster home. This table assumes a community land trust model, which ensures long-term affordability via a limited-equity approach, wherein a land trust facilitates all home sales to income-qualified buyers.

Affordability Level	Anticipated 2023 Household Income (1–3 people)	Affordable Purchase Price (2-bedroom condo)
60%–80% AMI	\$60,400–\$77,600	\$220,000
80%–100% AMI	\$86,200–\$97,000	\$323,000

Mass timber/mass plywood panels:
Mass timber construction, in contrast to light-frame wood construction, is built using a category of engineered wood products typically made of large, solid wood panels, columns or beams, often manufactured off site for load-bearing wall, floor and roof construction. The research conducted for this project focuses on the use of mass plywood panels (MPP) constructed with density-grade wood veneers that are glued and pressed together, creating large-format wood panels that can be manufactured in thickness of 1" increments to depths up to 24".

Development sites:
The research conducted for this project includes prototype cottage cluster homes designed across two middle housing-zoned development sites in the City of Milwaukie. Two adjacent properties are located along 36th Avenue (“36th Avenue site”) and one property is located along Harvey Street (“Harvey Street site”). By utilizing actual development parcels, the team can translate the energy analysis research into a real estate development feasibility analysis.

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1.0 EXECUTIVE SUMMARY

OVERVIEW

This research, which is part of an Energy Trust Net Zero Fellowship, seeks to prototype workforce housing at a "cottage cluster," utilizing mass timber panels and solar microgrids to meet community energy, affordability and resilience goals. The analysis focuses on the Milwaukie Courtyard Housing Project, a development of 25–35 for-sale workforce housing units across multiple properties in Milwaukie, Oregon.

APPROACH

This research was conducted in partnership with the University of Oregon Energy Studies in Buildings Laboratory, which led the technical analysis. Funding came from Energy Trust of Oregon. The research analysis includes:

- An energy model of a prototypical mass timber-panelized single-family home with an all-electric monobloc heat pump system configured either individually for each unit or as a district strategy.
- A physical mock-up of a higher-performance window that includes infiltration testing and thermal imaging.
- A courtyard "cluster" housing solar analysis that preserves existing tree canopy on three pilot testing sites in Milwaukie, Oregon.
- A cost and affordability analysis of solar cluster microgrids.
- Development feasibility analysis.

FINDINGS

- Combining mass plywood panels (MPP) and innovative window assembly with community solar electrical production and centralized hydronic HVAC and hot-water systems greatly increases energy efficiency compared to a more typical construction strategy.
- The solar installation provides 62%–66% of energy requirements. A two-story cluster housing site design optimizes the solar-to-energy usage ratio more efficiently than taller (3–4 story) buildings or those with individual unit arrays.
- The projected net cost is financially feasible for the model delivering units affordable up to 100% area median income (AMI), but will require additional subsidy for the model delivering units affordable up to 80% AMI.

From a development feasibility standpoint, this research has shown great potential for improving energy efficiency for workforce affordable housing, as well as for long-term operational savings for homeowners. The combination of MPP and innovative window assembly, with community solar PV production and centralized hydronic HVAC and hot-water systems, results in a significantly more energy-efficient project when compared to a typical construction strategy.

2.0
INTRODUCTION

2.0 INTRODUCTION

Our society is facing a set of converging challenges. Climate change—with its associated health impacts—social inequalities, homelessness, lack of access to healthcare, an aging population, unaffordable housing, and the after-effects of the COVID-19 pandemic are all affecting the well-being of individuals, communities and our planet.

The Milwaukie Courtyard Housing Project (MCHP) is a proposed systematic response to these challenges through the innovative use of panelized mass plywood panel (MPP) wood products in single-family residential construction, in combination with new urban cluster housing infill development and infrastructure models. Higher-density courtyard infill housing of small individual or paired units can provide an alternative to multifamily developments in traditional single-family neighborhoods, or what is called “workforce housing” (with an affordability of 80%–120% of AMI).

By working to meet net-zero energy goals, the MCHP homes are designed to be more energy efficient, have significantly less embodied carbon than light wood frame assemblies, and be affordable to middle-income families. The MPP panelized designs are optimized for aesthetics, affordability, energy efficiency, resilience and biophilic benefits of wood.

This new approach to residential construction seeks to decrease land costs per unit, reduce travel distances to work and play (thus, lowered transportation carbon emissions and cost savings), and provide shared ‘grid-enhancing’ solar microgrid energy and water infrastructure. This infrastructure will provide benefits to the larger grid during normal conditions while being capable of sustaining operations within the courtyard “cluster” during grid-disrupting events.

The courtyard cluster model is intended to be large enough to take advantage of economies of scale but small enough to facilitate construction without requiring significant municipal investment. On-site infrastructure is intended to increase the resiliency of water and energy resources while reducing lifetime operational costs.

The Milwaukie Courtyard Housing Project brings an affordable, replicable, mass timber, small-plex solution to an overpriced housing market. The research and development team hopes to demonstrate that this approach is affordable over time and can increase access to resilient clean energy and water resources in underserved communities that are increasingly exposed to the adverse impacts of climate change.

The project addresses overlapping issues that are designed to benefit the end users, including Energy Trust customers: smart densification, sustainable building, and below market-rate housing.

Figure 1: Neighborhood context for Milwaukie, Oregon demonstration project. Sites indicated in yellow.

2.1 ANALYSIS GOALS

This research intends to reduce the cost of net-zero energy construction in the residential sector—a primary barrier to deploying net-zero construction at scale without substantial subsidy—by examining the use of a new construction technology in the residential market, MPP, to create a higher-performing thermal envelope. The improved envelope is more monolithic than stick-frame construction and is coupled with energy-efficient heat pump technology to thermally condition a high-mass floor slab. The panelized wall assemblies facilitate a novel window integration that seeks to increase the energy performance and aesthetics of affordable off-the-shelf windows while maintaining simplicity to reduce construction costs.

Moreover, the new panelized construction technology is deployed as distributed multifamily units in urban infill site configurations of "clustered" courtyard housing. This creates opportunities where the units could share solar energy while balancing loads across the site and larger grid, and simultaneously preserving existing tree canopy. The buildings themselves will serve as thermal storage, facilitating proactive strategies for optimizing when and how energy is consumed on site. The goal of this research is to create net-zero residential construction that can be produced and delivered affordably, targeting the workforce segment of the housing market.

The research scope includes:

1. An energy model of a prototypical MPP panelized single-family house with slab-on-grade, and an all-electric heat pump system configured either individually for each unit or as a district strategy across the entire site.
2. A physical mockup of a frameless MPP higher-performance window that includes infiltration testing and thermal imaging.
3. A courtyard "cluster" housing solar analysis that preserves existing tree canopy on three pilot testing sites in Milwaukie, Oregon.
4. A cost and affordability analysis of solar cluster microgrids.

3.0

TECHNICAL ANALYSIS

3.0 TECHNICAL ANALYSIS

3.1 ENERGY MODEL

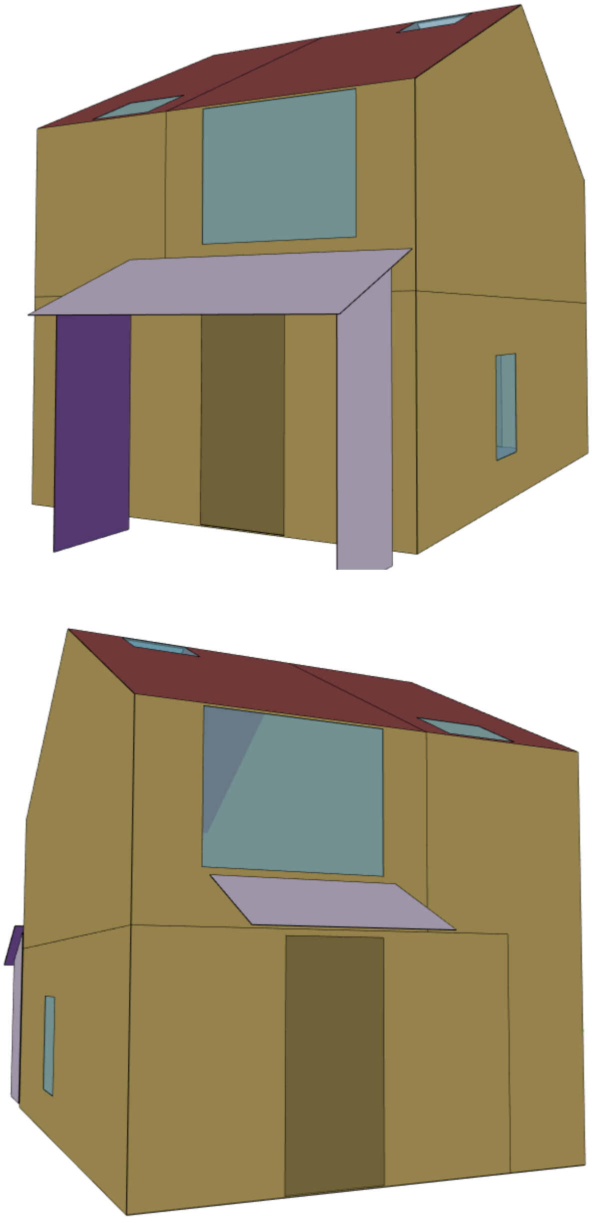
This energy analysis is based on a combination of Honeybee 1.4.0 (via Grasshopper and Rhinoceros 7) and OpenStudio 3.3.0, both of which rely on EnergyPlus 9.6.0 for the annual energy calculations. The MPP model geometry is based on the most recent design documents, as shown in Figure 2, while the model performance is reflective of the Department of Energy (DOE) Zero Energy Ready Homes (ZERH) standard, which is summarized in Table 1. The model is currently set with a packaged air-to-air heat pump HVAC system as baseline. The team is exploring system options, including a district heat pump and hot water strategy to serve multiple units.

The simulated results show an EUI of 17.1 kBtu/ft^2 for the packaged heat pump baseline. The three radiant slab HVAC schemes show EUI values of 25.3 kBtu/ft^2 for the single unit, 23.3 kBtu/ft^2 for a 15-unit district scheme and 23.3 kBtu/ft^2 for a 21-unit district scheme. The majority of energy consumption attributed to heating and interior equipment, as shown in Figures 3.1 through 3.4. To break this down further, the monthly energy consumption by each end use is shown in Figures 4, 7, 8 and 9. The monthly peak energy demand is shown in Figure 7 for the baseline only. The monthly district heating for the hot water service system is shown in Figure 8 for the baseline only.

Scheduling

The baseline model relies on established schedules that make up the DOE reference models and prototype residential models as developed by the Pacific Northwest National Laboratory (PNNL). The mid-rise apartment and single-family models are functionally the closest match to the MPP house and courtyard cluster, and allow us to base our assumptions on existing generalized modeling data.

Figure 2: OpenStudio model of MPP geometry

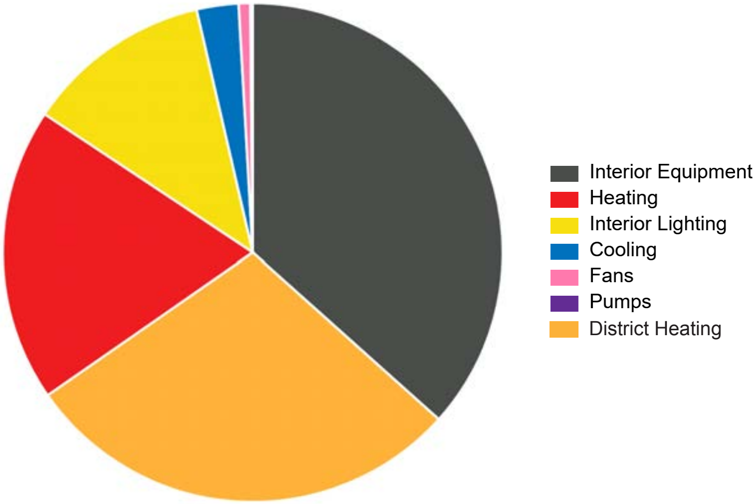


3.1 ENERGY MODEL

Table 1: DOE ZERH performance inputs

	Component	Input
Envelope	Slab Edge Perimeter	R-10 W/ 2-ft. Vertical Depth (F-0.540)
	Wall Insulation—Above Grade	R-20 (U-0.060)
	Windows	U-0.27/SHGC 0.30
	Exterior Doors	U-0.32
	Flat Ceilings	R-49 (U-0.021)
Mechanical Components	Split Heat Pump (Electric)	HSPF 10.0
	Split Cooling (Electric)	13 SEER
	Heating Set Point	71°F
	Cooling Set Point	76°F
	Thermostat	Programmable
	Water Heater (Electric)	EF = 2.0
	HW Pipe Insulation	None
	Air Sealing	2.5 & 3.0 ACH@50 Pa
	Ventilation Type	Balanced
	Ventilation Quantity/Time	62 cfm 24 hr/day
	Ventilation Fan Energy	52 W
Lighting	Interior Lighting	80% LED. 20% FL + CFL.
	Exterior Lighting	
Equipment	2-in-1 Washer/Dryer	16 W ENERGY STAR
	Dishwasher	13 W ENERGY STAR
	Refrigerator	12 W ENERGY STAR
	Misc. Plug Loads	0.23 W/ft^2

Figure 3.1: Annual energy end-use breakdown for packaged heat pump baseline



3.1 ENERGY MODEL

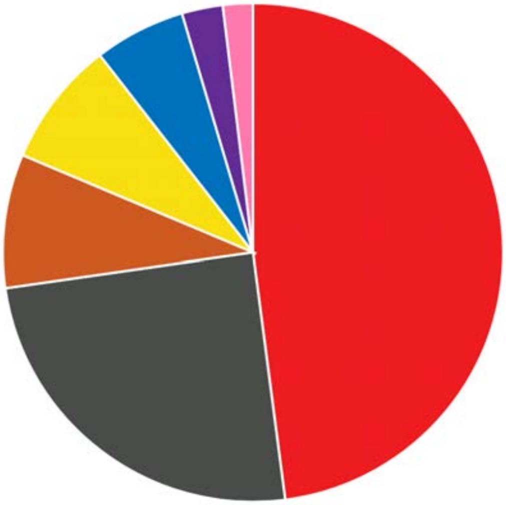


Figure 3.2: Annual energy end-use breakdown for single-unit district HVAC scheme

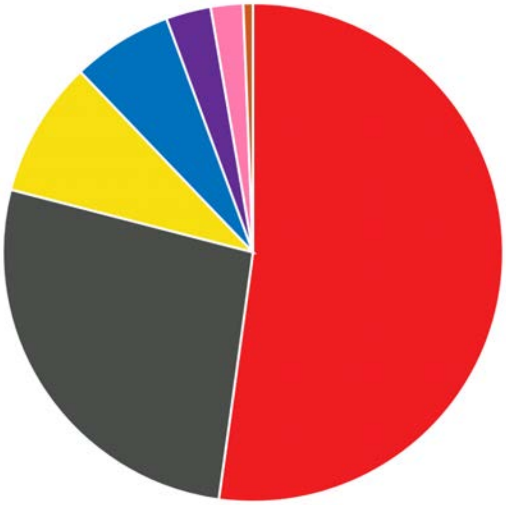


Figure 3.3: Annual energy end-use breakdown for 15-unit district HVAC scheme

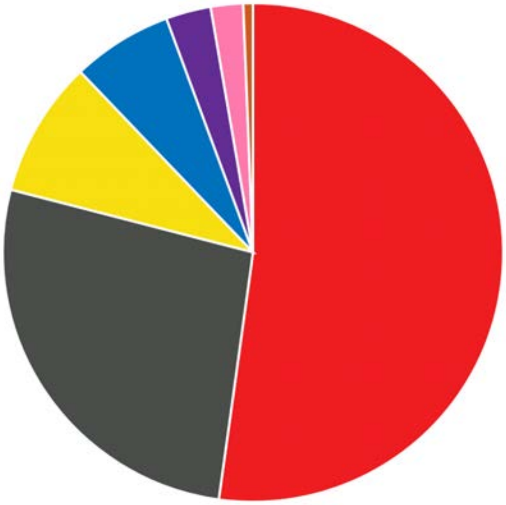


Figure 3.4: Annual energy end-use breakdown for 21-unit district HVAC scheme

3.1 ENERGY MODEL

Figure 4: Monthly overview of energy consumption by end uses for packaged heat pump baseline

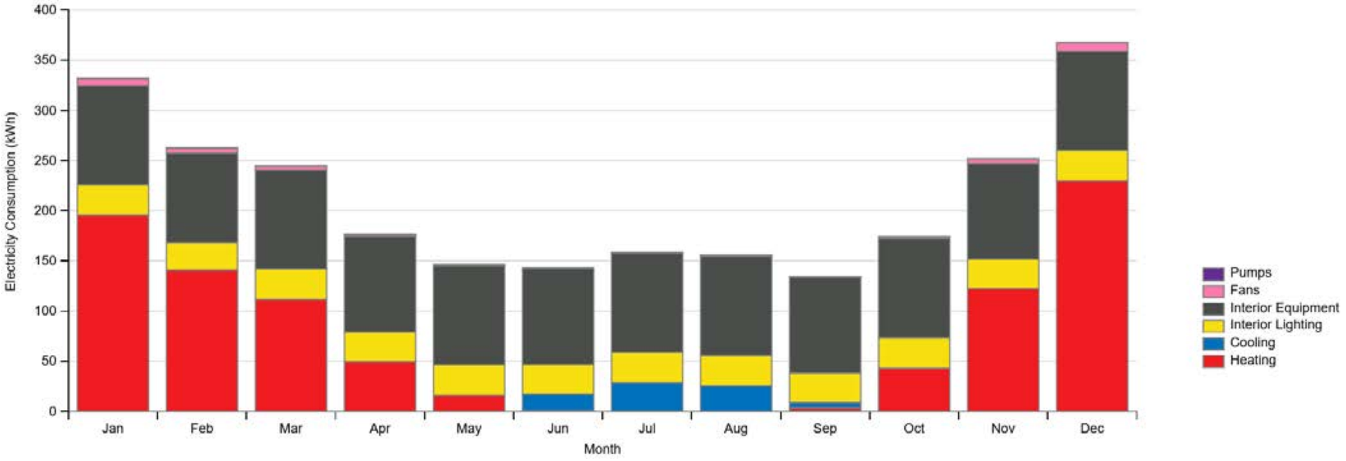


Figure 5: Monthly energy peak demand by end uses for packaged heat pump baseline

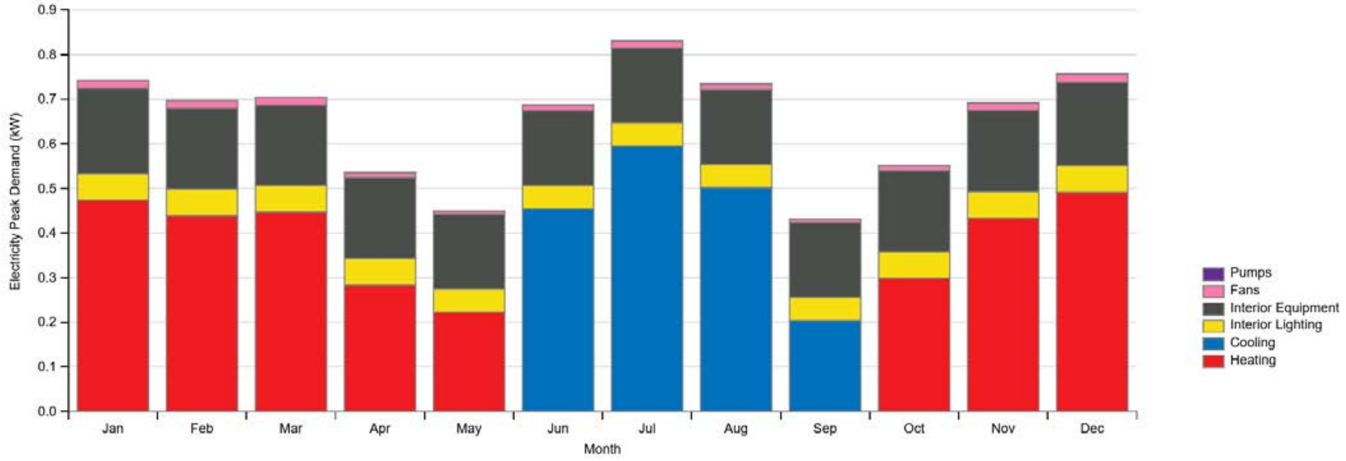
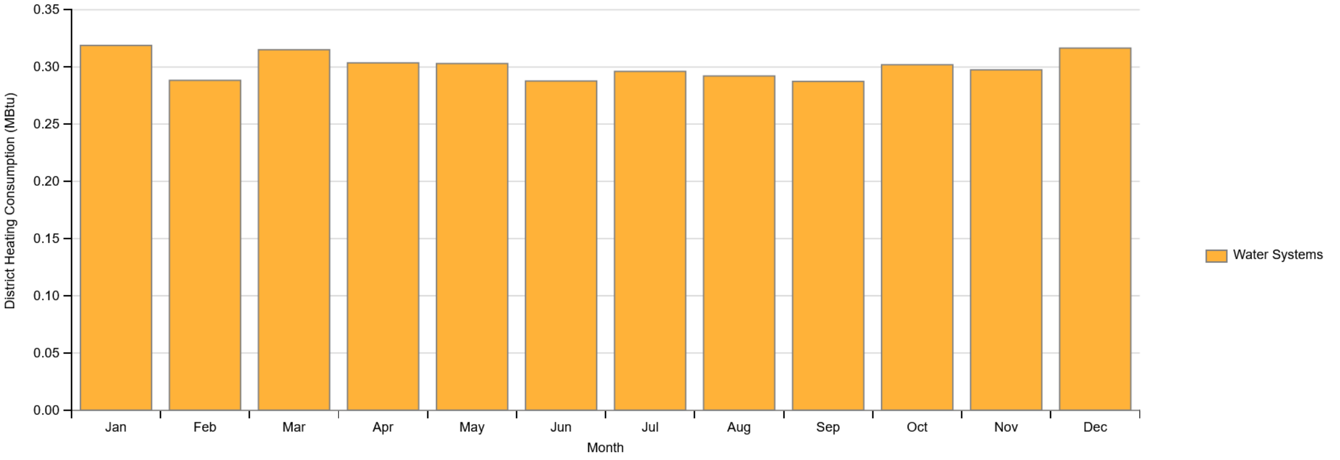


Figure 6: Monthly district heating energy consumption demand by end uses for packaged heat pump baseline



3.1 ENERGY MODEL

Figure 7: Monthly overview of energy consumption by end uses for single-unit radiant slab HVAC scheme

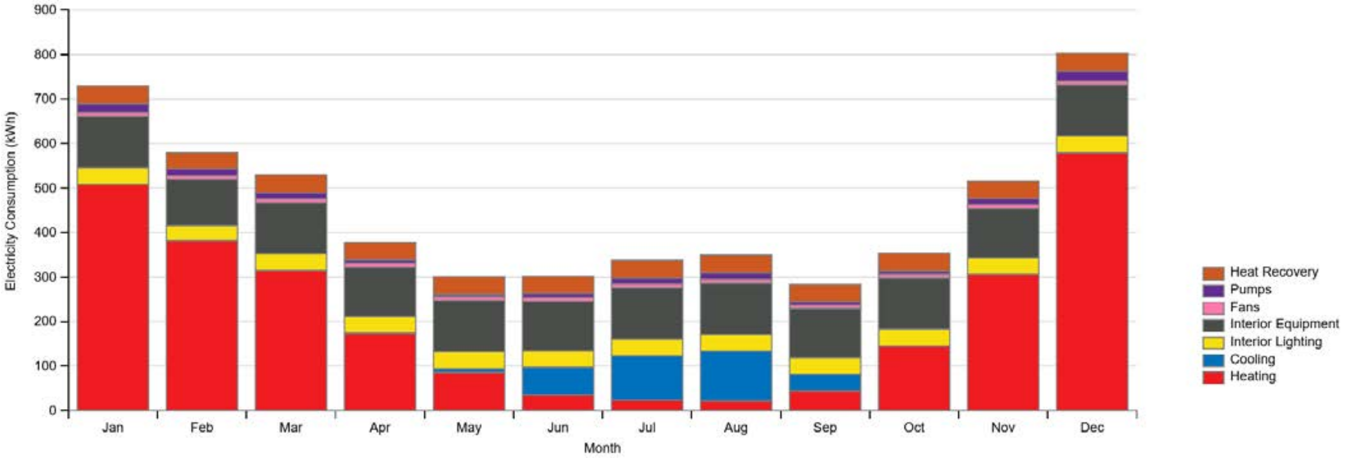


Figure 8: Monthly energy peak demand by end uses for 15-unit radiant slab HVAC scheme

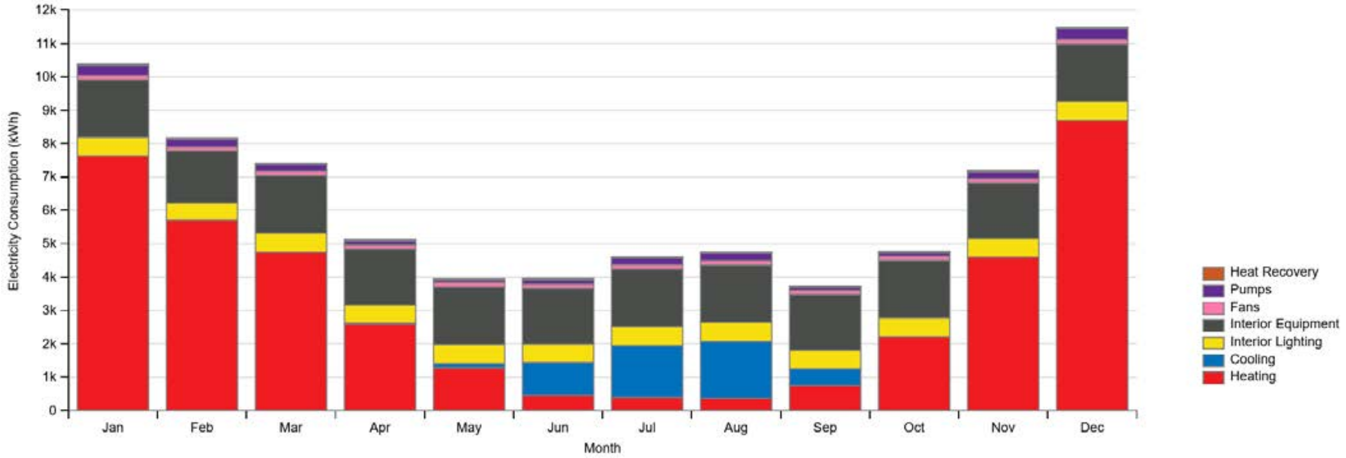


Figure 9: Monthly district heating energy consumption demand by end uses for 21-unit radiant slab HVAC scheme

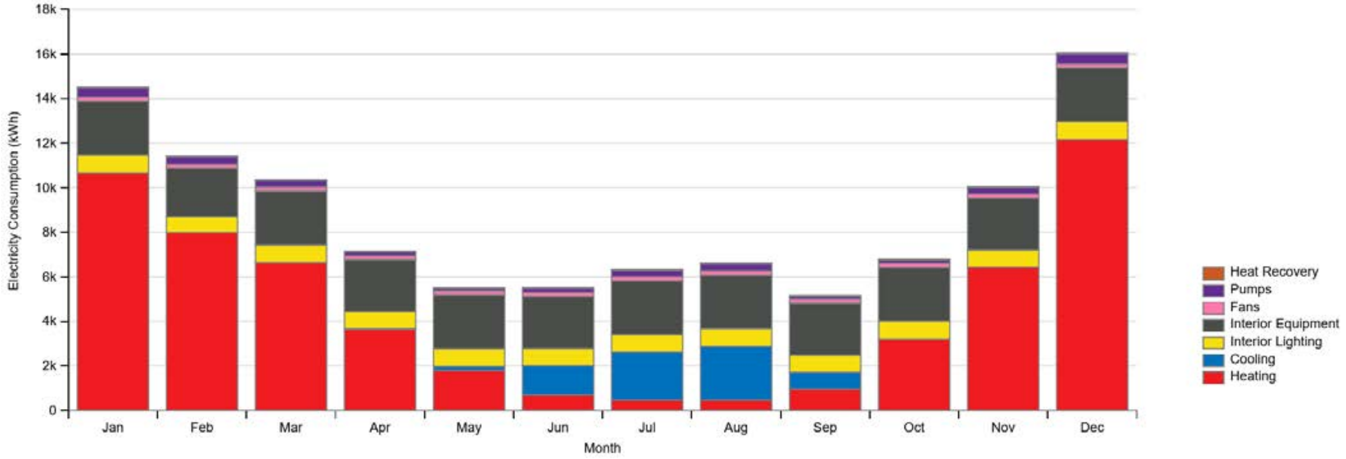


Figure 10 shows an example of a daily occupancy schedule that is used as part of the DOE/PNNL prototype single-family dwelling. This is a solid starting point that we can update with data that is more specific to the MPP housing project as it becomes available in the future.

Natural Ventilation

There are two ventilation strategies that have been implemented. The first is natural ventilation that simulates cross-ventilation on the first floor with the operation of the front and back doors, while on the second floor the operable windows and skylights in each bedroom allow for stack ventilation. The indoor temperature ranges from 71.6°F to 80.6°F. Additionally, a balanced mechanical ventilation system is included to supplement the DOE ZERH ventilation requirements, as summarized in Table 1.

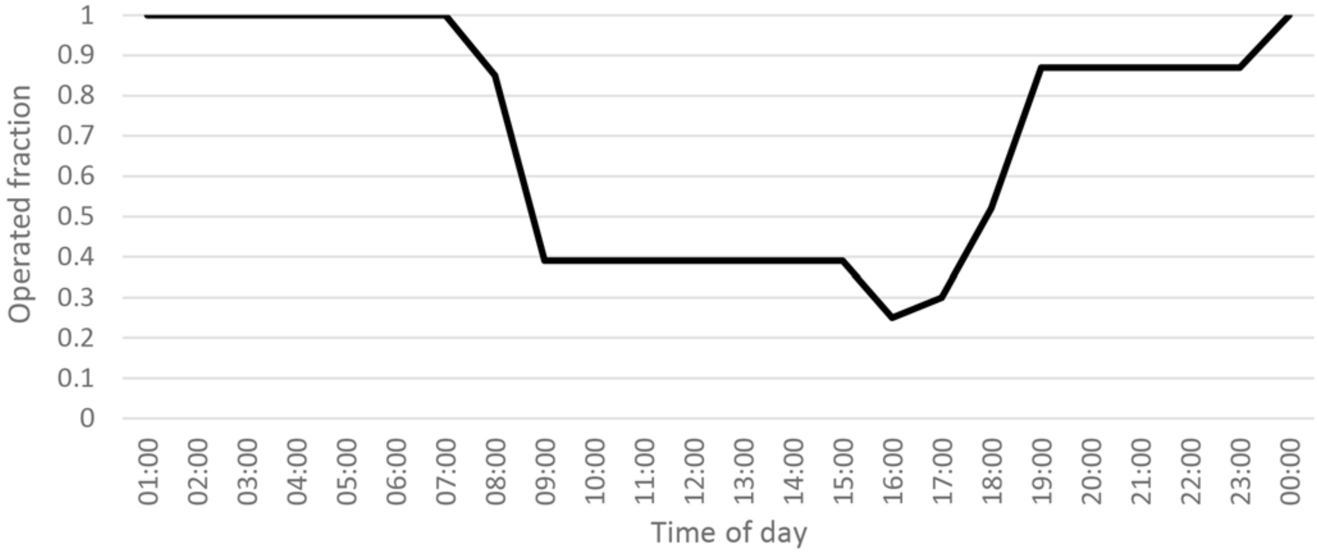
Zoning

The energy model is based on three spaces that are part of one thermal zone: (1) the living space that contains the entirety of the first floor, (2) the circulation corridor that contains the stairs and upstairs hallway, and (3) the upstairs bedrooms.

Equipment

The equipment loads are based on ENERGY STAR® appliances, as listed in Table 2. ENERGY STAR reports the total annual energy consumption, on average. This value was extrapolated to a total wattage value that is specified as the design wattage level in the energy model. It is then operated by a simple “always on” schedule, i.e., operated at 100% level, 24/7. With operation trend data, the model can incorporate a more representative equipment schedule, adjusting the total design wattage.

Figure 10: Example of generalized single-family dwelling occupancy schedule (DOE/PNNL)



3.1 ENERGY MODEL

Table 2: Examples of ENERGY STAR certified equipment that make up the equipment loads

TYPE	MAKE/MODEL	ENERGY USE	COST
Laundry Washer (Stackable)	Beko WTE7604XLW0	67 kWh/year	$849
Laundry Dryer (stackable)	Samsung DV25B69**H*	125 kWh/year	$1,165
Dishwasher	Fisher & Paykel DD24STX6l1	113 kWh/year	$1,199
Refrigerator	Insignia NS-RTM10BK2	283 kWh/year	$360
Range	Magic Chef MCSRE24S	1,200 W–2,200 W	$1,079
Microwave	Panasonic NN-SN67HS	1,200 W	$155
TV	Spectre 435BV-F	65.4 kWh/year	$158
Laptop	Misc.	10 kWh/year	$1,300–$3,500

3.1.1 MEP SYSTEMS SCHEMATIC

The design of each housing unit is configured for hydronic heating, cooling and coupled domestic hot water. Units can be coupled with a district heating loop using staged air-to-water heat pumps that supply domestic hot water all year using a dedicated heat exchanger and additional space heat to the floor slab during heating and shoulder seasons. During the cooling season, natural ventilation will provide the primary cooling with supplemental cooling provided by centralized heat pumps that are staged to deliver chilled water via a cooling loop and floor slab hydronics valved to switch from heating to cooling.

For both space heating and cooling, the slab and centralized thermal storage tanks can be either heated or chilled at night to take advantage of off-peak electrical rates from the grid. This design is intended to not only reduce unit energy use but provide overall operational affordability, load sharing and resilience since the centralized heat pumps can be operated by site microgrid photovoltaics during a grid outage. For the SE 36th Avenue site, the district will serve 19 homes (replacing two existing homes) and for the SE Harvey Street site, the district will serve 14 homes (replacing one existing home).

In the case of a single-unit configuration (e.g., ADU), the district heating and cooling loops can be substituted by an air-to-water heat pump (BOD: Sanco$_2$) and a small indoor hot water thermal storage tank.

Figure 11: Single-unit hydronic configuration

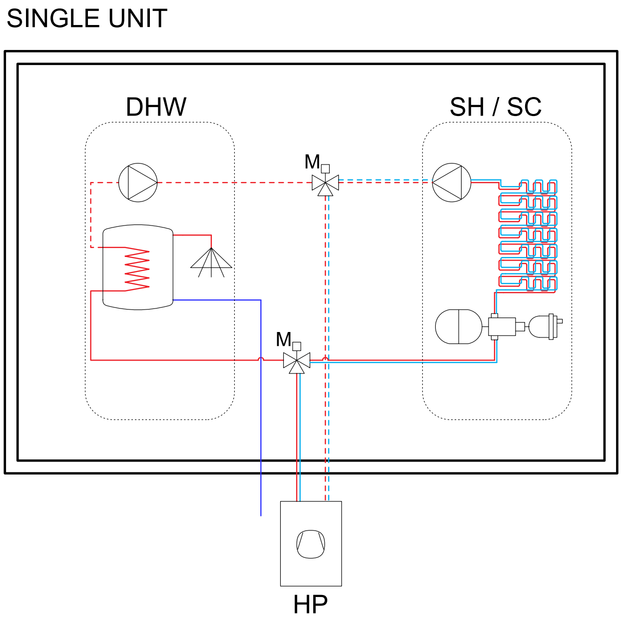
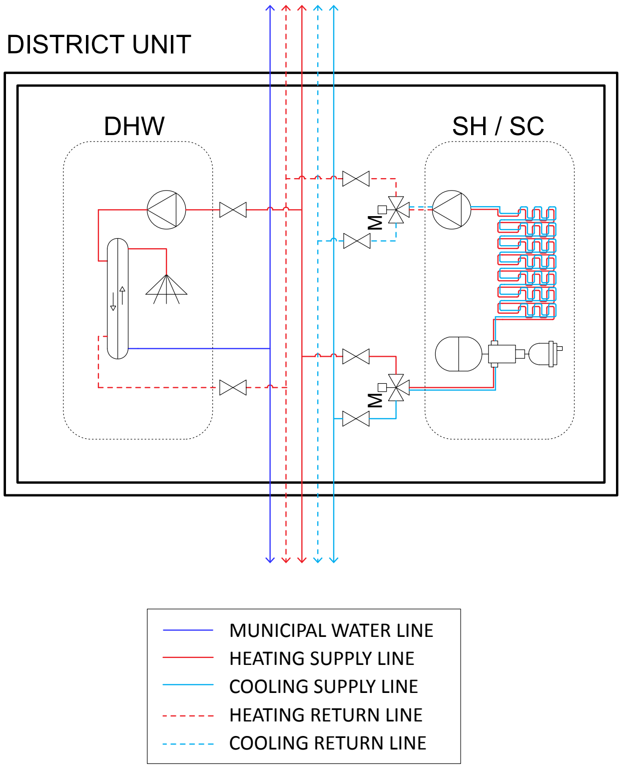


Figure 12: District unit hydronic configuration

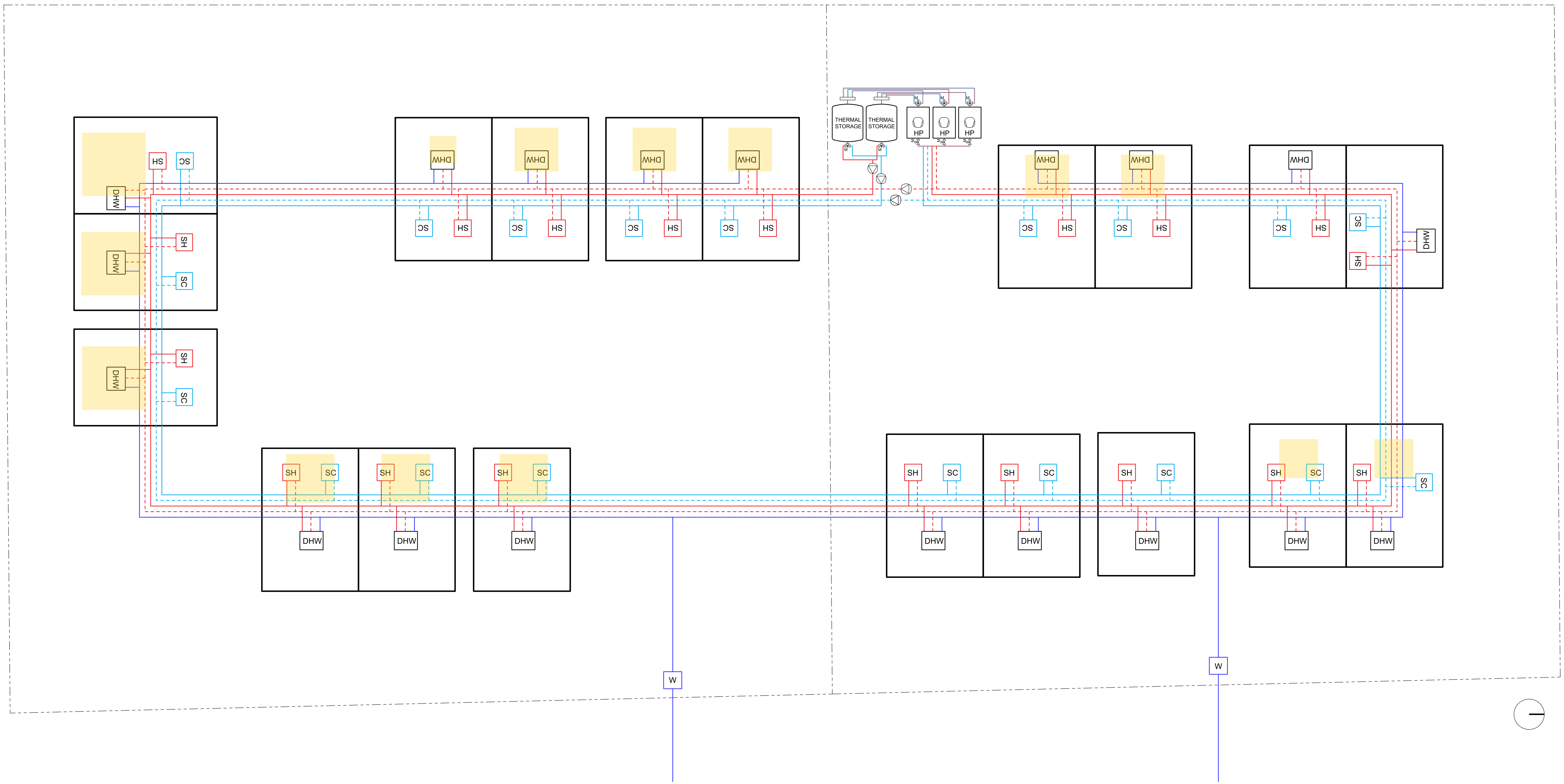


3.1.2 MEP SYSTEMS SITE SCHEMATIC SE 36TH AVENUE

DHW DOMESTIC HOT WATER (DHW)
SH SPACE HEATING (SH)
SC SPACE COOLING (SC)
W MUNICIPAL WATER METER
🟨 UNIT SOLAR CONTRIBUTION

— MUNICIPAL WATER LINE
— SPACE HEATING (SH) SUPPLY LINE
— SPACE COOLING (SC) SUPPLY LINE
- - - SPACE HEATING (SH) RETURN LINE
- - - SPACE COOLING (SH) RETURN LINE

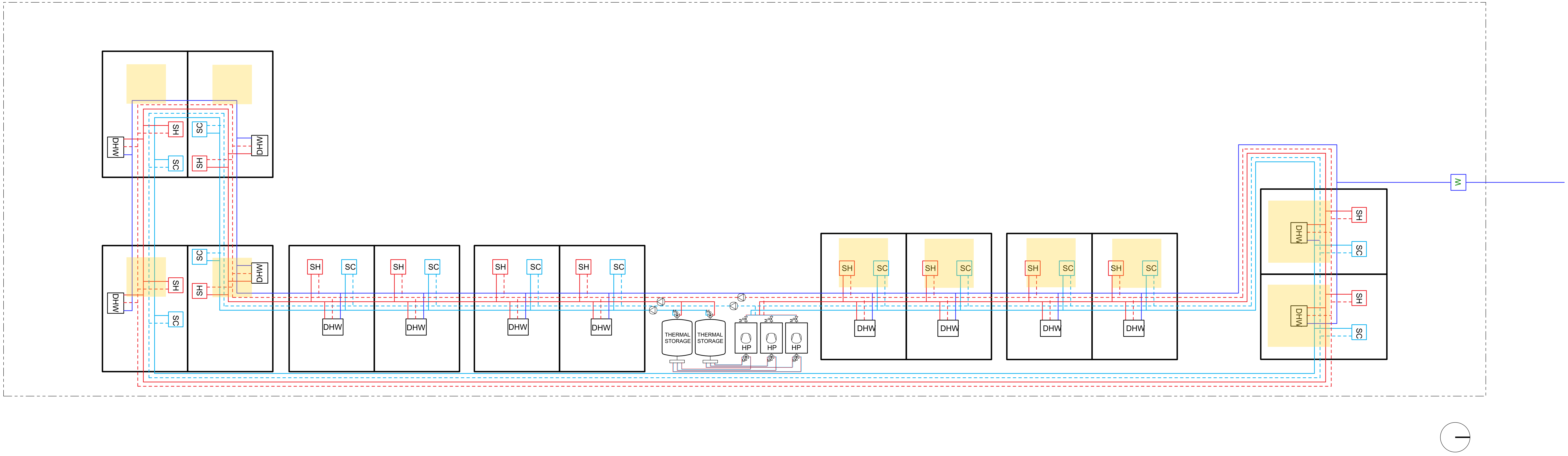
Figure 13: District system configuration for SE 36th Ave site



3.1.3 MEP SYSTEMS SITE SCHEMATIC SE 36TH AVENUE

DHW	DOMESTIC HOT WATER (DHW)	—	MUNICIPAL WATER LINE
SH	SPACE HEATING (SH)	—	SPACE HEATING (SH) SUPPLY LINE
SC	SPACE COOLING (SC)	—	SPACE COOLING (SC) SUPPLY LINE
W	MUNICIPAL WATER METER	- - -	SPACE HEATING (SH) RETURN LINE
🟨	UNIT SOLAR CONTRIBUTION	- - -	SPACE COOLING (SH) RETURN LINE

Figure 14: District system configuration for SE Harvey St site



3.1.5 NATURAL VENTILATION COOLING

Visualizations of two wind speeds (1 m/s and 2 m/s) at three directional conditions with either stack ventilation provided by a skylight and downstairs inlet or a combination of stack + cross ventilation. Downstairs has an inlet/outlet on opposing walls. Upstairs stack is above stair, and bedrooms have wall and ceiling inlet/outlets.

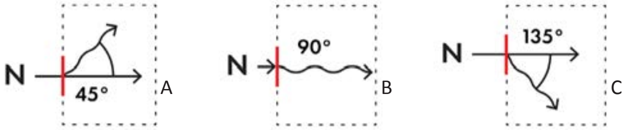
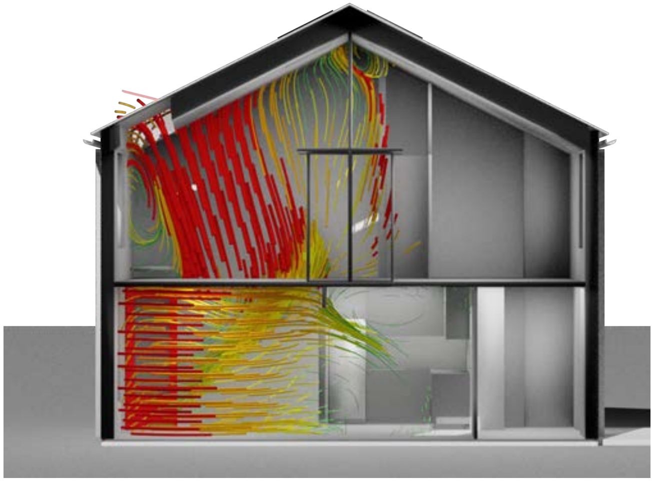
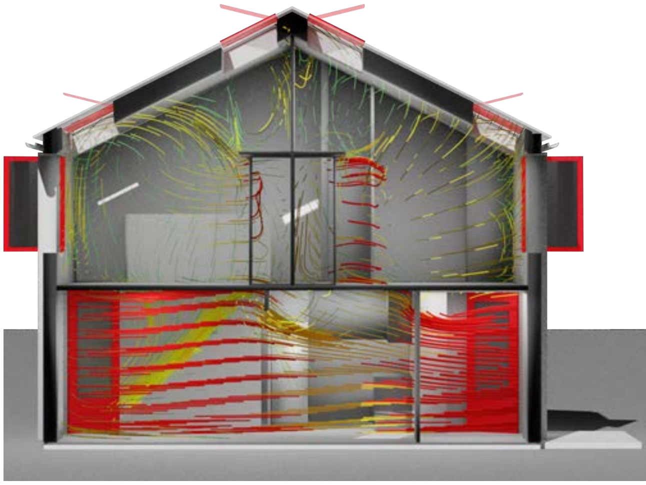


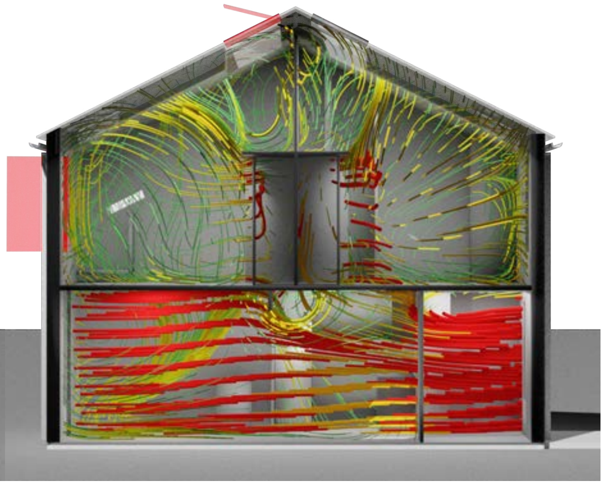
Figure 15: Cross and stack ventilation shown at two different wind speeds and three different wind directions



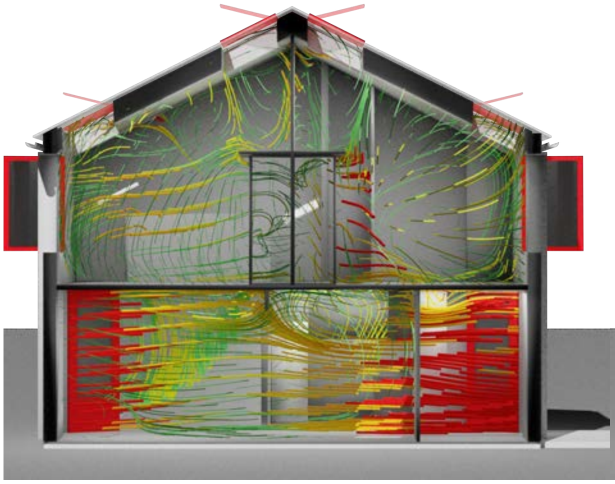
Stack vent: single skylight open and front door, 2m/s wind, condition A



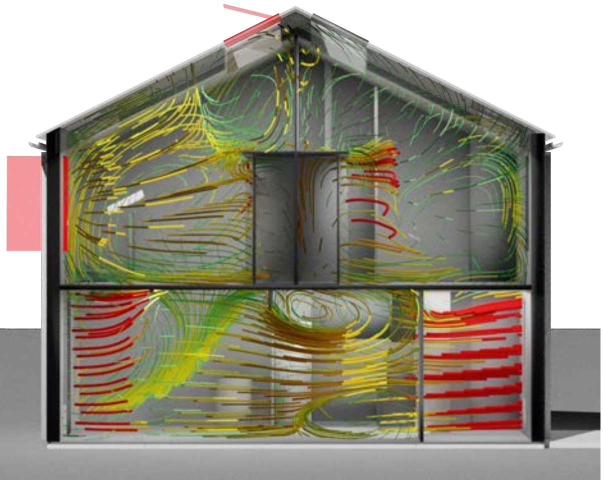
Cross + stack ventilation: all open, 1m/s wind, condition B



Cross + stack ventilation: all open, 2m/s wind, condition B



Cross + stack ventilation: all open, 2m/s wind, condition C



Cross + stack ventilation: all open, 1m/s wind, condition A

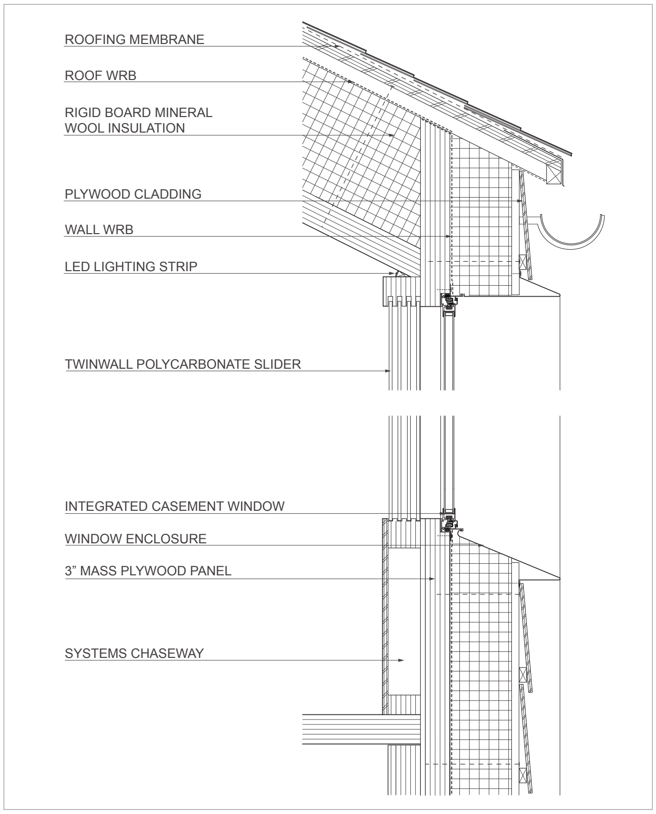
3.2 PHYSICAL MOCK-UP

Window mock-up fabrication
The process of modeling and fabricating finished window openings in MPP was put to the test at the time of window installation. Translating window dimensions to 3D model form, and then again to CNC fabrication-cut files for an inset rough opening that would also serve as interior finish surface, was largely a success.

The tolerance for a CNC-cut window opening is allowed to be held much tighter than that of a conventional stick framed rough opening, where a process of shimming and squaring a window during installation requires extra space in the site-built structure. The precision fabrication possible on the CNC allowed for the rough opening in the MPP to be 1/16" larger than the window itself on all sides, whereas window manufacturers require rough openings for conventional construction to be anywhere from 1/2" to 1" larger on each side. The tighter tolerance meant that the window was square as soon as it was placed in the opening and air sealing becomes more precise.

An assembly detail prototyped with the mock-up had the window frame sit within the thickness of the MPP panel, including 2" of MPP (R-value of 2.50) covering the window frame when viewed from the interior. The intent was to have the MPP serve as both structure, finish material and frame insulation; thus, requiring no additional trim work or finish treatment. Furthermore, situating the window frame and operable casement sash in this configuration allowed for the addition of an “energy shutter” on the interior, which was fabricated from twin-wall polycarbonate and allowed privacy, shading and additional insulation as a secondary system over the glazing. Functionally this window placement worked well. The one exception was that additional relief of the MPP was required for the specific window operator selected to have clearance to operate. This was corrected in the field and the operable window works well and as intended in this configuration.

Figure 16: Window mock-up section detail



One drawback of having the cut edge of the MPP serve as finish material, identified through mock-up construction, is that special care and attention must be taken during CNC operations that wouldn’t be necessary if the MPP were intended to be covered with additional finish material. For example, the MPP needs to be secured to a spoil board to minimize fiber tear out. Cutting tool selection and speed also needs to be optimized to produce the best finish surface, and the practice of tabs being left between the wall panel and the cutout material—to be cutout by hand later—is not ideal to achieve a uniform surface finish.

Some additional manual steps such as sanding may still be required, which reduces some of the cost savings gained through limiting additional finish materials. For the mock-up, MPP window corner tabs were hand cut; however, the team should consider leaving a small corner radius to allow a fully machine operation.

One benefit to panelized wall construction using MPP is a significant reduction in the possible locations for air infiltration to occur. With fasteners not penetrating the surface, potential infiltration locations are limited to panel-to-panel joints and panel penetrations like window openings. Furthermore, electrical outlets located on exterior walls are all surface mounted, thereby reducing the need to pay particular attention to outlet air sealing.

Hoisting hardware for maneuvering panels during fabrication and again on-site during installation are an avoidable additional MPP penetration. We piloted the use of hardware requiring a panel through hole as lifting point. The advantage of this type of lifting point is that it is easily installed and retrieved without tools or fasteners. However, it leaves an additional panel penetration that must be properly sealed on site as part of the installation process. Lifting hardware that requires fasteners that do not penetrate the full depth of the MPP may be a better option from the standpoint of infiltration. Custom lifting hardware that remains attached after installation and serves an additional purpose in the building, such as being part of a panel-to-panel connection, is an area we hope to explore further based on the lessons learned from this mock-up.

Performance testing

An enclosure was constructed and air sealed to the interior side of the mock-up for the use of a blower door fan and instrumentation to positively pressurize the interior of the wall assembly. Smoke was introduced to the pressurized interior side of the mock-up at 30 Pascals and ramped to 62 Pascals while the exterior was visually inspected for smoke leakage. The only apparent smoke leakage was found in the vicinity of the windows.

The operable window had some ex-filtration occurring at the sealing surface. The weep holes in the frame of the windows, included as part of the window assembly to allow condensation to drain to the exterior were another source of visible smoke exiting the mock-up while pressurized. Some additional smoke was visible around the window assembly and cladding interface. This air path was not immediately identifiable and will be further investigated when the mock-up is deconstructed. With some of the cladding removed, the ex-filtration location should be more apparent.

Window penetrations were sealed with a liquid applied membrane (Soprema Sopraseal Liquid Flashing, SKU: A508) and should provide a good air seal between the window flange and the weather barrier (Soprema Sopraseal Stick VP, SKU: D21501) over the MPP. Potential air leakage may be occurring through the window frame itself. If air leakage is occurring around the window, there is an opportunity for additional air sealing installation steps (that were not used in the mock-up) to be employed in the future, as this current installation trialed only the liquid applied membrane when sealing the windows to the panels.

3.2 PHYSICAL MOCK-UP

On the interior side of the mock-up, an integrated sliding "energy shutter" system was piloted utilizing 6 mm twin-wall translucent polycarbonate panels that slide horizontally in an MPP track at both the head and sill of the window. The upper track additionally conceals LED strip up-lighting. The space between the lower track and the floor allows for a service chase running the length of the window wall to be used for electrical and other services without any penetrations or chases occurring through the MPP wall panel.

The polycarbonate shutters provide a building integrated privacy, shading and radiant barrier, allowing some thermal envelope improvement and user control in a space where it is believed most homeowners would install some type of blinds for privacy anyway. Additional design iterations of the shutters will take lessons learned from the mock-up and improve how the panels slide in their track to reduce noise and develop a way for panels to interlock and move together and create a more contiguous thermal mitigation layer when deployed.

The relatively thick outboard insulation with rain-screen and cladding to the exterior allows the window plane to be recessed, providing some inherent exterior shading. A sheet metal window surround including vertical mullion between the two windows adds some depth and improves shading performance while acting as window trim. The sheet metal work proved a complex process between model, fabrication and installation. A number of interface issues are able to be refined and improved based on mocking up this façade integrated element.

Alternate materials (e.g., fiberglass, plate steel, wood) may also be pursued for constructability, cost, thermal and durability considerations.

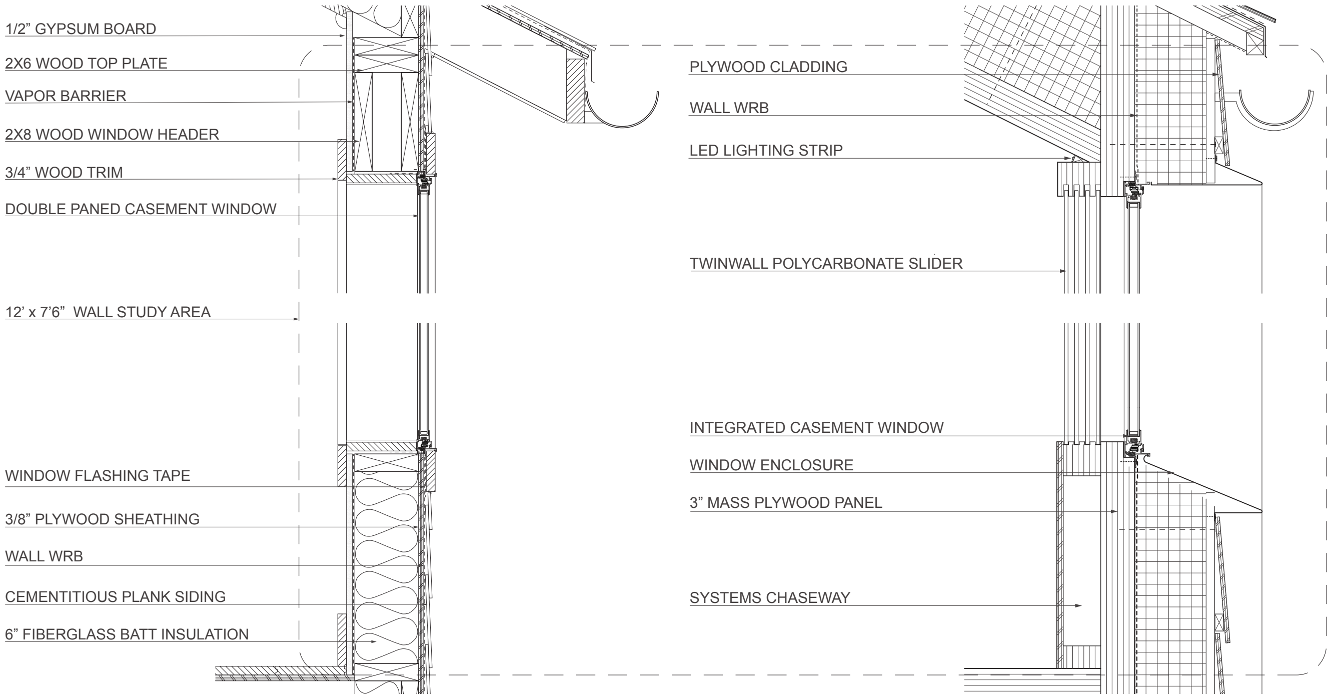
The mock-up is located outdoors and able to be reoriented to different solar exposures. Infrared images were taken when a large temperature differential could be achieved between artificially elevating the interior air temperature of the mock-up and cooler ambient outdoor conditions. These false color images investigate the thermal performance of the façade and will inform future design refinement.

This window and façade mock-up has allowed the research and development team to secure additional funding to advance the larger project and we will continue to use the mock-up and what we've learned from constructing it to advance the energy performance and design of future full-scale prototypes and ultimately permanent workforce housing.

3.2 PHYSICAL MOCK-UP

Window Cost Comparison

Figure 17: Conventional window and MPP mock-up window section detail



Labor Cost Comparison

Table 3: Conventional window and MPP mock-up window labor cost comparison

Conventional Window System

Task	$/hr	Minutes	Cost
Wall framing with rough opening	$25	50	$20.83
Sheathing	$25	30	$12.50
Cut rough opening in sheathing	$25	5	$2.08
Place WRB	$16	20	$5.33
Shim, square, attach window	$25	5	$2.08
Flash window with tape	$16	3	$0.80
Trim exterior window	$25	10	$4.17
Fabricate and install metal drip cap	$25	10	$4.17
Cladding	$25	60	$25.00
Caulk exterior window joint	$16	5	$1.33
Interior insulation	$16	15	$4.00
Interior vapor barrier	$16	15	$4.00
Interior drywall	$30	45	$22.50
Spray foam rough opening gap	$16	2	$0.53
Window casing	$40	10	$6.67
Window trim interior	$40	10	$6.67
Tape and mud drywall	$30	50	$25.00
Paint drywall/trim	$20	30	$10.00
Install window coverings	$16	10	$2.67
TOTAL		**385**	**$160.33**

MPP Window System

Task	$/hr	Minutes	Cost
Manual panel cutting/finishing	$25	20	$8.33
Manual routing with jig	$25	60	$25.00
WRB application	$16	20	$5.33
Install insulation	$25	60	$25.00
Liquid flashing, window install	$25	30	$12.50
Window flashing	$16	10	$2.67
Cutting polycarbonate sheet	$16	10	$2.67
Dado MPP for slider	$25	20	$8.33
Cladding	$25	60	$25.00
Install sheet metal surround	$25	30	$12.50
Caulk exterior window joint	$16	5	$1.33
TOTAL		**325**	**$128.67**

3.2 PHYSICAL MOCK-UP

Figure 18: MPP window mock-up construction process photos

3.2 PHYSICAL MOCK-UP

Figure 19: Window installation in MPP mock-up construction process photos

3.2 PHYSICAL MOCK-UP

Figure 20: Completed MPP mock-up photos including polycarbonate energy shutter

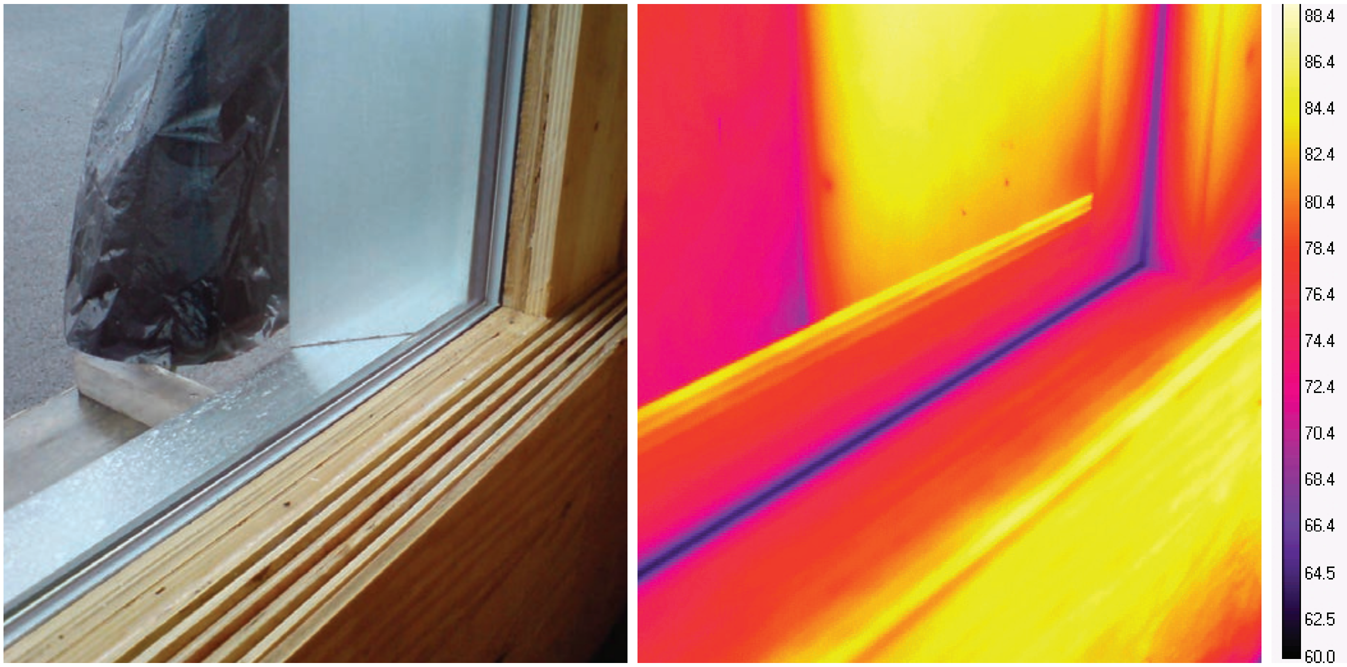
3.2 PHYSICAL MOCK-UP

Figure 21: Exterior thermal imaging of enclosed and heated mock-up

3.2 PHYSICAL MOCK-UP

Figure 22: Interior thermal imaging of enclosed and heated mock-up; operable window

Figure 23: Interior thermal imaging of enclosed and heated mock-up; fixed window



3.2 PHYSICAL MOCK-UP

Figure 24: Blower door testing and pressurized smoke testing photos

3.3 PV SOLAR STUDY

The City of Milwaukie, Oregon has placed an emphasis on preserving existing tree canopy for any new development, recently adopting a tree code. The demonstration sites used for this analysis have legacy trees, most of which will be preserved, and the research team is interested in tree-preserving solar models made possible by courtyard cluster infill, such as renewable microgrids with battery storage and peer-to-peer sharing.

Figure 25: Site images of tree canopy on both project sites

Images above represent annual insolation on 36th Avenue site.

Images a, b and c are the 36th Avenue site, and d and e are the Harvey Street site.

3.3 PV SOLAR STUDY SITE PLANS

Site plans (NTS) for proposed demonstration projects in Milwaukie, Oregon
Figure 26 is 36th Avenue site, which includes three tax lots and is approximately 120' deep x 280' wide and Figure 27 is the Harvey Street site, which is 300' deep x 80' wide. The research and development team engaged Vince McClellan of **Energy Design** (Eugene, Oregon) **for site solar analysis, system design and pricing.** Energy Design's analysis and proposal for each site is presented in the following pages.

Figure 26: Site plan, 36th Ave site

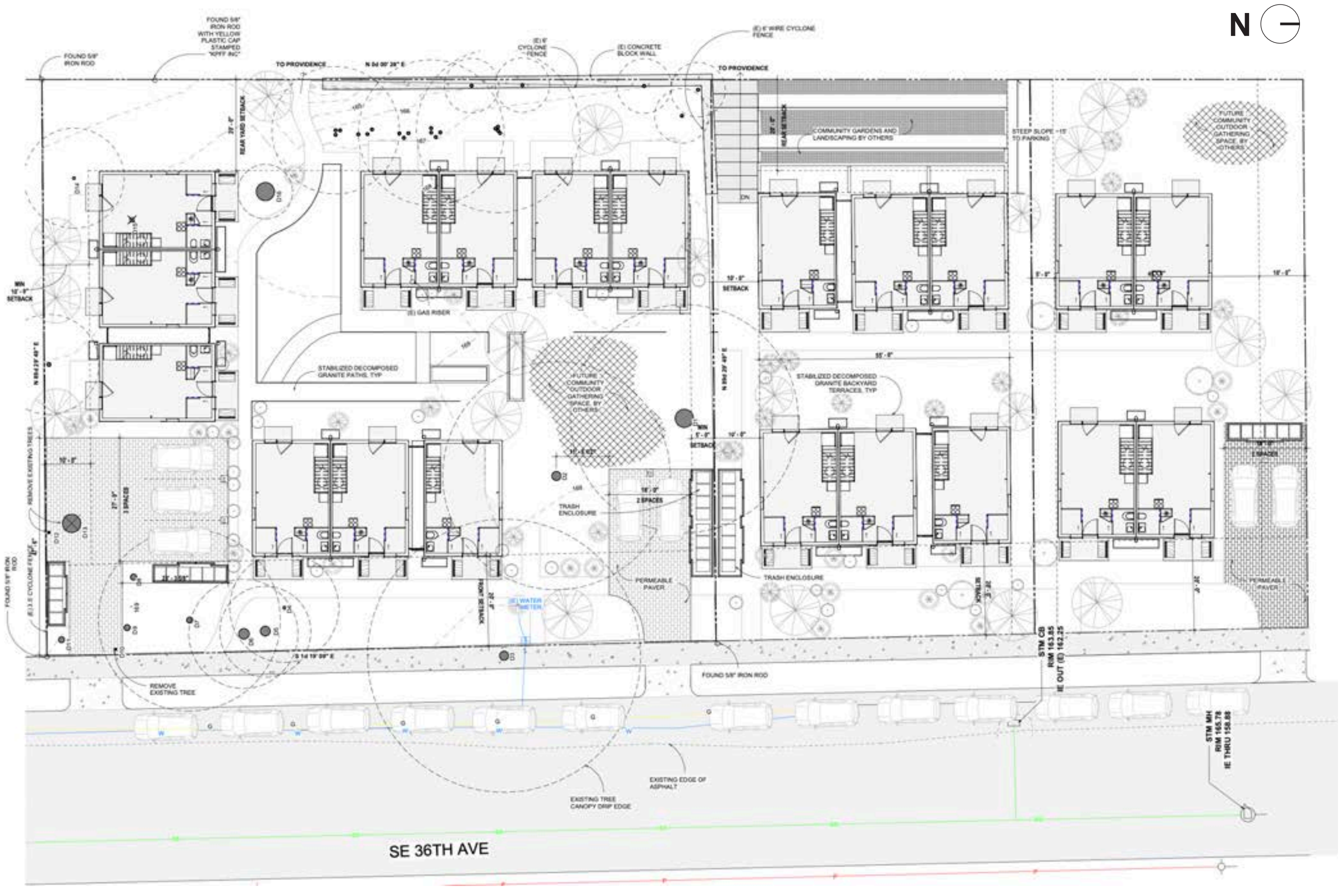
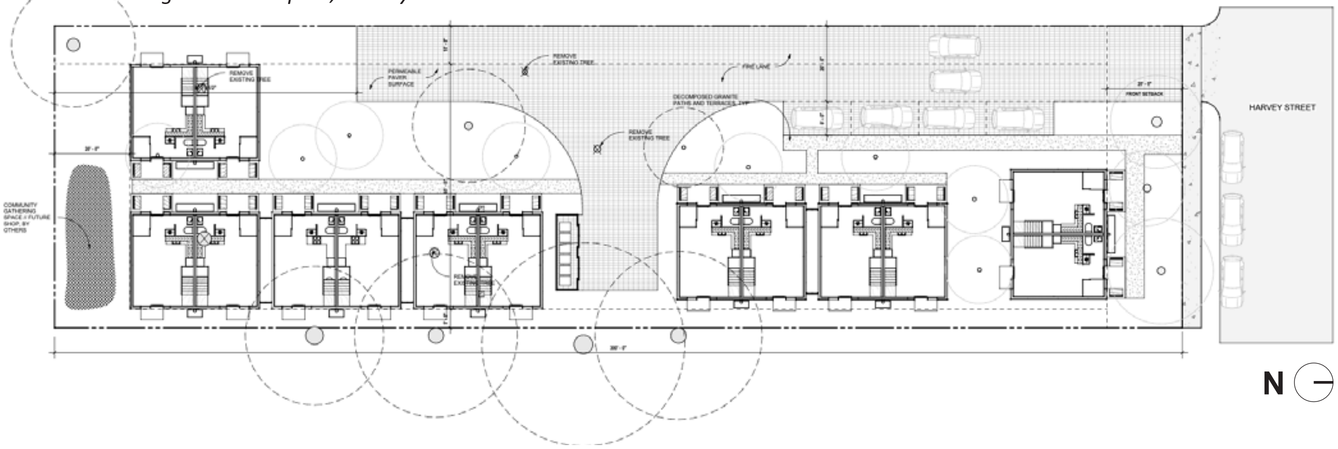


Figure 27: Site plan, Harvey St site



3.3 PV SOLAR STUDY SITE PLANS

The solar PV installation results in 62% of energy from solar for the 36th Avenue site and 66% of energy from solar for the Harvey Street site. In particular, the two-story cottage cluster housing design for the development sites optimizes the solar-to-energy usage ratio more efficiently than can be achieved with taller (3–4 story) buildings or with individual home arrays.

Energy Design

The sun is rising on a new energy future

SOLAR

energy for today

A customized proposal for:

Milwaukie Courtyard Housing
Project 36th Ave
Mark Fretz
10325 SE 36th Ave
Milwaukie, OR 97222

Energy Design
Designer Contact: Vince McClellan
541-517-2121
vince@solarenergydesign.com

36 AVENUE SITE PROPOSAL BY ENERGY DESIGN

Energy Design
The sun is rising on a new energy future

10325 SE 36th Ave
Milwaukie, OR 97222

You would generate

62%

of your energy from solar

System summary

118 REC REC370NP2 Black

Enphase Energy Inc. IQ 7+ (240V)

118

System size	43.66 **kW**
Year 1 Production	43,760 **kWh**

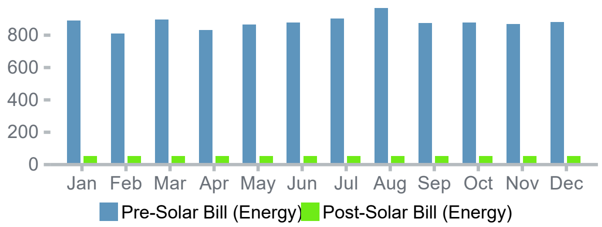
Home Work

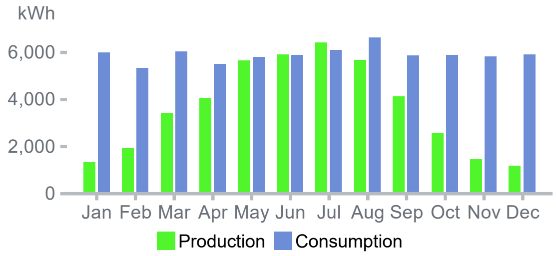
UNIVERSITY OF OREGON

Energy Studies in Buildings Laboratory

3.3 36 AVENUE SITE PROPOSAL BY ENERGY DESIGN

Average monthly electric bill





Energy Design

The sun is rising on a new energy future

SOLAR

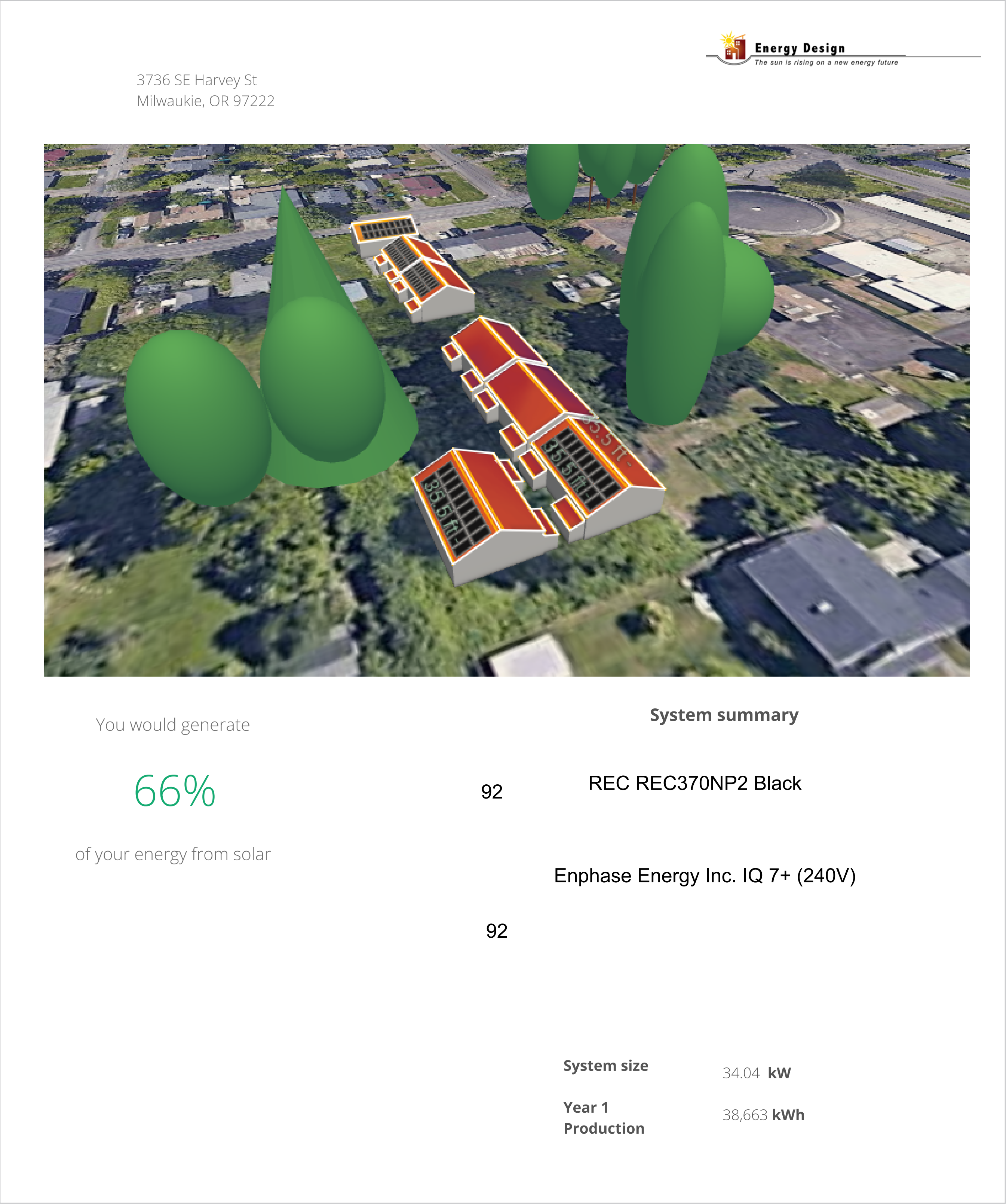
energy for today

A customized proposal for:

Milwaukie Courtyard Housing
Project SE Harvey ST
Mark Fretz
3736 SE Harvey St
Milwaukie, OR 97222

Energy Design
Designer Contact: Vince McClellan
541-517-2121
vince@solarenergydesign.com

3.3 HARVEY SITE PROPOSAL BY ENERGY DESIGN



Energy Design

The sun is rising on a new energy future

3736 SE Harvey St
Milwaukie, OR 97222

You would generate

66%

of your energy from solar

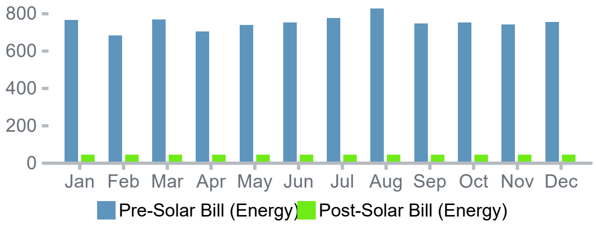
System summary

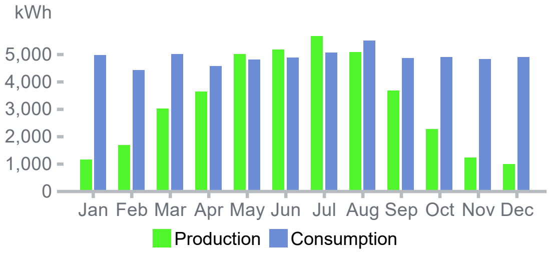
92	REC REC370NP2 Black
	Enphase Energy Inc. IQ 7+ (240V)
92	

System size	34.04 **kW**
Year 1 Production	38,663 **kWh**

3.3 HARVEY SITE PROPOSAL BY ENERGY DESIGN

Average monthly electric bill

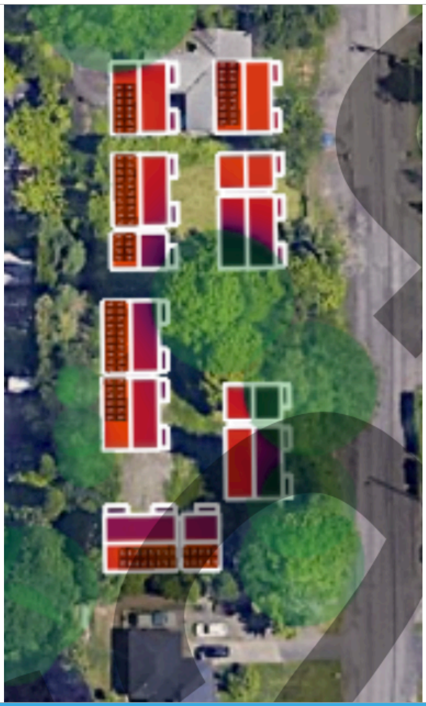




3.4 SOLAR SYSTEM PRICING · PV SYSTEM PRICING FOR 36 AVENUE BY ELEMENTAL ENERGY

PROJECT DESIGN + SCOPE

SITE PLAN



10325 SE 36th Ave Milwaukie, OR 97222

SCOPE OF WORK

☑ Solar PV
☐ Energy Storage
☐ Electrical Upgrades
☐ Electric Vehicle Charging
☐ Lighting Upgrades
☐ Consulting
☐ (Other)

PV SYSTEM SIZE

43.7 kW

ENERGY STORAGE

0 kWh

ITEMS INCLUDED

- ☑ Provide filing assistance for net-metering paperwork
- ☑ All local permits
- ☑ All wiring, conduit, disconnects, and grounding according to 2020 NEC
- ☑ 2 year workmanship warranty
- ☑ System operation and safety walkthrough
- ☑ Final energy storage price subject to change after technical audit
- ☑ Owner's manual with all design documentation

SYSTEM

Modules (118)

REC 370w or Tier 1 — Warranty: 10 Years

Enphase IQ8 — Warranty: 25 Years

BATTERY (0)

Tesla Powerwall 2

EV CHARGING (0)

Tesla Wall Connector

3.4 SOLAR SYSTEM PRICING · PV SYSTEM PRICING FOR 36 AVENUE BY ELEMENTAL ENERGY

$ PROJECT ECONOMICS

INSTALLED COST....................	$140,260
Federal Tax Credit	$42,078
MACRS Depreciation	$42,443
Energy Trust of Oregon	$8,732
Annual Utility Savings	$4,149
NET COST YEAR 1	**$42,858**

CAPITAL RETURNED IN YEAR 1

69%

SIMPLE PAYBACK (YEARS)

10.6

RATE OF RETURN

8.6%

TOTAL RETURN ON INVESTMENT

406%

30 Year Cash Flow

Year	Installed PV Cost	Federal ITC	Energy Trust	MACRS Depreciation	O&M	Loan Payment	Utility Savings	Annual Cash Flow	Cumulative Cash Flow
0	($140,260)							($140,260)	($140,260)
1		$42,078	$8,732	$42,443			$4,149	$97,402	($42,858)
2			($3,109)				$4,265	$1,156	($41,702)
3							$4,384	$4,384	($37,318)
4							$4,506	$4,506	($32,812)
5							$4,631	$4,631	($28,181)
6							$4,760	$4,760	($23,421)
7							$4,892	$4,892	($18,529)
8							$5,029	$5,029	($13,500)
9							$5,169	$5,169	($8,331)
10							$5,313	$5,313	($3,019)
11							$5,460	$5,460	$2,442
12							$5,612	$5,612	$8,054
13							$5,769	$5,769	$13,823
14							$5,929	$5,929	$19,752
15					($2,700)		$6,094	$3,394	$23,146
16							$6,264	$6,264	$29,410
17							$6,438	$6,438	$35,848
18							$6,617	$6,617	$42,465
19							$6,802	$6,802	$49,267
20							$6,991	$6,991	$56,258
21							$7,186	$7,186	$63,444
22							$7,386	$7,386	$70,829
23							$7,591	$7,591	$78,420
24							$7,802	$7,802	$86,223
25							$8,020	$8,020	$94,242
26							$8,243	$8,243	$102,485
27							$8,472	$8,472	$110,957
28							$8,708	$8,708	$119,665
29							$8,950	$8,950	$128,616
30							$9,200	$9,200	$137,815

Assumptions:	28% Federal Tax Rate	7.6% State Tax	3.30% Annual Utility Rate Escalation
	0.50% Module Degradation Per Year	Inverter Replacement Year 15	$0.090 /kWh Utility Rate

3.4 SOLAR SYSTEM PRICING · PV SYSTEM PRICING FOR HARVEY STREET BY ELEMENTAL ENERGY

PROJECT DESIGN + SCOPE

SITE PLAN

3736 SE Harvey St Milwaukie, OR 97222

SCOPE OF WORK

- ☑ Solar PV
- ☐ Energy Storage
- ☐ Electrical Upgrades
- ☐ Electric Vehicle Charging
- ☐ Lighting Upgrades
- ☐ Consulting
- ☐ (Other)

PV SYSTEM SIZE

34.0 kW

ENERGY STORAGE

0 kWh

ITEMS INCLUDED

- ✓ Provide filing assistance for net-metering paperwork
- ✓ All local permits
- ✓ All wiring, conduit, disconnects, and grounding according to 2020 NEC
- ✓ 2 year workmanship warranty
- ✓ System operation and safety walkthrough
- ✓ Final energy storage price subject to change after technical audit
- ✓ Owner's manual with all design documentation

SYSTEM

Modules (92)	
REC 370w or Tier 1	Warranty: 10 Years
Enphase IQ8	Warranty: 25 Years
BATTERY (0)	
Tesla Powerwall 2	
EV CHARGING (0)	
Tesla Wall Connector	

3.4 SOLAR SYSTEM PRICING · PV SYSTEM PRICING FOR HARVEY STREET BY ELEMENTAL ENERGY

$ PROJECT ECONOMICS

INSTALLED COST....................	$109,183
Federal Tax Credit	$32,755
MACRS Depreciation	$33,039
Energy Trust of Oregon	$6,808
Annual Utility Savings	$3,235
NET COST YEAR 1	**$33,346**

CAPITAL RETURNED IN YEAR 1

69%

SIMPLE PAYBACK (YEARS)

10.5

RATE OF RETURN

8.6%

TOTAL RETURN ON INVESTMENT

406%

30 Year Cash Flow

Year	Installed PV Cost	Federal ITC	Energy Trust	MACRS Depreciation	O&M	Loan Payment	Utility Savings	Annual Cash Flow	Cumulative Cash Flow
0	($109,183)							($109,183)	($109,183)
1		$32,755	$6,808	$33,039			$3,235	$75,837	($33,346)
2			($2,424)				$3,325	$902	($32,445)
3							$3,418	$3,418	($29,027)
4							$3,513	$3,513	($25,514)
5							$3,611	$3,611	($21,903)
6							$3,711	$3,711	($18,192)
7							$3,814	$3,814	($14,378)
8							$3,921	$3,921	($10,457)
9							$4,030	$4,030	($6,427)
10							$4,142	$4,142	($2,285)
11							$4,257	$4,257	$1,972
12							$4,376	$4,376	$6,348
13							$4,498	$4,498	$10,845
14							$4,623	$4,623	$15,468
15					($2,100)		$4,751	$2,651	$18,120
16							$4,884	$4,884	$23,003
17							$5,020	$5,020	$28,023
18							$5,159	$5,159	$33,182
19							$5,303	$5,303	$38,485
20							$5,451	$5,451	$43,936
21							$5,602	$5,602	$49,538
22							$5,758	$5,758	$55,296
23							$5,918	$5,918	$61,215
24							$6,083	$6,083	$67,298
25							$6,253	$6,253	$73,551
26							$6,427	$6,427	$79,977
27							$6,605	$6,605	$86,583
28							$6,789	$6,789	$93,372
29							$6,978	$6,978	$100,350
30							$7,173	$7,173	$107,523

Assumptions:			
	28% Federal Tax Rate	7.6% State Tax	3.30% Annual Utility Rate Escalation
	0.50% Module Degradation Per Year	Inverter Replacement Year 15	$0.090 /kWh Utility Rate

3.5 MICROGRID

Roof-mounted photovoltaic panels could be configured as a simple grid-tied system for each housing unit or all units on a given site, but PV alone would not provide power if there was a utility service disruption. Adding battery storage capacity would allow for some supplemental power when there is a utility disruption and would add functionality to the proposed rooftop PV for resilience. On-site energy storage would require equipment and controls in addition to batteries and could also happen at each house or collectively on the site. Adding an additional layer of smart control at the community level to manage all on-site energy generation, energy storage and when and how much to rely on utility grid distribution would mean the cottage cluster development was operating a microgrid.

With the proposed site-scale central heating and cooling system and a single utility grid electrical service drop tie-in for all units, centrally locating and controlling energy storage would be appropriate and reduce the number of components, complexity, and cost. It would also allow for system maintenance, repair, and fire suppression requirements to occur in a single location and not at every house.

With the proposed rooftop PV being connected via PV string inverters at each panel, energy generation will be delivered to the site main switchboard. The centrally located direct current (DC) battery bank would have its own inverter, eliminating any long DC wire runs and maintaining all AC distribution across the site. The battery bank could be considered as another node on the microgrid, equally able to draw and store energy from the utility and rooftop PV or deliver energy to meet demand loads from any house on the microgrid. The electrical panel at each housing unit will be equipped with controllable circuit breaker(s or controllable contactor(s) to enable load shedding of non-resilient electrical loads at each unit. C

Three scenarios of site-level microgrid system configurations are explored. Power and energy requirements based on energy model derived loads are shown for each site, and microgrid rough order of magnitude installed costs are further estimated based on those values and the description of each scenario.

Scenario #1 sizes battery capacity for a full day of normal energy use, meaning the microgrid could both be completely disconnected from the utility grid for this period and additionally not reliant on PV generation. Any PV generation would extend the period the microgrid could run self-sufficient or in “islanding” mode.

Scenario #2 aims to describe a lower cost, and consequently lower level of resilience than the previous scenario. But it also aims to capitalize on infrastructure and community structure inherent to the site. Energy storage for scenario #2 is sized to meet the full heating or cooling demand, as those systems are central site-level systems. It further provides emergency electrical circuits at a central location for changing devices and minor equipment loads. This supports and perhaps strengthens to the nature of such a community to come together and look out for one another in times of uncertainty or crisis.

Scenario #3 describes an operational mode that could be in place most of the time, as a microgrid system will typically be connected to the utility grid and service interruptions are hopefully rare. The intent of this scenario is to size the on-site energy storage system to cover loads for all units for a five-hour period of peak demand. This relieves strain on the utility grid at critical times of high demand and is referred to as “peak shaving”. It can also lead to a reduction in the overall cost of energy from the grid, either by buying and storing energy when it is cheaper, or as has occurred in some cases, by negotiating a reduced rate based on an agreement to not draw from the grid during peak periods.

A cottage cluster microgrid system would be a relatively small system by the standard of today’s existing installations. Most systems would be described in MW/MWh and serve a campus, industrial complex, or large community. There is a wide range of normalized system costs for existing microgrid systems. Existing system cost data suggests that component cost per MW goes down as overall system size increases. Component cost has also been shown to go down as system complexity decreases. There may be a lower cost-limit threshold for the microgrid controller that has a sufficiently sophisticated level of control complexity regardless of the relatively small sizing of a system for 15 or 21 housing units. A more detailed system specification would be needed to identify these issues and cost breakpoints.

Lithium iron phosphate batteries are used in this estimate and the batteries comprise roughly 90% of the energy storage system cost. Sodium-ion batteries are soon to be mass produced in the US (2023) and should be available at a significant cost saving over current battery technologies due to the abundance and low cost of this much safer and environmentally friendly technology. Current pricing for sodium-ion batteries is three times less than lithium iron phosphate, and that margin could be expected to grow as production of sodium-ion batteries increases.

Electric vehicle charging is not included in the scenarios presented. The microgrid controller could provide some advantages when EV charging is done as part of the microgrid. Bi-directional charging, however, may not be viable in the time frame and ownership model of this project. Currently only the Nissan Leaf allows bi-directional charging, where the storage capacity of the EV can be depleted and used to meet demand on the microgrid. If such a system were included, a 2023 Nissan Leaf has a 40 or 60 kilowatt-hour battery pack.

An electrical microgrid system integrates well with other district-type systems and the community shared resource potential of rooftop photovoltaic panels planned for these sites. Like the cost of PV, battery cost for on-site energy storage should come down with the advancement of new technologies. Microgrid controller technology cost and capabilities vary widely. A utility grade microgrid controller with associated engineering and programming services could be more expensive than the rest of the system combined. A microgrid will help these communities put less strain on the utility grid, make full use of renewable energy generation and provide some level of energy resilience and peace of mind for residents.

Main Switchboard
The main switchboard will include provisions for supply of all housing unit electrical panels and the central district HVAC equipment. It will also be the point of connection for the PV inverters and BESS inverter at each site. The main switchboard will also include the following key components to enable microgrid operation at each MCHP site.

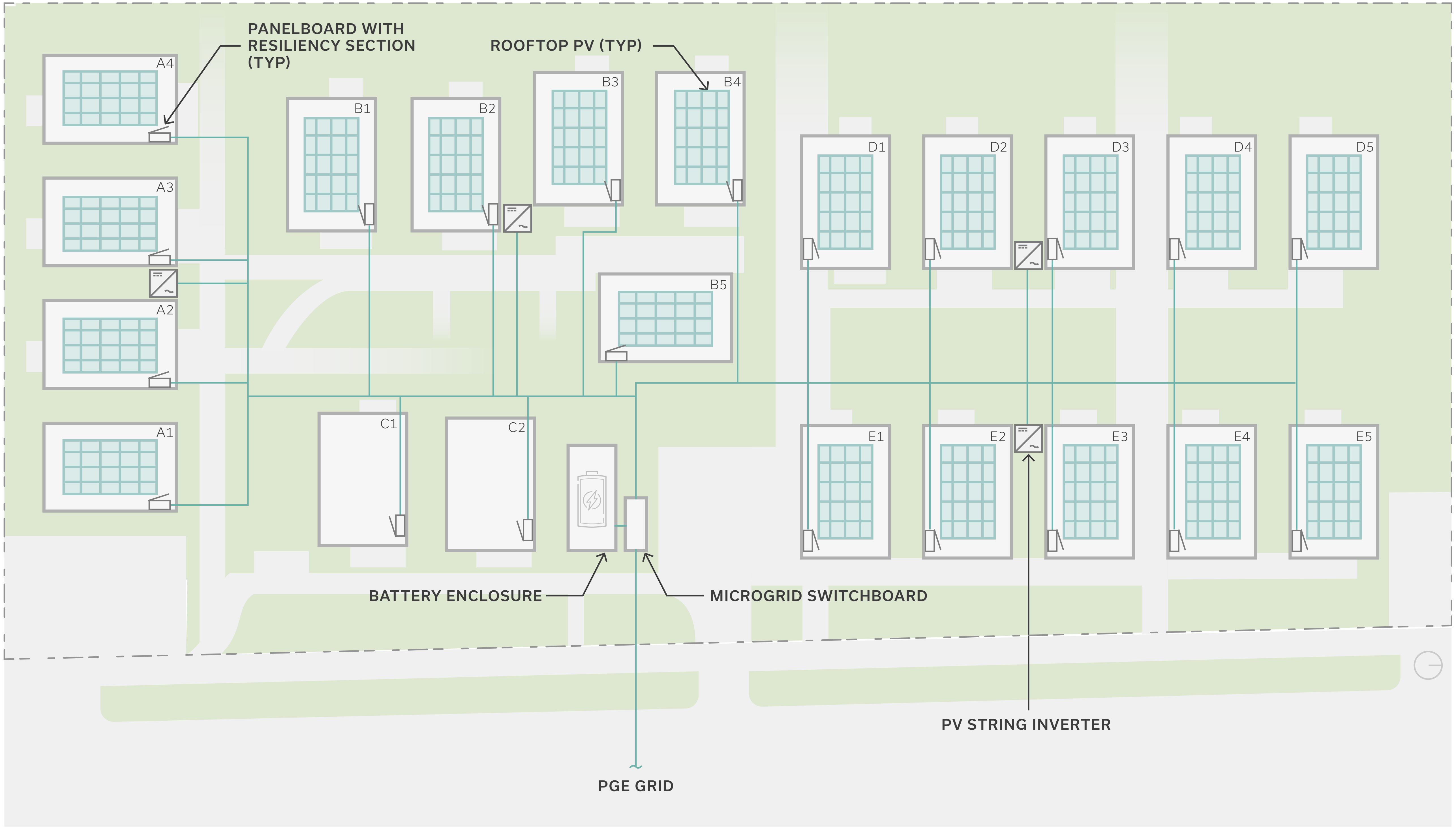
3.5 MICROGRID

1. **DER Disconnect** – The Distributed Energy Resource (DER) Disconnect is a single point of disconnecting means for the entire site. It permits the utility to safely disconnect and isolate the facility microgrid system from the utility grid should that be required for utility grid repair operations. The DER disconnect will include a visible open inspection window and a locking hasp to enable utility lock-out-tag-out procedures. This single disconnecting mean with location as indicated in the concept one line diagram is preferred over individual disconnects for the PV and battery systems that would prohibit operation of the facility microgrid if utilized by the utility during as outage event.
2. **MID Breaker and Relay** – The Microgrid Interconnect Device (MID) and associated controlling relay serve as the automatic means of disconnection for the facility electrical power system from the utility grid. The MID breaker must be electrically operable and accompanied by the MID Relay which will supervise voltage, frequency and power flow at the MID breaker. If the MID relay detects out of tolerance voltage or frequency, as would be the case during a power grid brownout/blackout, it will command the MID breaker to open and signal the microgrid control system (via its local agent) to initiate the sequence of operations to island the facility electrical system.
3. **Microgrid Local Area Network** – The main switchboard is an advantageous location for housing auxiliary components of the microgrid control system including dedicated local area network (LAN) switches. The microgrid LAN will be required for communications between microgrid control agents. The LAN will require a source of uninterruptable power so that the network stays up during microgrid transition or switching events that will cause momentary interruptions on the local electrical power system.
4. **Black Start UPS** – An uninterruptable power supply (UPS) is required to provide what is know as "Black Start" power for the microgrid control system. The UPS provides a continuous source of power for all microgrid control components so that the control components do not suffer a loss of power during transitions from grid connected to islanded and vice-versa. The black start UPS also provides a source of power for the MID breaker's electrically operable opening and closing mechanisms so that the breaker can be operated in the absence of utility power or local microgrid power from the BESS and PV systems.

Agent Based Microgrid
An agent based microgrid control scheme is distinct from a centralized microgrid scheme in that there are multiple microgrid appliances, aka. "Agents" that are utilized to implement the microgrid control system across the site. Agent based microgrid control systems are somewhat more complex than centralized control schemes due to the need to have multiple agents all communicating with each other and with each agent programmed to collaboratively accomplish microgrid switching transitions and steady-state operational modes. The advantage of the agent-based scheme is that it reduces some single points of failure within the control system, and it can potentially operate faster than a centralized scheme because each agent can initiate actions in parallel with each other vs. sequentially as would be the case with a centralized system.

3.5.1 MICROGRID SITE PLANS

Figure 28: District Microgrid – Electric Systems – Site Plan for SE 36th Ave site



3.5.1 MICROGRID SITE PLANS

Figure 29: District Microgrid – Electric Systems – Concept One Line Diagram for SE 36th Ave site

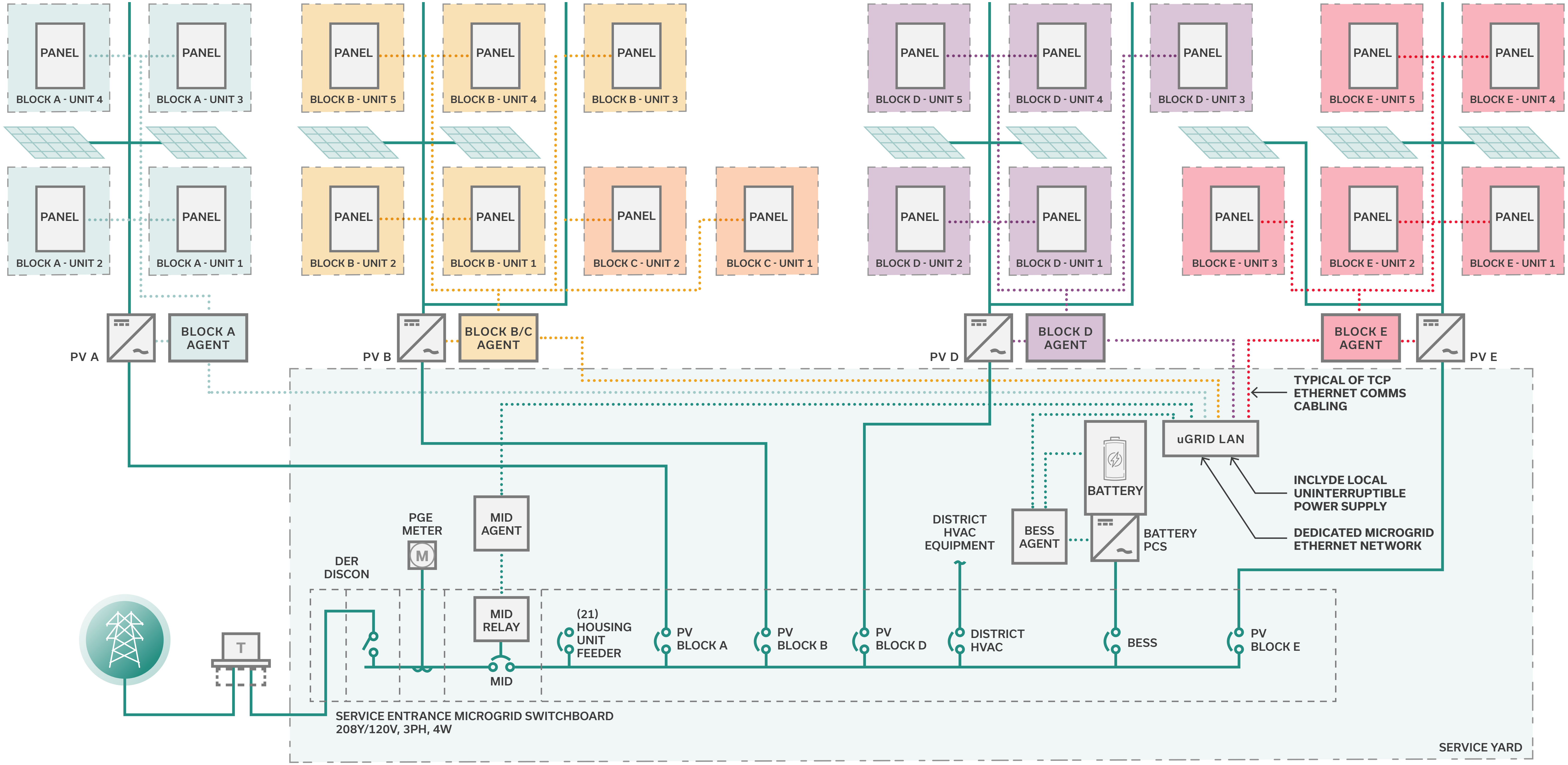
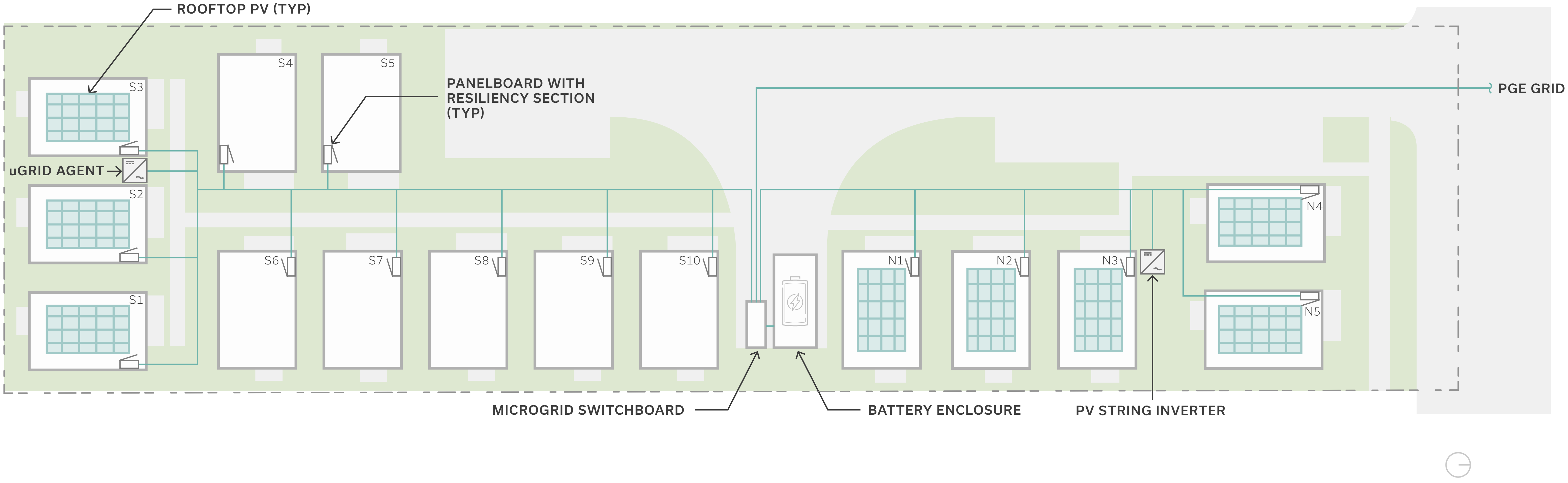
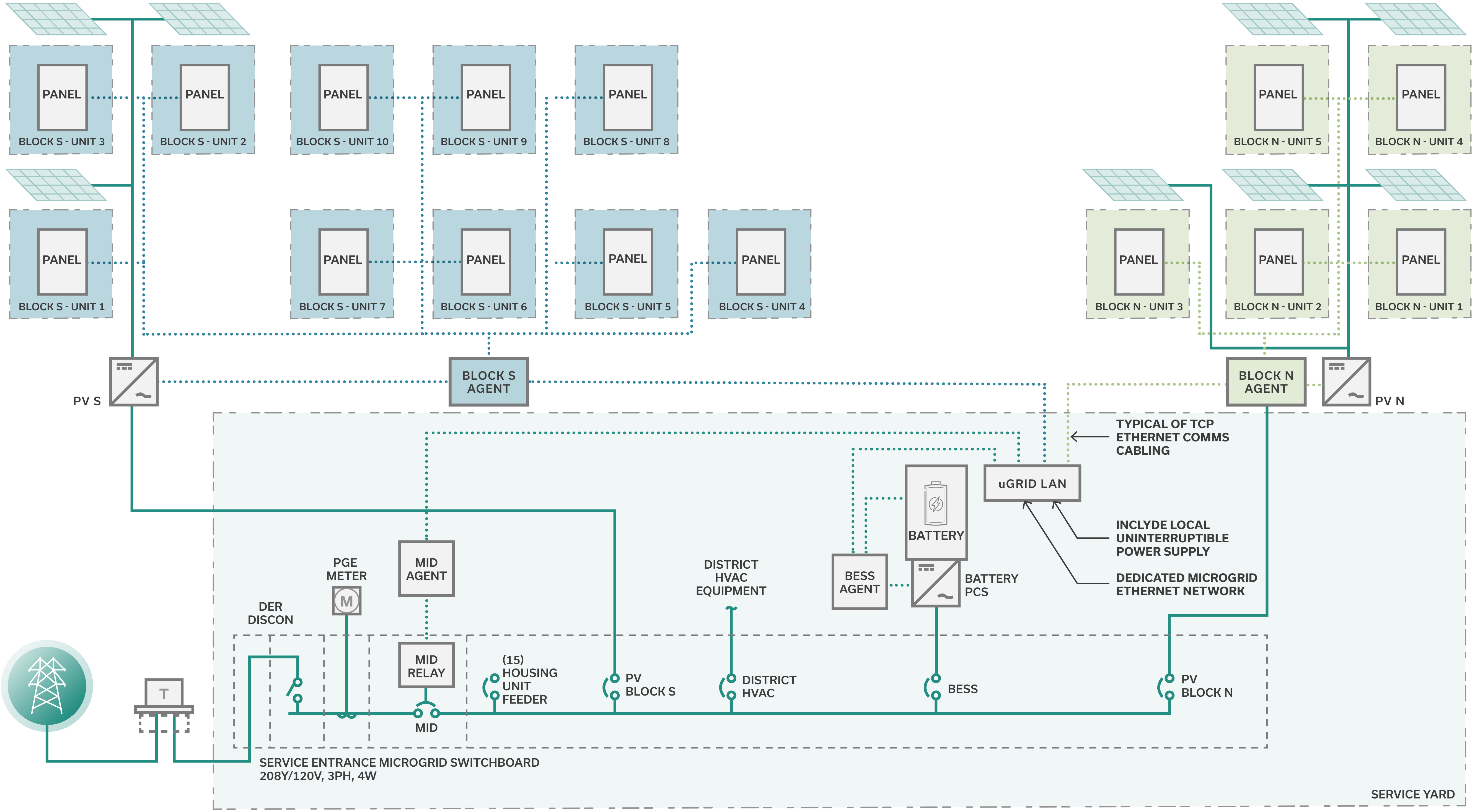


Figure 30: District Microgrid – Electric Systems – Site Plan for SE Harvey site



3.5.1 MICROGRID SITE PLANS

Figure 31: District Microgrid – Electric Systems – Concept One Line Diagram for SE Harvey site



3.5.2 MICROGRID SIZING AND COST

Table 4: Microgrid system sizing and cost scenarios

System Sizing Scenarios

Site/system Component	**Units**	**1. Full day of normal use.**	**2. Full day of normal use for heat/cooling/pump only plus a couple central electric circuits for community to use for charging and minor equipment.**	**3. Utility peak shaving by removing community from the utility network for 5 hours.**
15-unit development	kw	23.3	19.0	23.3
21-unit development	kw	32.6	26.6	32.6
15-unit development	kwh	240.9	170.8	116.3
21-unit development	kwh	337.2	237.0	162.8
15-unit installed battery/inverter/ controller	$	$111,031	$89,639	$105,999
21-unit installed battery/inverter/ controller	$	$155,379	$125,409	$148,335
15-unit installed microgrid controller	$	$7,211	$5,889	$7,211
21-unit installed microgrid controller	$	$10,091	$8,245	$10,091
15-unit total	$	$118,242	$95,528	$113,209
21-unit total	$	$165,469	$133,654	$158,425

4.0

CONCLUSION AND DEVELOPMENT FEASIBILITY

4.0 CONCLUSION AND DEVELOPMENT FEASIBILITY

From a development feasibility standpoint, this research has shown great potential to improve energy efficiency for workforce affordable housing as well as for long-term operational savings for homeowners. The combination of MPP and innovative window assembly, with community solar PV production and centralized hydronic HVAC and hot-water systems, results in a significantly more energy-efficient project as compared to a typical construction strategy.

The solar PV installation results in 62% of energy from solar for the 36th Avenue site and 66% of energy from solar for the Harvey Street site. In particular, the two-story cottage cluster housing design for the development sites optimizes the solar-to-energy usage ratio more efficiently than can be achieved with taller (3–4 story) buildings or with individual home arrays.

There are pros and cons of designing a central community solar microgrid system with centralized MEP systems. Below is a summary of how this research has surfaced opportunities and challenges to meeting the energy, affordability and resilience goals of the project.

Opportunities:

- Save space inside units and keep units compact without in-unit hot water heaters and heating/cooling equipment.
- Utility sharing allows for load balancing across the community.
- Solar PV at the community level provides shared solar output for units with better solar access vs. units that are shaded by tree canopy; also preserves more of the existing tree canopy.
- Allows for the addition of an onsite battery energy storage system (BESS) to provide energy resiliency and support of grid decarbonization. Although this is technically possible at the individual unit level, it's likely more costly and perhaps infeasible due to space constraints. The shared resource approach for renewables and storage is the recommended solution.
- Leverages trenching for central community solar PV; adding lines for central HWH and/or heating/cooling system more efficient.

Challenges:

- Up-front cost for equipment and distribution is more expensive than in-unit systems.
- Sub-metering and management of billing can be expensive and time consuming.
- One option to consider is a microgrid owner/operator partner who would develop, own and operate the system and sell the services to the homebuyers connected to it.

The crux of the development financial feasibility is whether the cost of the solar installation is offset sufficiently by an increase in-unit purchase price due to lower utility expenses for the homeowner. With a homeownership development model, the Federal solar tax credit and MACRS depreciation benefit is not realized in the same way it would be for a multifamily rental development model. There are a few incentives that would likely be eligible in this application.

4.0 CONCLUSION AND DEVELOPMENT FEASIBILITY

Below is a summary of the financial analysis for this strategy:

SOLAR COST CALCULATIONS

All costs are estimations only.

	36 Avenue Site	Harvey Street Site	Total
Solar Sizing	43.7 kW	34 kW	77.7 kW
Solar Installation Cost	140,260	109,183	249,443
Microgrid Infrastructure	80,000	70,000	150,000
Site Distribution (trenching, conduit)	40,000	30,000	70,000
Total Cost	**260,260**	**209,183**	**469,443**
HOMEOWNER AFFORDABILITY CALCULATIONS			
Utility Expense Savings (annual)* *Assumes PGE power rate of $0.12 per KWh	720		
Amortization	30		
Interest Rate	7.00%		
Present Value of Additional Mortgage	8,935		
Number of Units	21	15	36
Total Additional Sales Proceeds	187,627	134,020	321,647
FINANCIAL FEASIBILITY SUMMARY			
Cost After Incentives	221,528	177,375	393,903
Additional Sales Proceeds	(187,627)	(134,020)	(321,647)
Net Cost	**33,901**	**43,355**	**77,256**
Net Cost Per Unit	**1,614**	**2,890**	**2,146**

The concluded net cost for the solar microgrid system is $77,256, or around $2,150 per unit.

4.0 CONCLUSION AND DEVELOPMENT FEASIBILITY

The projected net cost is financially feasible for the model delivering units affordable up to 100% AMI but will require additional subsidy for the model delivering units affordable up to 80% AMI.

Next steps for this team to determine if the proposed solar microgrid and centralized utility strategy is feasible for a “real world” development:

- Engage with PGE to assess whether a true microgrid strategy is feasible.
- Engage with PGE to assess whether a master metering strategy is feasible for a condo homeownership structure.
- Engage MEP consultants to design full systems and price comparatively to conventional single-unit systems.
- Design and price the district heating loop system and utility expense offset.
- Consider emergency/community resilience solar battery back-up system for a reduced power load during an outage.
- Confirm eligibility for ODOE incentive for Low-Income Service Provider for homeownership model. If not eligible, incentive per homeowner will be lower.
- Pursue additional incentives to cover finance gap of solar/microgrid application.