A PROTOTYPE FOR AFFORDABLE, RESILIENT, LOW ENERGY COTTAGE CLUSTER HOUSING

Home Work

UNIVERSITY OF OREGON | Energy Studies in Buildings Laboratory

Energy Trust of Oregon

ACKNOWLEDGEMENTS

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OVERVIEW

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

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.

NEIGHBORHOOD CONTEXT FOR MILWAUKIE, OREGON DEMONSTRATION PROJECT. SITES INDICATED IN YELLOW.

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.

MASS TIMBER/MASS PLYWOOD PANELS

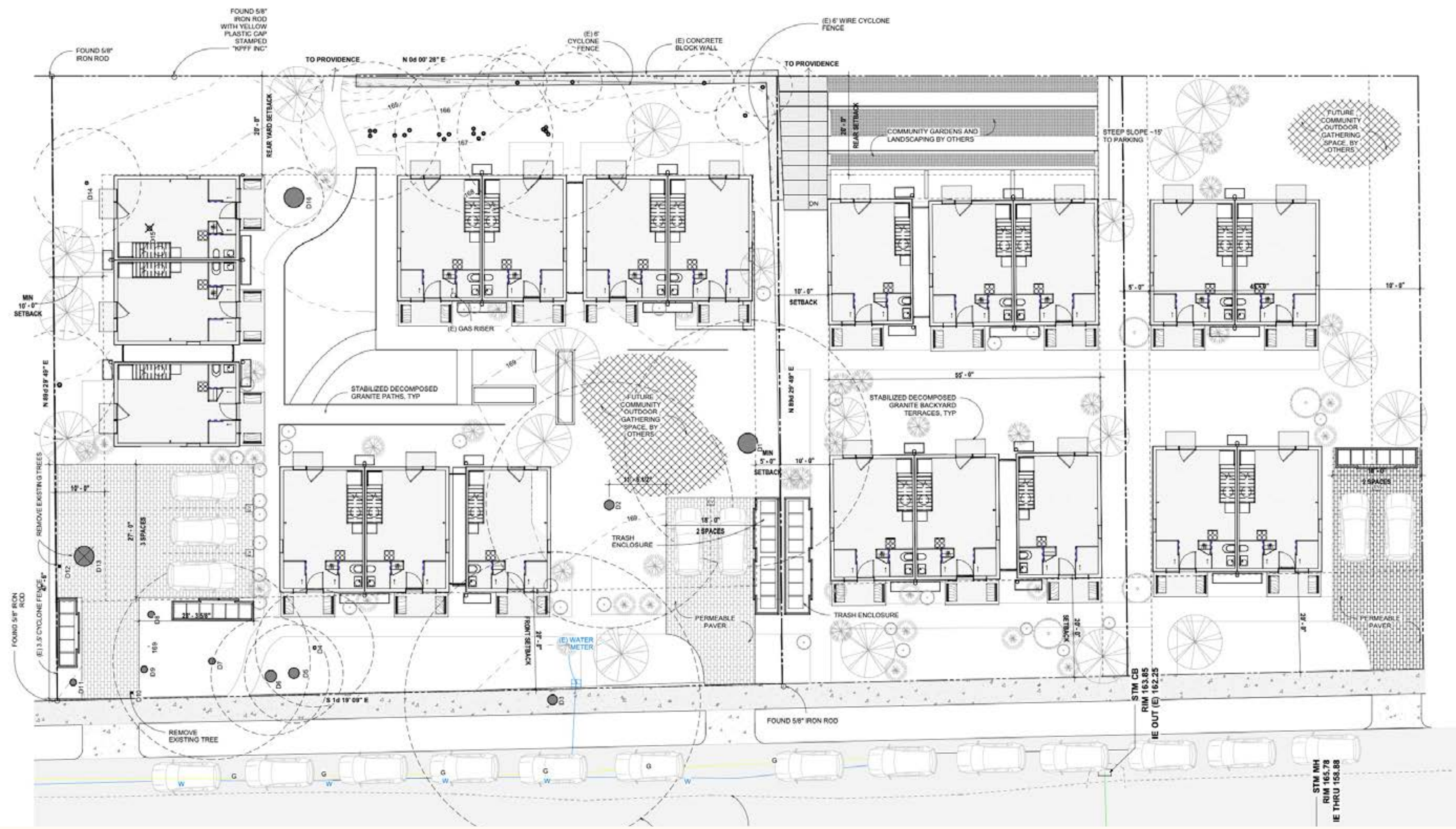
Mass timber construction, in contrast to light-frame wood construction, is built using a category of engineered wood products typically made of large, solid wood panels, columns or beams, often manufactured off site for load-bearing wall, floor and roof construction. The research conducted for this project 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. One property is 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.

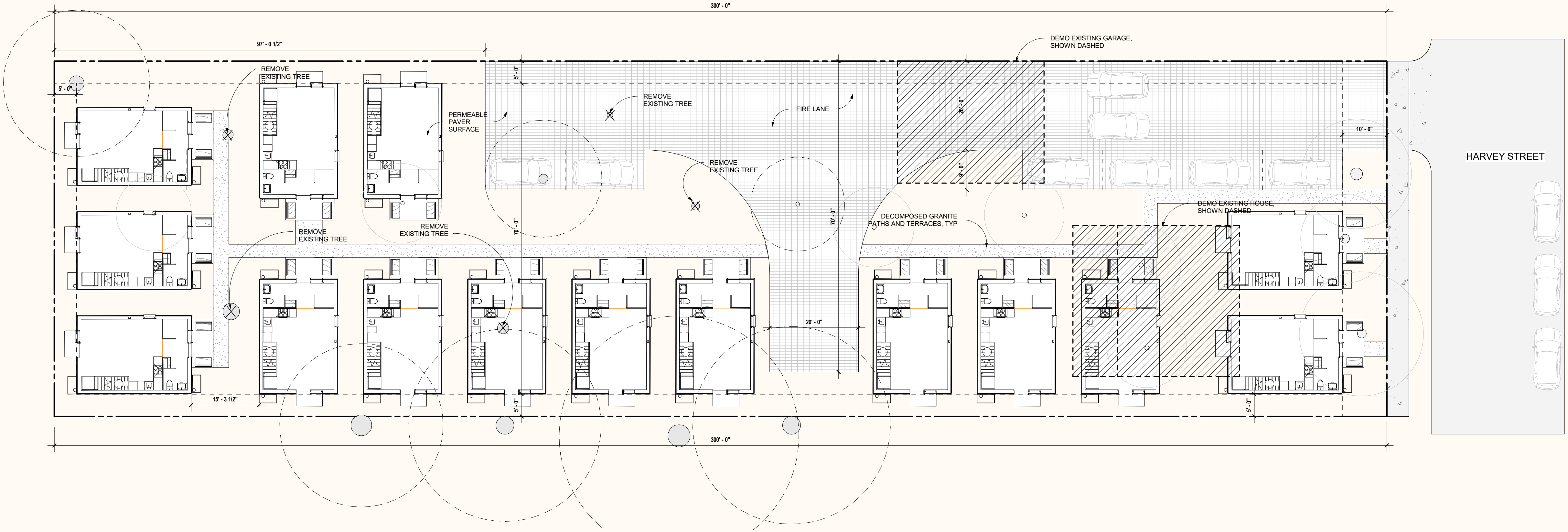
SITE PLAN

36TH AVE PROPERTY // 21 UNITS



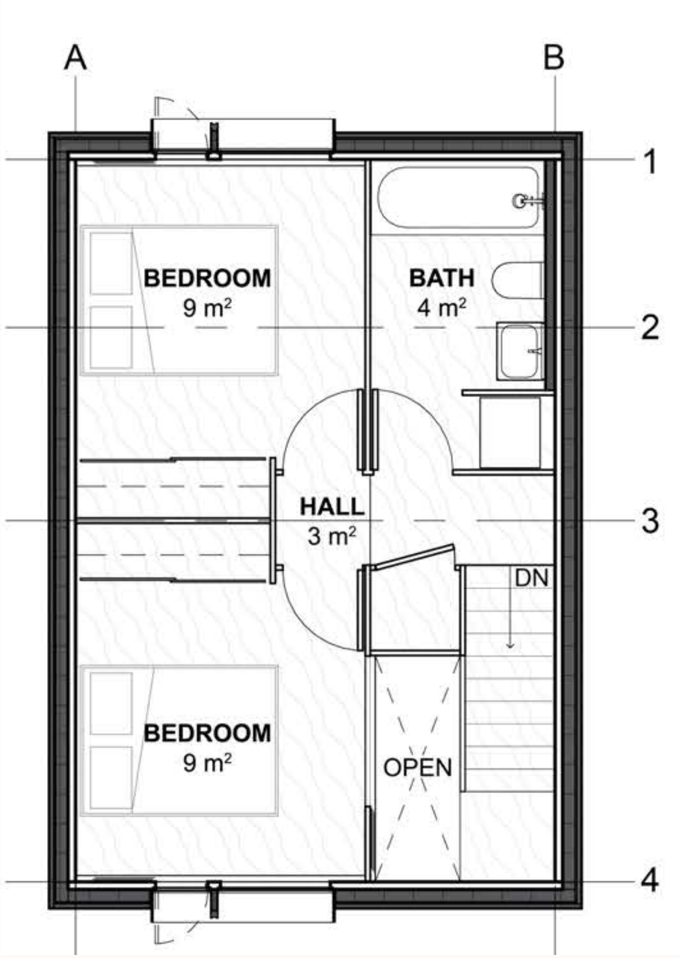
SITE PLAN

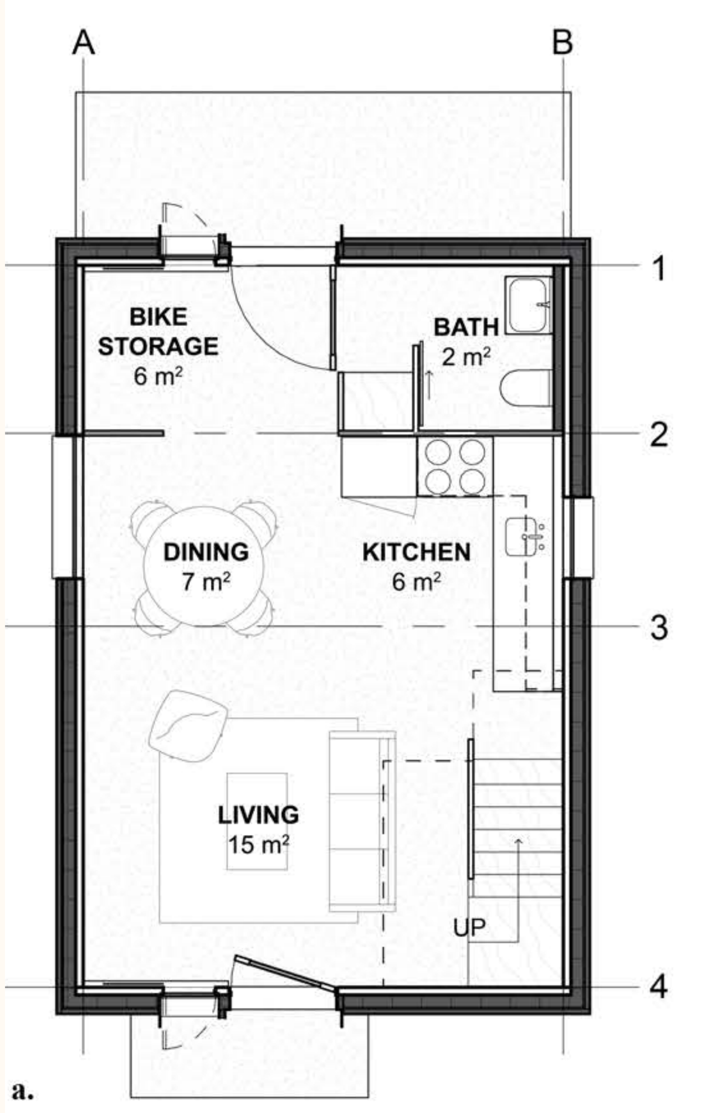
HARVEY STREET PROPERTY // 15 UNITS



UNIT PLAN

TYPICAL UNIT LAY OUT // 900 SF 2-BDRM HOME





RESEARCH

THE RESEARCH ANALYSIS INCLUDES

1. **An energy model** of a prototypical mass timber-panelized single-family home configured either individually for each unit or as a district strategy.

2. **A physical mock-up** of a higher-performance, low-cost window that includes infiltration testing and thermal imaging.

3. **A courtyard "cluster" housing solar analysis** that preserves existing tree canopy on two pilot testing sites in Milwaukie, Oregon.

4. **A solar microgrid cluster analysis.**

5. **Development feasibility analysis.**

FINDINGS

- Combining mass plywood panels (MPP), innovative window assembly, community solar 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); requires additional subsidy for affordability at 80% AMI.
- The project addresses overlapping issues that are designed to benefit the end users: smart densification, operational efficiency, and below market-rate housing.

Image credit: Simone O'Halloran

RESEARCH

ENERGY MODEL [1]

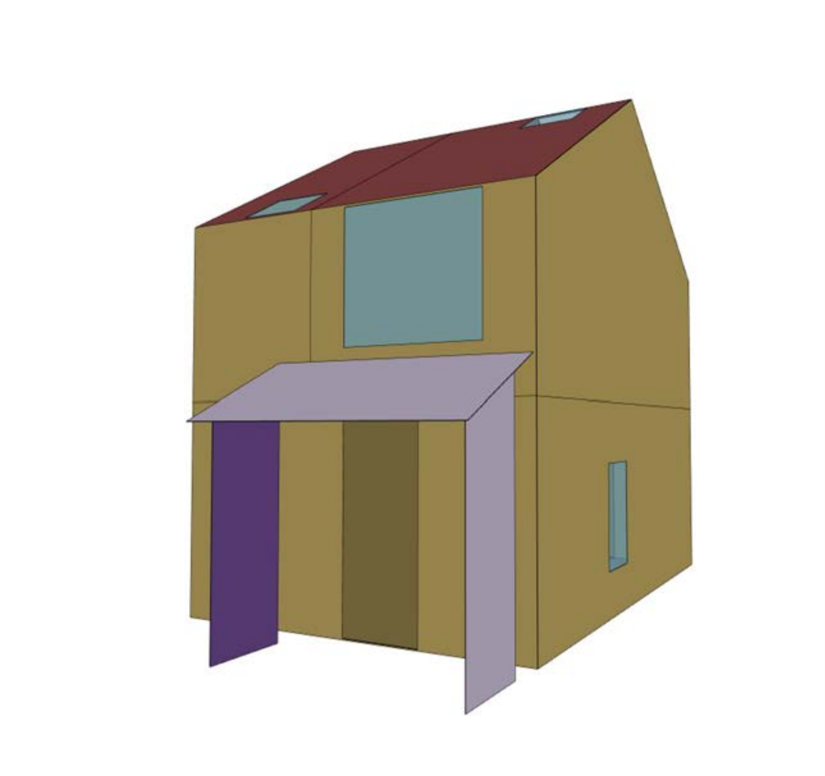
- The energy analysis is based on a combination of Honeybee 1.4.0 (via Grasshopper and Rhinoceros 7) and OpenStudio 3.3.0, both of which rely on EnergyPlus 9.6.0 for the annual energy calculations.
- The model performance is reflective of the Department of Energy (DOE) Zero Energy Ready Homes (ZERH) standard, which is summarized in the table to the right.
- 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.

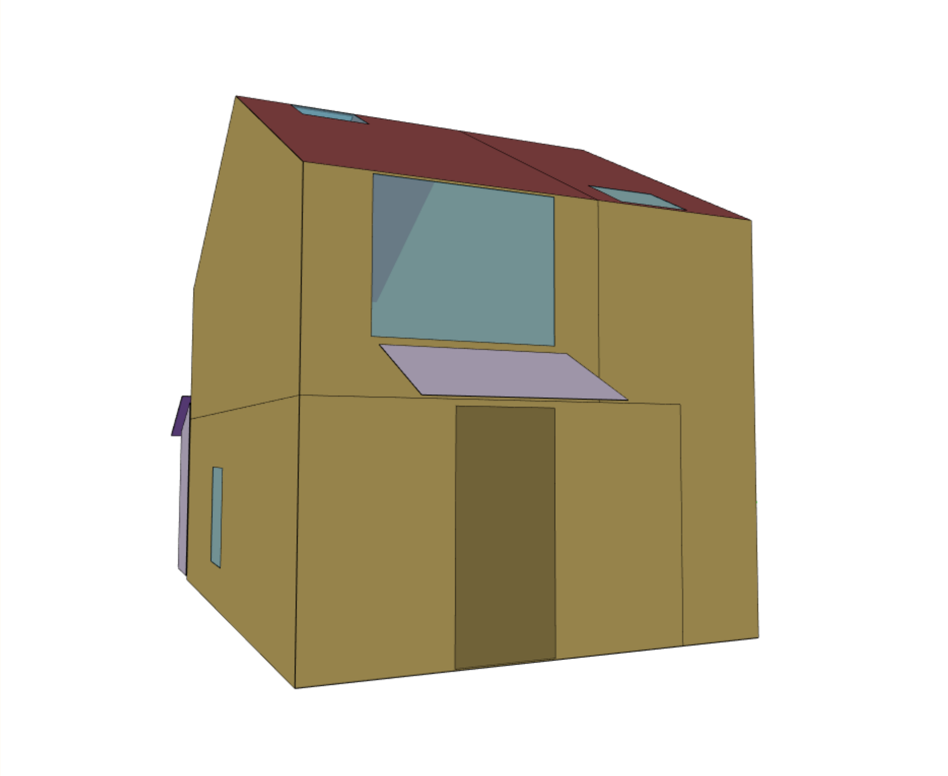
	Component	Input
Envelope	Slab Edge Perimeter	R-10 W/ 2-ft. Vertical Depth (F-0.540)
	Wall Insulation—Above Grade	R-20 (U-0.060)
	Windows	U-0.27/SHGC 0.30
	Exterior Doors	U-0.32
	Flat Ceilings	R-49 (U-0.021)
Mechanical Components	Split Heat Pump (Electric)	HSPF 10.0
	Split Cooling (Electric)	13 SEER
	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

RESEARCH

ENERGY MODEL [1]

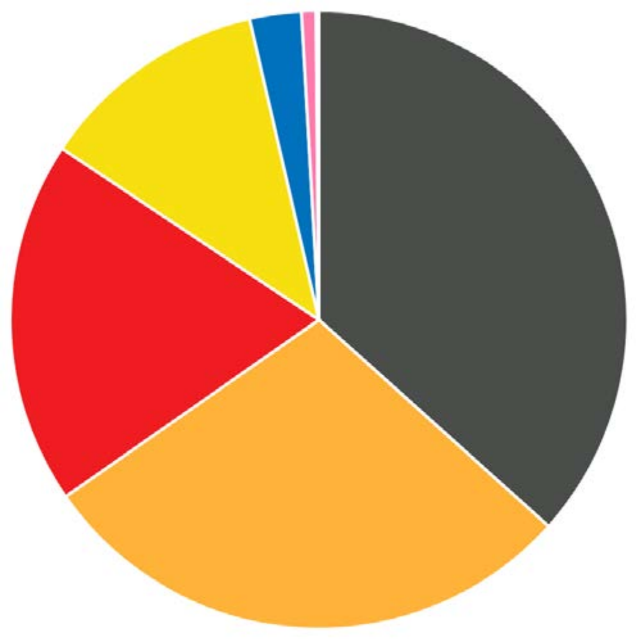
OPENSTUDIO MODEL OF MPP GEOMETRY



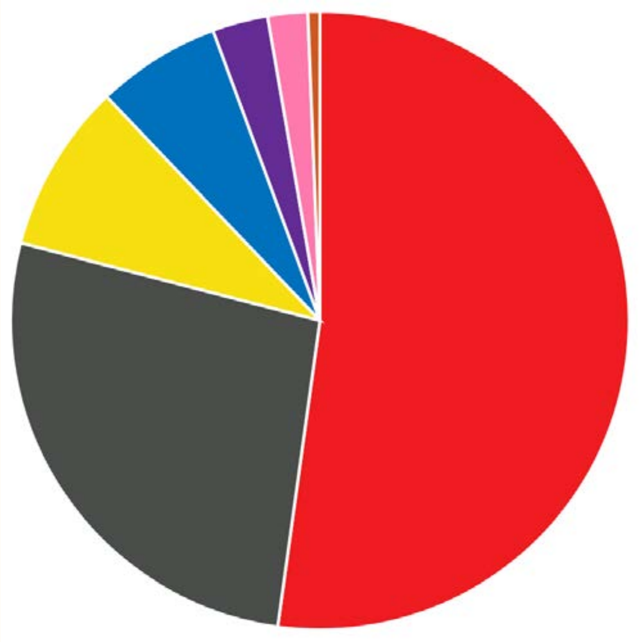


ENERGY MODEL [1]

ANNUAL ENERGY END-USE BREAKDOWN FOR PACKAGED HEAT PUMP BASELINE

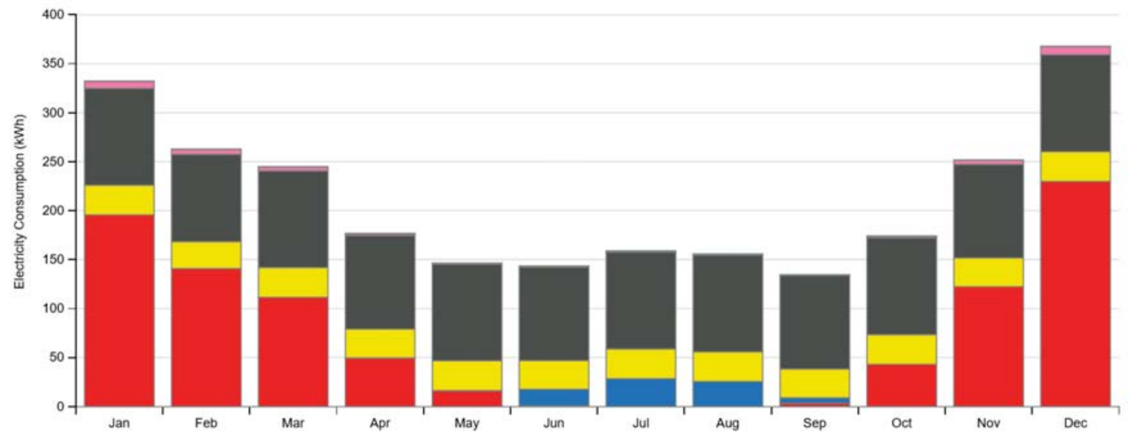


ANNUAL ENERGY END-USE BREAKDOWN FOR 15-UNIT DISTRICT HVAC SCHEME

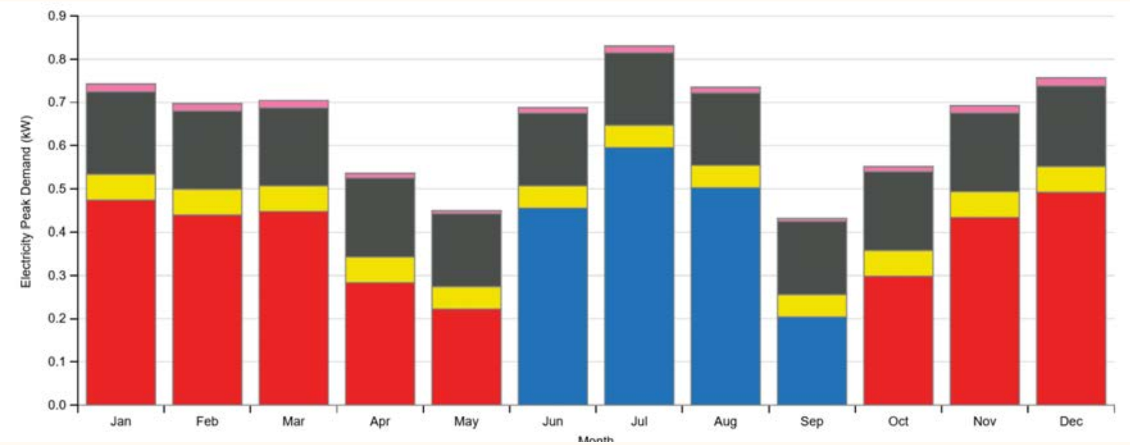


RESEARCH

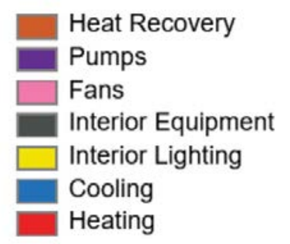
ENERGY MODEL [1]



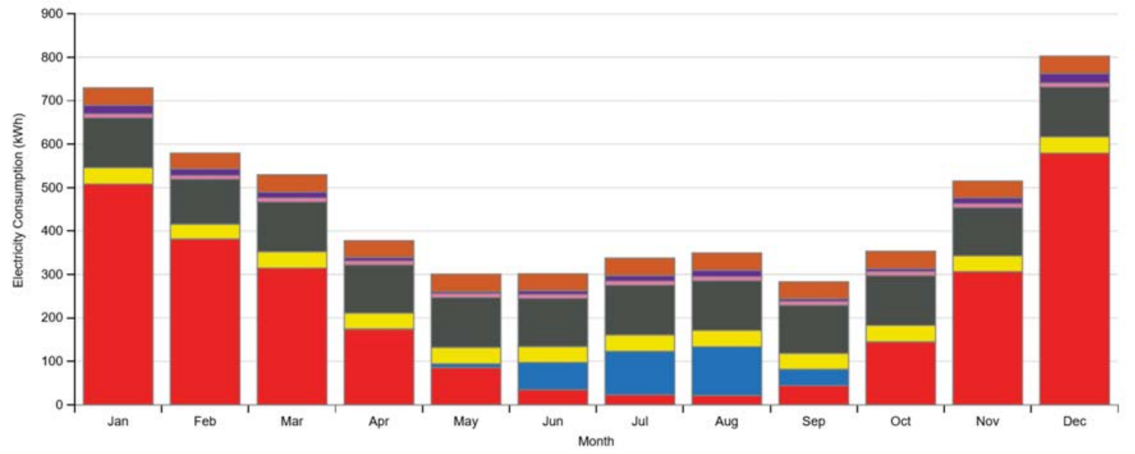
MONTHLY OVERVIEW OF ENERGY CONSUMPTION BY END USES FOR PACKAGED HEAT PUMP BASELINE



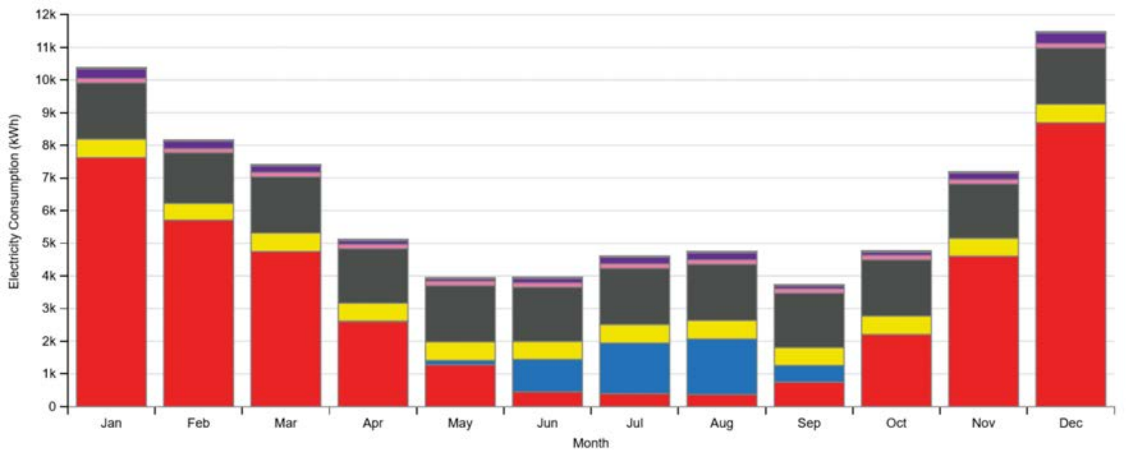
MONTHLY PEAK ENERGY DEMAND BY END USES FOR PACKAGED HEAT PUMP BASELINE



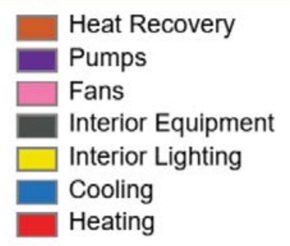
ENERGY MODEL [1]



MONTHLY OVERVIEW OF ENERGY CONSUMPTION BY END USES FOR SINGLE-UNIT RADIANT SLAB HVAC SCHEME



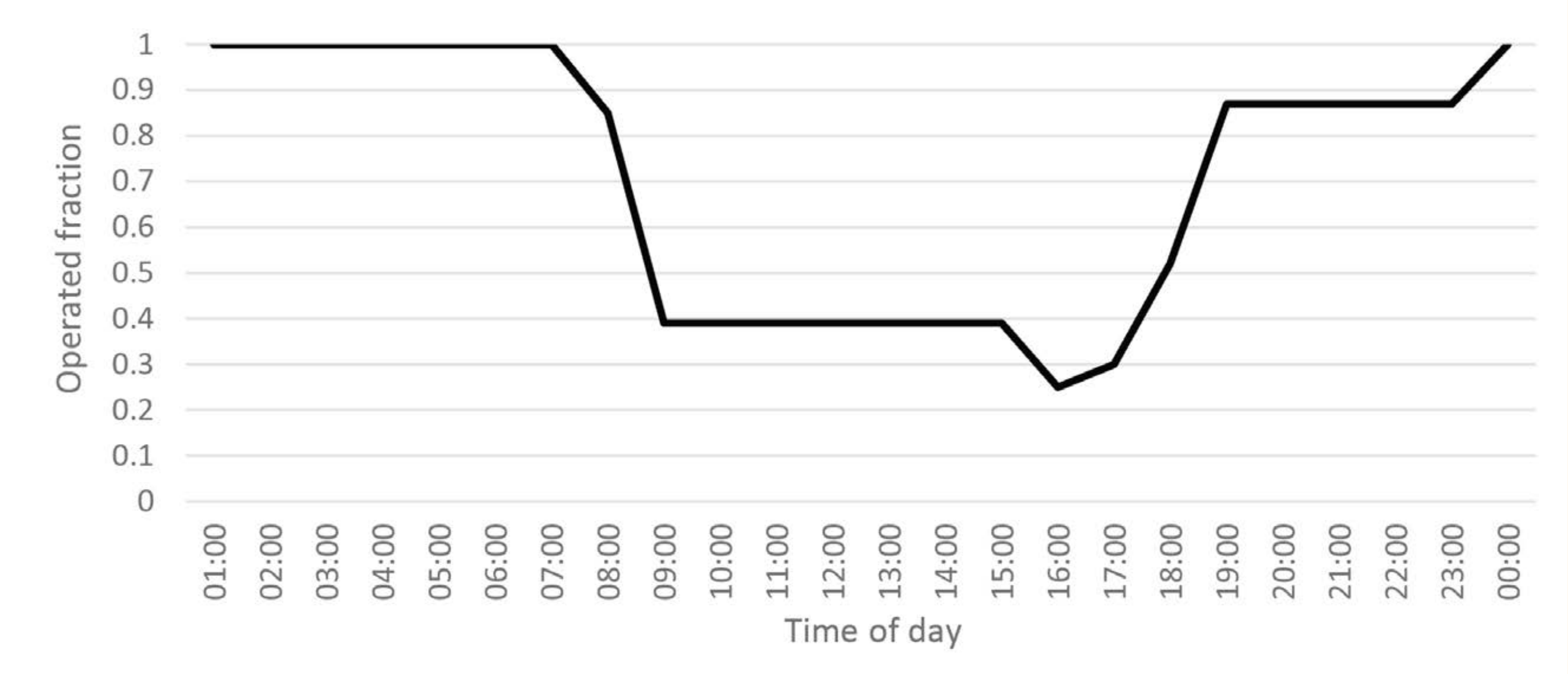
MONTHLY PEAK ENERGY DEMAND BY END USES FOR 15-UNIT DISTRICT HVAC SCHEME



RESEARCH

ENERGY MODEL [1]

EXAMPLE OF GENERALIZED SINGLE-FAMILY DWELLING OCCUPANCY SCHEDULE (DOE/PNNL)



RESEARCH

ENERGY MODEL [1]

TWO VENTILATION STRATEGIES

1 Natural ventilation

2 A balanced mechanical ventilation system

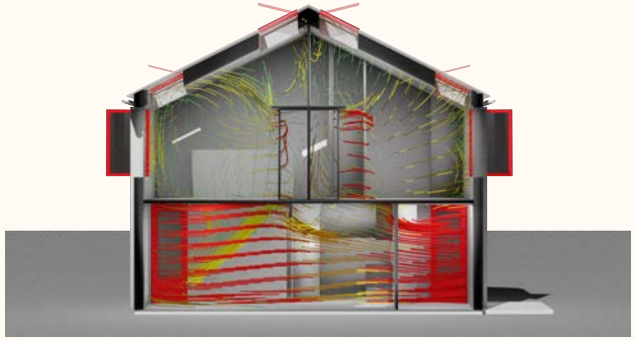
ZONING

- The living space that contains the entirety of the first floor;
- The circulation corridor that contains the stairs and upstairs hallway, and;
- The upstairs bedrooms.

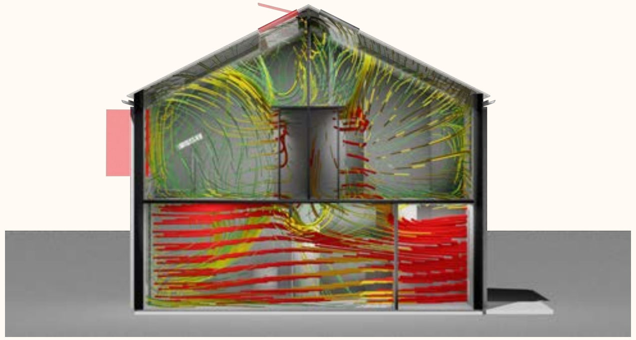
EQUIPMENT

The equipment loads are based on ENERGY STAR® Appliances.

CROSS+STACK VENTILATION: ALL OPEN, 1 M/S WIND, CONDITION B



CROSS+STACK VENTILATION: ALL OPEN, 2 M/S WIND, CONDITION B

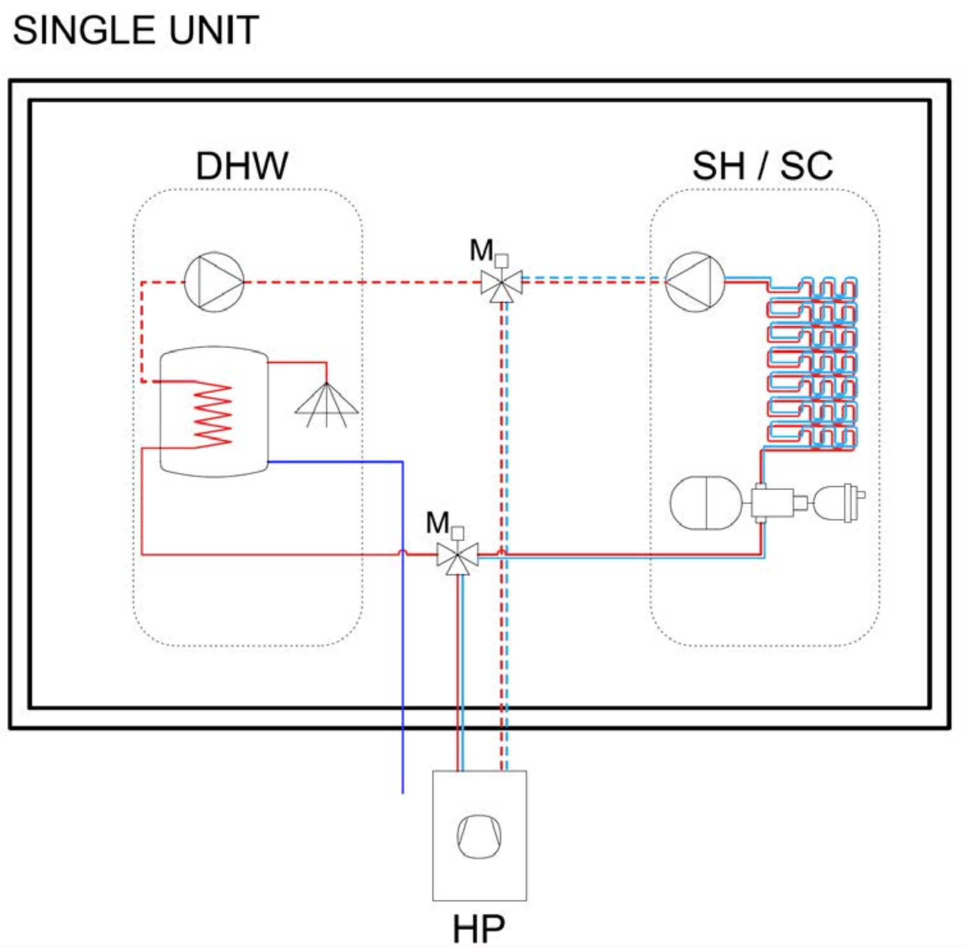


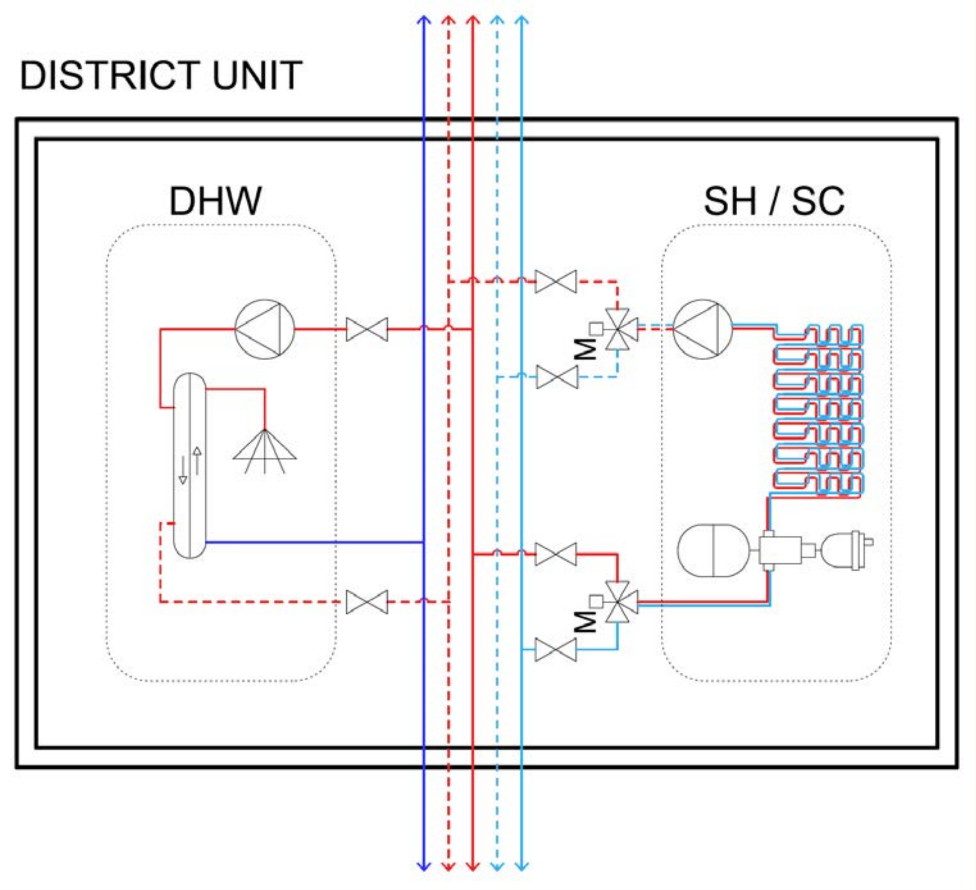
EXAMPLES OF ENERGY STAR CERTIFIED EQUIPMENT THAT MAKE UP THE EQUIPMENT LOADS

Type	Make/Model	Energy use	Cost
Laundry Washer (stackable)	Beko WTE7604XLW0	67 kWh/year	$849
Laundry Dryer (stackable)	Samung DV25B69**H*	125 kWh/year	$1,165
Dishwasher	Fisher & Paykel DD24STX6I1	113 kWh/year	$1,199
Refrigirator	Insignia NS-RTM10BK2	283 kWh/year	$360
Range	Magic Chef MCSRE24S	1200W-2200W	$1,079
Microwave	Panasonic NN-SN67HS	1200W	$155
TV	Spectre 435BV-F	65.4 kWh/year	$158
Laptop	Misc.	10 kWh/year	$1,300-$3,500

RESEARCH

ENERGY MODEL [1]

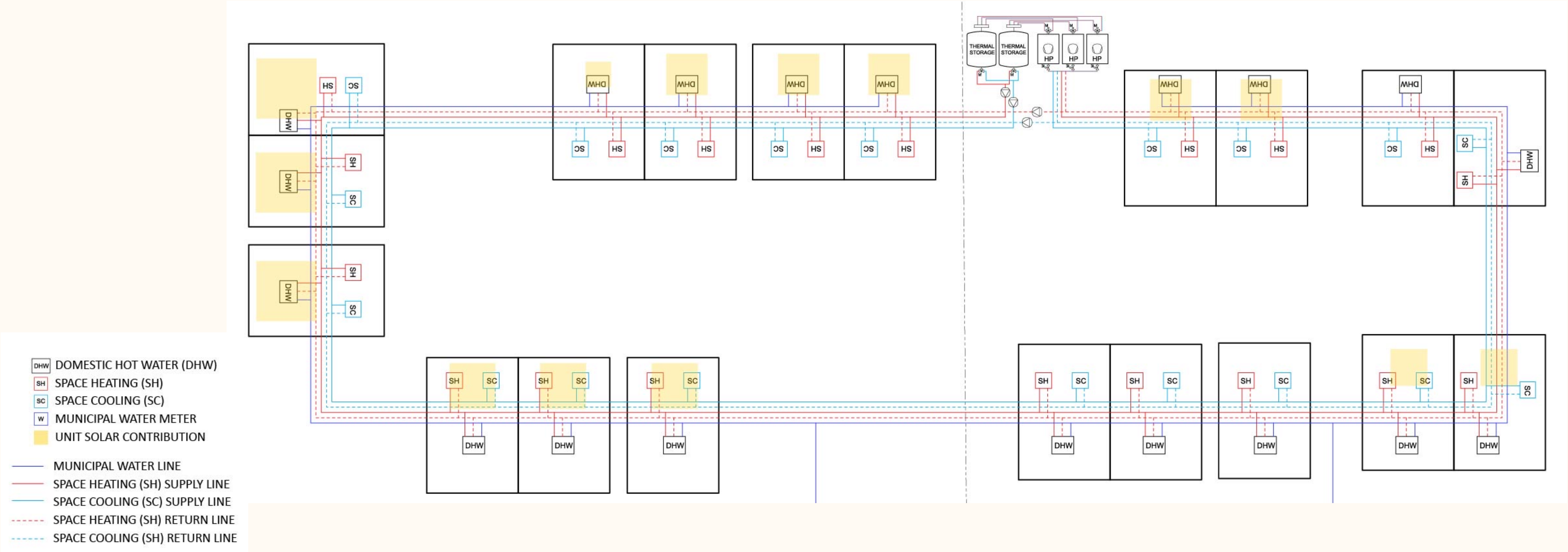




RESEARCH

ENERGY MODEL [1]

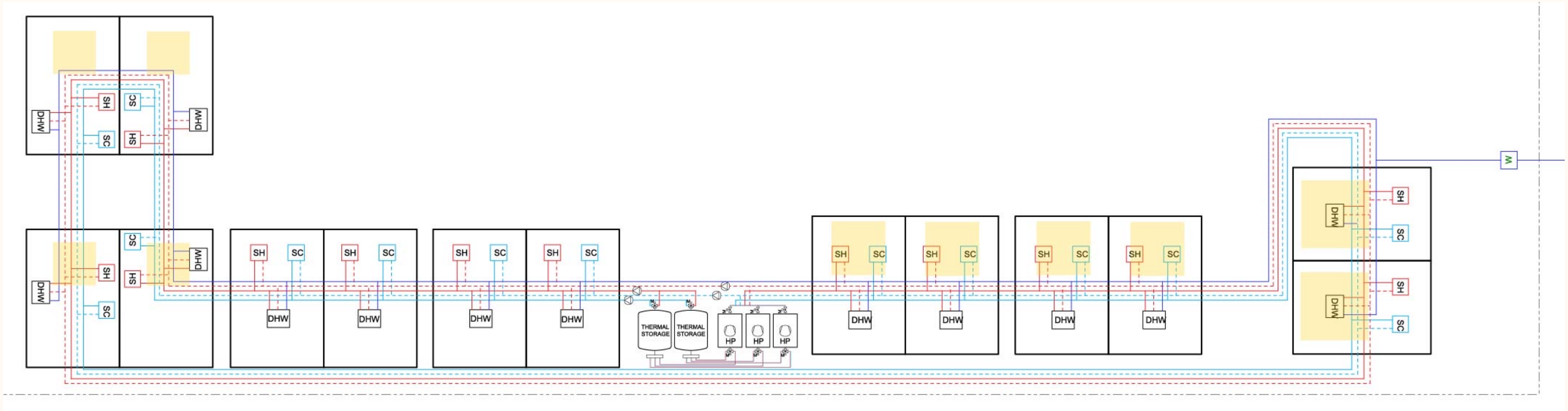
MEP SYSTEMS SCHEMATIC // SE 36TH AVE SITE



RESEARCH

ENERGY MODEL [1]

MEP SYSTEMS SCHEMATIC // SE HARVEY ST SITE



RESEARCH

MOCK-UP [2]

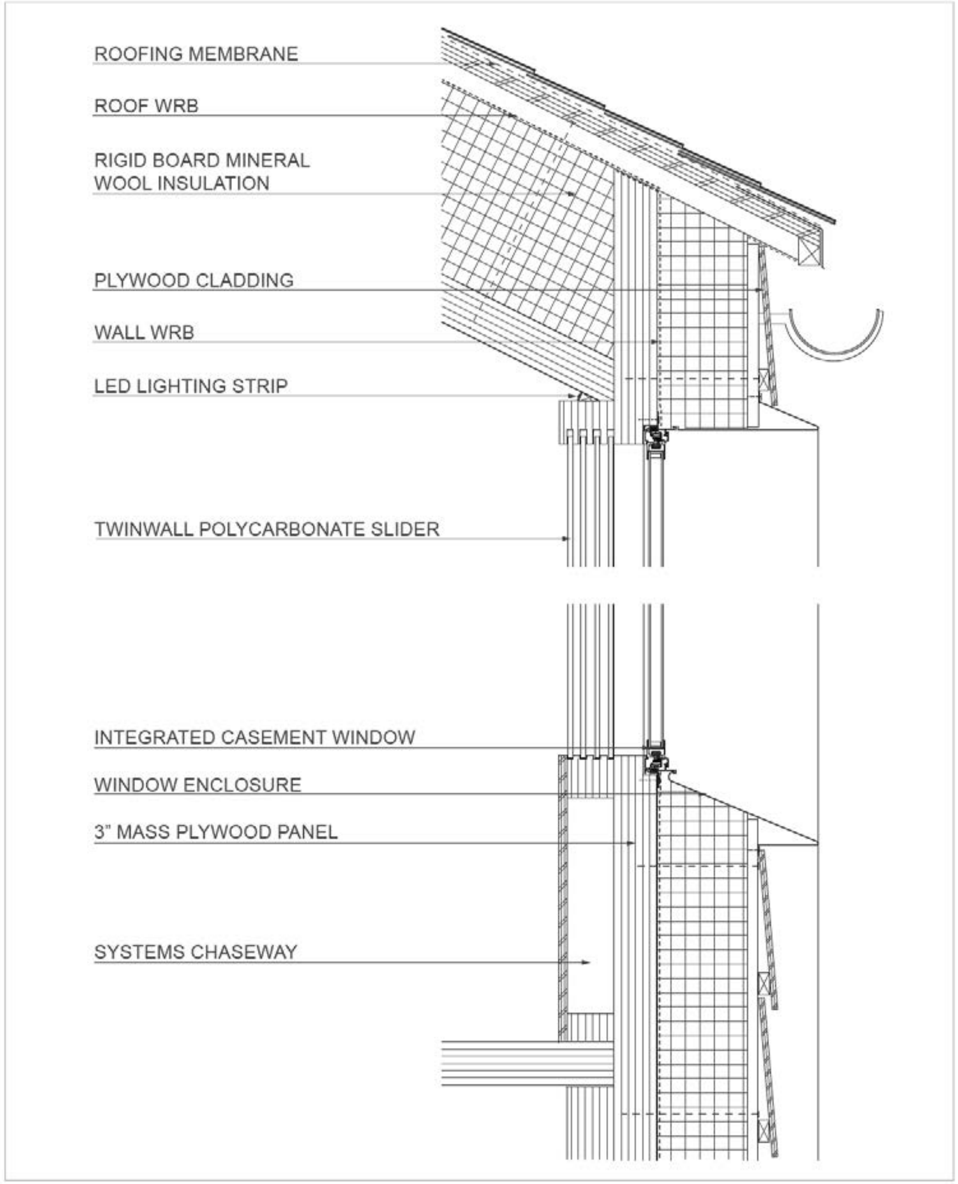
WINDOW MOCK-UP FABRICATION

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 intent was to have the MPP serve as both structure, finish material and frame insulation; thus, requiring no additional trim work or finish treatment.

One benefit to panelized wall construction using MPP is a significant reduction in the possible locations for air infiltration to occur.



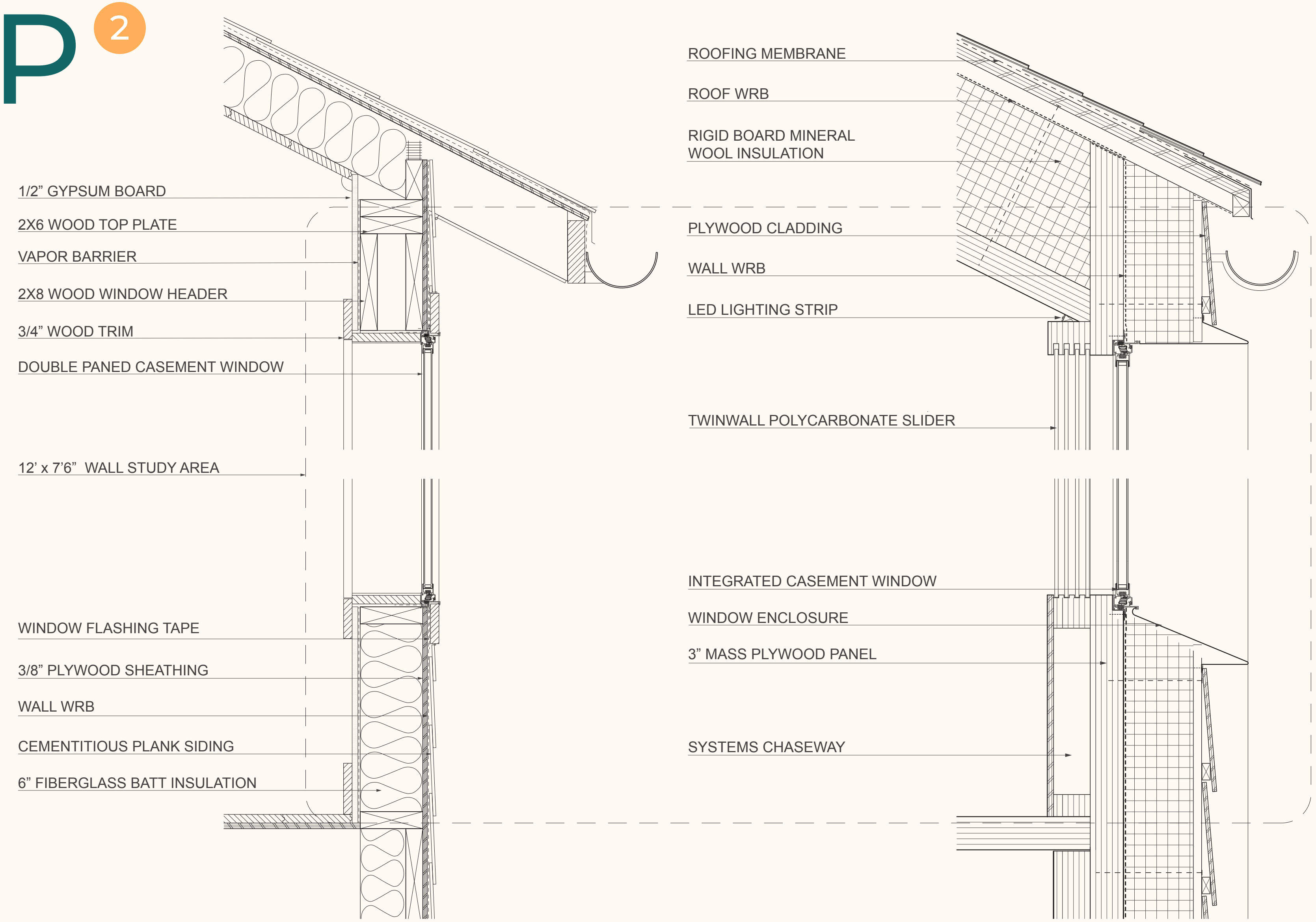
RESEARCH

MOCK-UP 2

CONVENTIONAL VS MPP MOCK-UP WINDOW SECTION DETAIL

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.

One benefit to panelized wall construction using MPP is a significant reduction in the possible locations for air infiltration to occur.



RESEARCH

MOCK-UP 2

MODELING & FABRICATING FINISHED WINDOW OPENINGS IN MPP

RESEARCH

MOCK-UP 2

MODELING & FABRICATING FINISHED WINDOW OPENINGS IN MPP

RESEARCH

MOCK-UP 2

PERFORMANCE TESTING

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.

INTERIOR THERMAL IMAGING OF ENCLOSED AND HEATED MOCK-UP; OPERABLE WINDOW

INTERIOR THERMAL IMAGING OF ENCLOSED AND HEATED MOCK-UP; FIXED WINDOW

RESEARCH

MOCK-UP [2]

BLOWER DOOR TESTING AND PRESSURIZED SMOKE 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.

RESEARCH

MOCK-UP 2

CONVENTIONAL WINDOW VS 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**

RESEARCH

SOLAR ANALYSIS

3

SITE IMAGES OF TREE CANOPY ON BOTH SITES

RESEARCH

SOLAR ANALYSIS

3

PV SOLAR STUDY

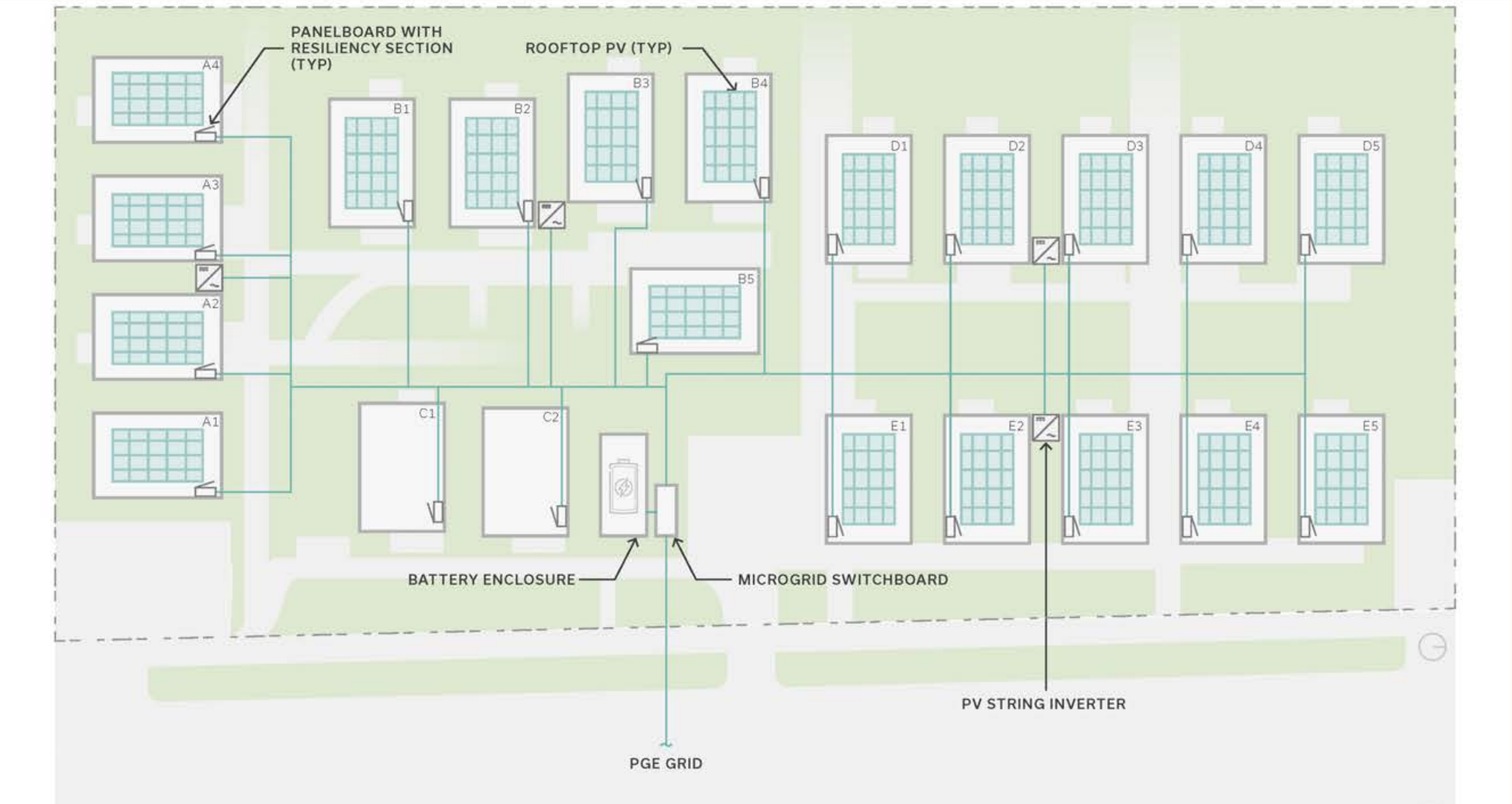
Solar Study by Energy Design

RESEARCH

MICROGRID ANALYSIS

4

DISTRICT MICROGRID SITE PLAN // 36TH AVE SITE



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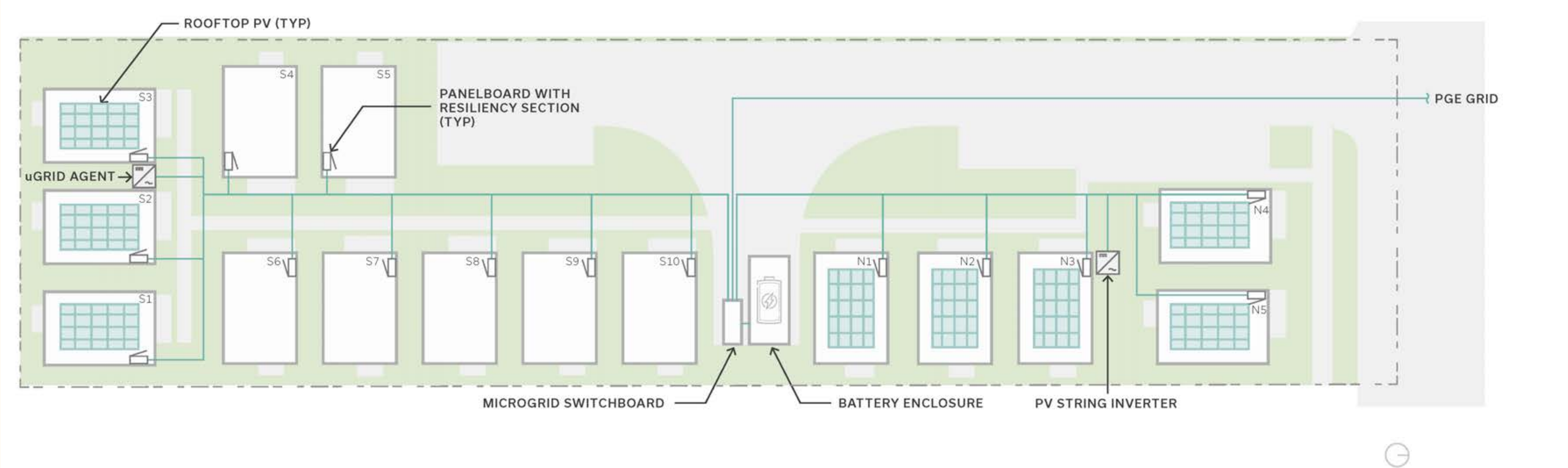
RESEARCH

MICROGRID ANALYSIS

4

DISTRICT MICROGRID SITE PLAN // HARVEY ST. SITE



RESEARCH

MICROGRID ANALYSIS

4

SWITCHBOARD COMPONENTS

DER DISCONNECT

- Distributed Energy Resource (DER) Disconnect is a single point of disconnecting means for the entire site.
- 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.

MID BREAKER AND RELAY

- Microgrid Interconnect Device (MID) and controlling relay serve as the automatic means of disconnection for the power system from the utility grid.

MICROGRID LOCAL AREA NETWORK

- The microgrid LAN (at the main switchboard) is required for communications between microgrid control agents.

BLACK START UPS

- An uninterruptable power supply (UPS) is required to provide what is know as "Black Start" power for the microgrid control system.
- UPS provides a continuous source of power for all control components to avoid loss of power during transitions from grid connected to islanded and vice-versa.

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.
- Advantages over a centralized control scheme include reduction of single points of failure and potential to operate faster.

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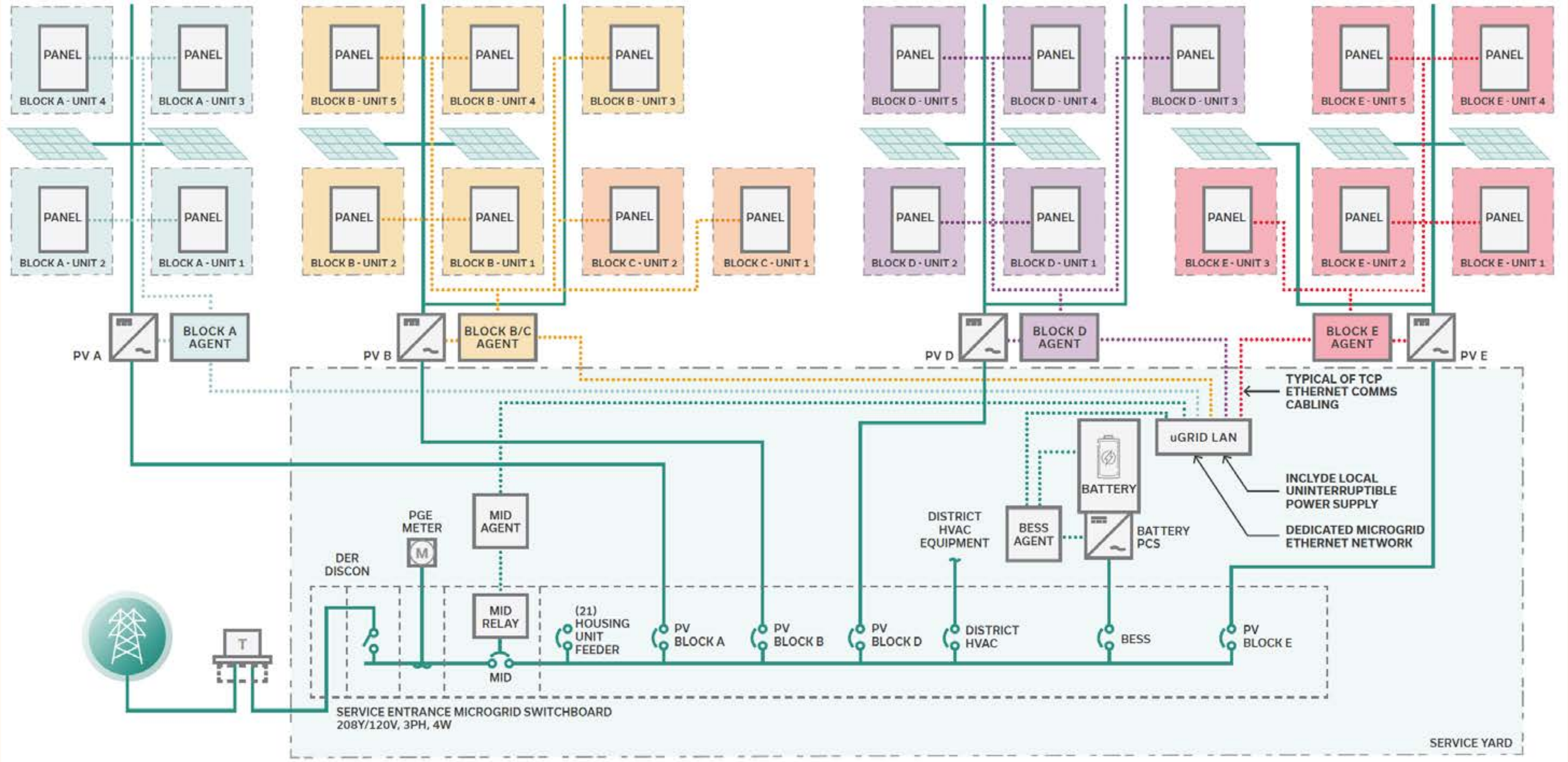
RESEARCH

MICROGRID ANALYSIS

4

DISTRICT MICROGRID CONCEPT ONE LINE DIAGRAM // 36TH AVE SITE



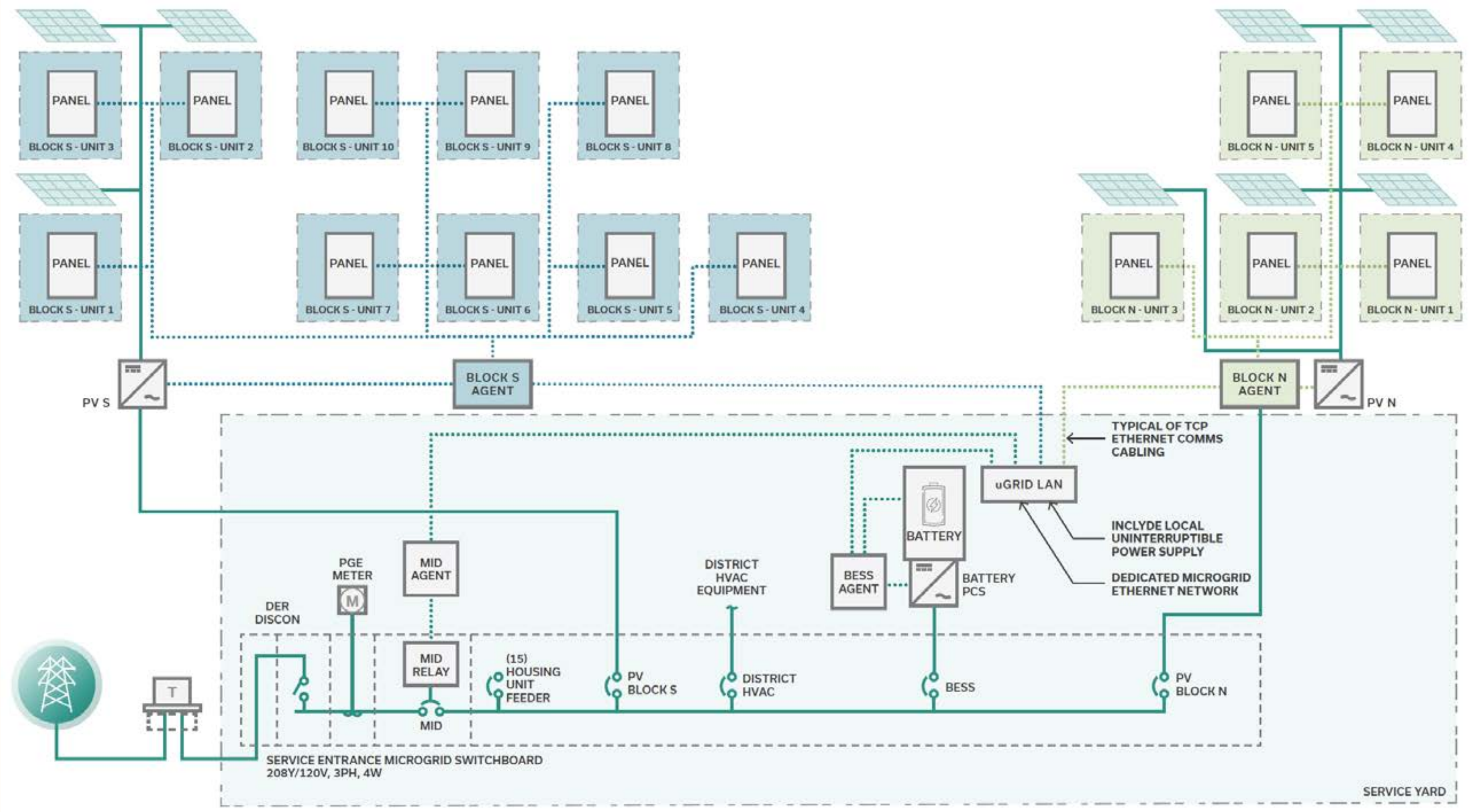
PAE

RESEARCH

MICROGRID ANALYSIS

4

DISTRICT MICROGRID CONCEPT ONE LINE DIAGRAM // HARVEY ST. SITE



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RESEARCH

MICROGRID ANALYSIS

4

MICROGRID COST CONSIDERATIONS

A cottage cluster microgrid system would be a relatively small system. 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.

Component cost per MW goes down as overall system size increases and as system complexity decreases.

Image credit: Simone O'Halloran

FINANCIAL ANALYSIS

5

DEVELOPMENT FEASIBILITY

- Costs shown are estimates for install of the community solar PV system, not including battery back-up.
- With affordable homeownership, the purchase price is capped at a level affordable at a specific AMI. With reduced utility costs the home-owner can afford to pay more for the home within their affordable level.
- Utilizing available ODEO incentives, this table shows how the net cost per unit can be achievable for affordable homes up to 100% AMI, with minimal net cost add.

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.

DEVELOPMENT POTENTIAL

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.
- 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.

NEXT STEPS

NEXT STEPS TO DETERMINE IF THE PROPOSED SOLAR MICROGRID AND CENTRALIZED UTILITY STRATEGY IS FEASIBLE:

- 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.

THANK YOU

Home Work

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