NET ZERO ENERGY ALLEY DWELLING INITIATIVE FINAL REPORT

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BUILDING INNOVATION DESIGN ASSISTANCE GRANT

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GRANT PERIOD: MAY 18, 2021 - SEPTEMBER 30, 2021

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PROJECT SUMMARY AND GOALS

ENERGY

The Net Zero Energy Alley Dwelling Initiative is a project by a group of two architects, a builder, and a property developer, to design a proto-type two-story dwelling for an alley lot in the District of Columbia with the objective of creating strategies for cost-effective net zero energy construction of this housing type. A net zero energy (NZE) building is one that produces as much, or more, energy from renewable sources than the building consumes over the course of a year.

This report shows how the group analyzed the schematic, Passive House design of this building to determine the best options for massing, solar orientation, shading, fenestration, and building envelope strategies to ensure it is capable of meeting the requirements of a zero energy building that is durable, affordable, and build-able with readily available materials and basic construction skills. A Passive House building is one that maximizes strategies for summer shading, winter heat gain, and natural ventilation. A Passive House uses continuous insulation and air-tight construction, along with shading and heat gain strategies to minimize the amount of heating and cooling that needs to be added by mechanical means. With the addition of renewable energy sources, like solar photo-voltaic panels, a Passive House building can operate at zero energy over the course of the year.

The results of this project are a series of recommendations for cost-effective, easy to build, energy efficient wall assemblies that contribute to a successful zero energy structure that can be deployed on designs for houses on alley lots throughout the city. The Net Zero Energy Alley Dwelling Initiative supports the goals of Clean Energy DC by promoting knowledge of net zero energy design and construction.

SOCIAL ENGAGEMENT

The project has partnered with teachers and students at Phelps Architecture, Construction and Engineering (ACE) High School, a public preparatory and vocational school in the District of Columbia, to create opportunities for students to learn Passive House principles, and the building science behind assembly details contributing to a high performance, zero energy building. Understanding the building science related to moisture flow through a building enclosure is important to ensure that water vapor is not allowed to condense inside the building walls, roof or floors which could lead to deterioration of materials or mold growth.

The project team has developed building science and energy analysis content to complement the school’s core curriculum and team members will deliver classroom lessons during the 2021/22 school year. The team has also created workshops for students to build full-scale construction models of walls developed through this grant. Community volunteers experienced with high-performance construction techniques, will assist in the workshops.

INTRODUCTION TO ALLEY LOTS

The District of Columbia has a long and complicated history with alley dwellings, housing units located on lots that abut alleys rather than regular streets. In the early 20th century there were thousands of inhabited dwellings on the District's alleys. Many of those were demolished by mid-century. Few new alley dwellings were constructed in the latter half of the 1900s, in part because the 1958 zoning code heavily restricted alley uses.

In 2016, the District government adopted its first major zoning revisions since 1958, known as ZR16. One component of ZR16 was a wholesale revision of the zoning rules for alley lots, including provisions that allowed dwelling units to be constructed by right if the lot meets a minimum size, and the dwelling is maximum two stories, not more than twenty feet high, with only a single dwelling unit per lot. Alley dwellings also require at least one parking space.

In the District, there are over 700 vacant alley lots that are above the minimum square footage for development (450 ft2). While there are some alley lots that are quite large--over 3000 ft2--most are smaller. The median size of a vacant alley lot in DC is just over 1000 ft2, which is about two-thirds the size of the alley lot we use in our case study.

ALLEY DWELLING AFFORDABILITY

Alley lots are generally less desirable than street-facing lots, since they look out upon the 'working' parts of the city, like backyards, garages, and loading areas. Most alley lots in DC are small, and the dwellings that can be constructed on them are also small. Alley lots are typically rectangular, meaning the typical building constructed will be a rectangular box. And the architectural forms common in alleys are simple, pragmatic, and without the adornment of many street-facing homes. Because many alley lots are zoned for house construction by right, they are simpler to develop than other sites that might require lengthy review and approvals. One caveat to the affordability of developing housing on alley lots, is that some alley lots require expensive infrastructure to connect to water and sewer.

For all of these reasons, alley lots are well-suited to constructing dwellings that are relatively more cost-effective than typical DC single family homes. The lots are less expensive, the buildings have relatively less square footage, the architectural styles are simple, and the structures are relatively simple to build. While alley lots are not a solution to the District's affordable housing problem, they can be an important part of supporting affordability by increasing the amount of lower cost, available housing units. Alley lots can support a single family home at a price point that will be lower than a street-fronted row house.

PROJECT DESCRIPTION

ALLEY DWELLING ENERGY

Small buildings pose challenges when it comes to achieving some high performance building certifications, like Passive House, since the ratio of living space to building envelope--walls, floor, and roof--is higher than for larger buildings. Typically, the greatest energy demand in a single-family house is driven by the loss of heating or cooling through the building envelope. On the other hand, small houses use less energy overall than larger houses, so alley lots are consistent with low energy use buildings, including those that meet Net Zero Energy targets. Our goal in this research is to determine how to build cost-effective, easily buildable, high-performing homes on alleys.

TARGET AUDIENCE

The Net Zero Energy Alley Dwelling Initiative targets property-owners, designers, engineers, builders, and students to prepare them to participate in NZE design and construction with a knowledge base of successful, low-cost NZE strategies. The project engages students through a partnership with Phelps ACE High School. The curriculum and workshops developed for Phelps can inform future curriculum and support engagement with other students at local schools throughout the District and metro area. The project engages designers, property-owners, developers, and builders through the publication of this report that will be coordinated for dissemination with the DC Department of Environment and Energy, and the Net Zero Energy Coalition - National Capital Region. Residents of the District will benefit from the educational opportunities presented by this project. Designers, property-owners, developers and builders working in the District will benefit from shared knowledge of net zero energy strategies. Long term benefits to the District will be an increased building stock of net zero energy buildings and lower carbon emissions.

METHODOLOGY

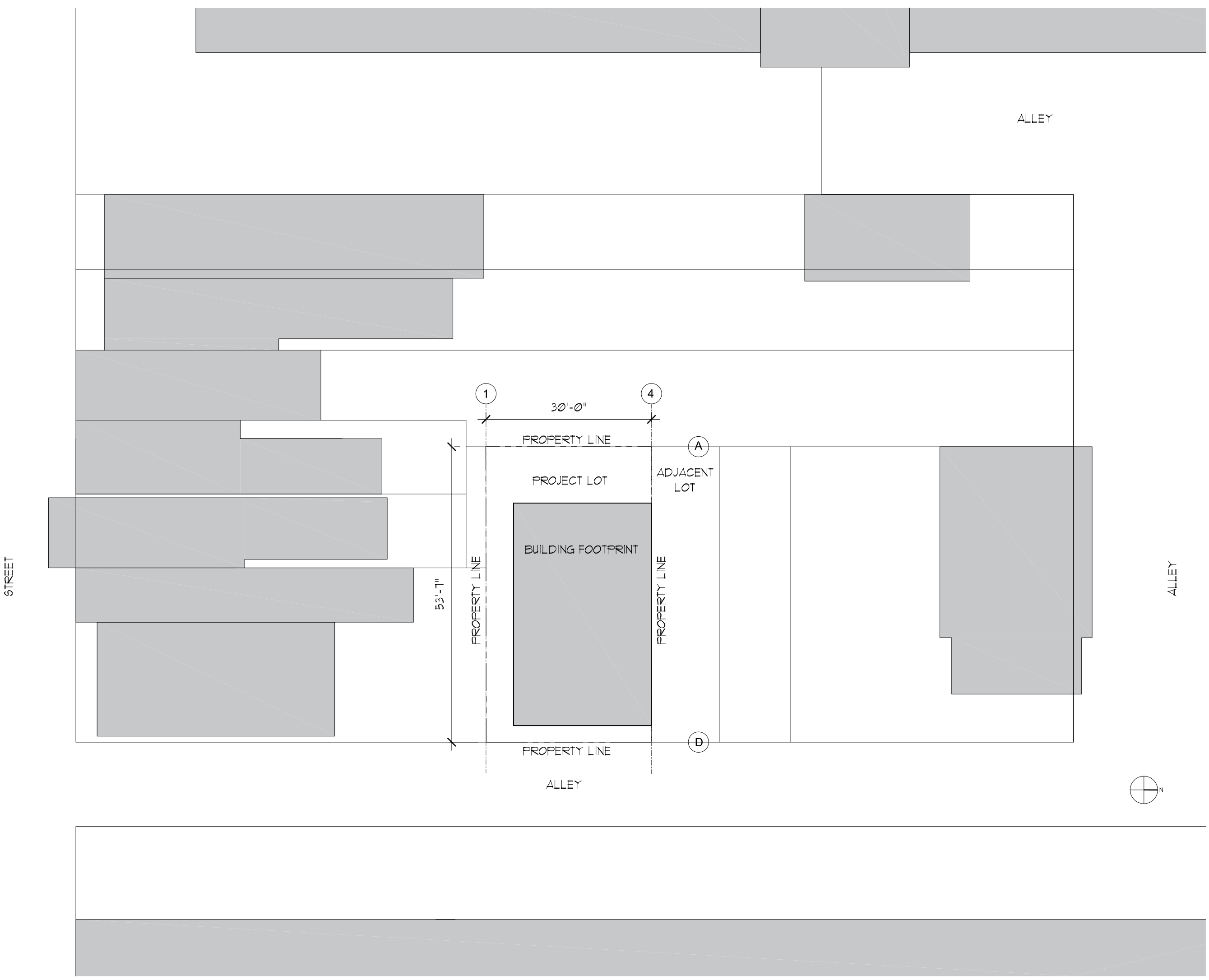
The Net Zero Energy Alley Dwelling Initiative team has used recognized energy modelling, building analysis software, and other architectural design tools to explore the appropriate massing, orientation, and window to wall ratio strategies to support a net zero energy design. The team has used that analysis to design building slab, wall and roof assemblies and then analyzed them in relation to heat gains and losses, and in consideration of moisture management, to come up with several wall assemblies that support a zero energy building. The design team then worked with the general contractor to price the several vetted options in terms of materials cost and ease of construction to come up with the recommendations for cost-effective, easily built wall assemblies.

A successful zero-energy building requires the careful integration of wall, floor and roof assemblies; windows and doors; mechanical and ventilation strategies; as well as lighting, equipment; and even occupant patterns of use. The scope of this study is not to recommend a fully detailed zero-energy building construction strategy, but rather to introduce the concepts of an integrated zero-energy building and show that the wall assemblies for these buildings do not need to be complicated or expensive.

SCHEMATIC DESIGN

ZONING CONSIDERATIONS

The design team made some initial decisions regarding alley lot zoning regulations and did not position the dwelling to the front and rear set-backs, as allowed by the zoning rules. The relatively large size of our lot made this an easy decision. The property lines are shown in the site plan below on column lines 1, 4, A, and D. The team pulled the front of the building 3 feet from the property line to provide a buffer space when entering and exiting the building. The team pulled the rear of the building 11 feet from the property line to provide back yard space at the first floor and a deck at the second floor, as well as space for ground-mounted heat pump compressor units. On the

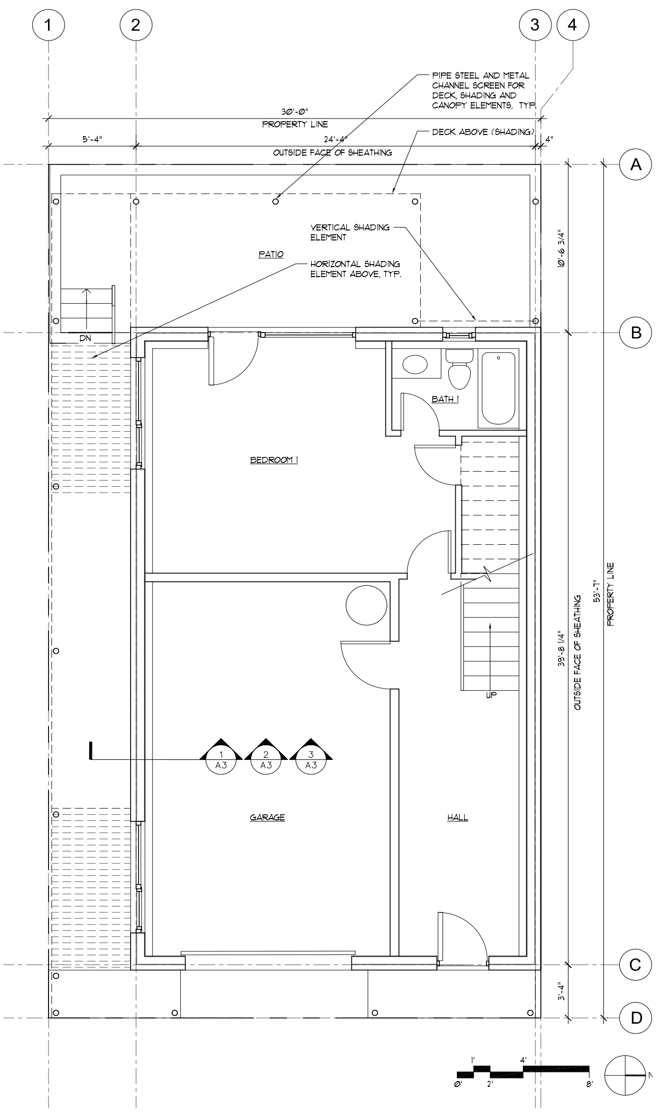


SITE PLAN

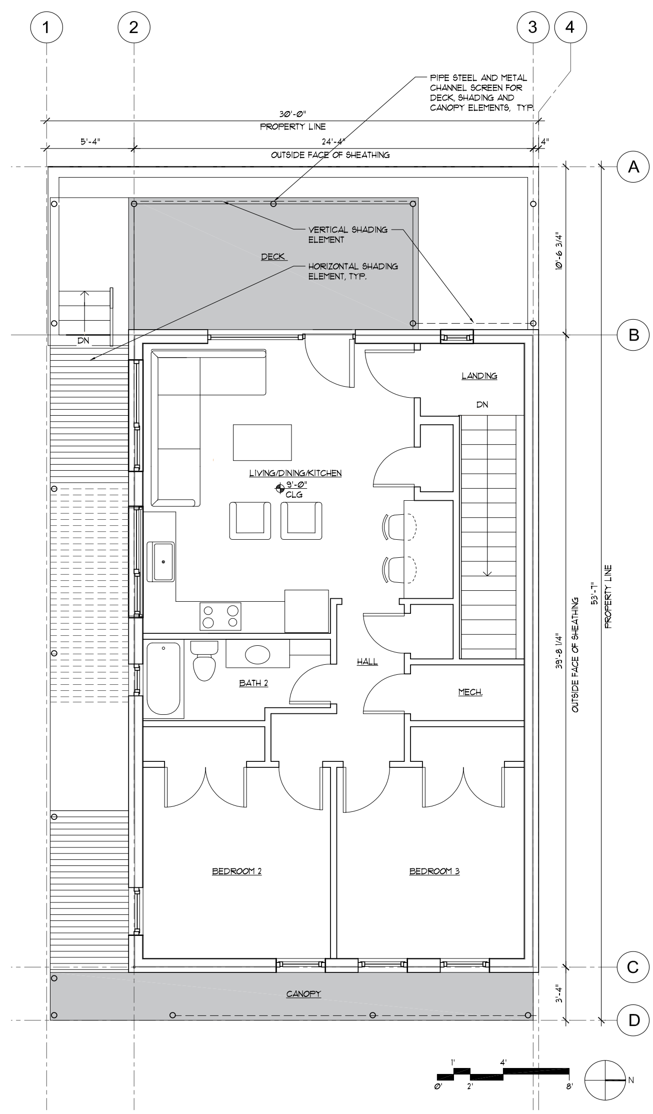
south side of the building, zoning requires a 5 foot set-back from the back lot line of the adjoining property. On the north side, the design team chose to build to the property line, without windows, as another building could be built as a party-wall condition in the future.

SITE ORIENTATION

The setbacks on the east, south and west sides of the property are important to the energy strategy for the building as they allow us to construct an external frame at the exposed sides of the building to support horizontal and vertical shading devices, and to provide overhead cover at the doors and windows for rain protection. This independent structural element is freestanding from the building to avoid interfering with the continuous insulation and air barrier of the building enclosure. It is flexible to

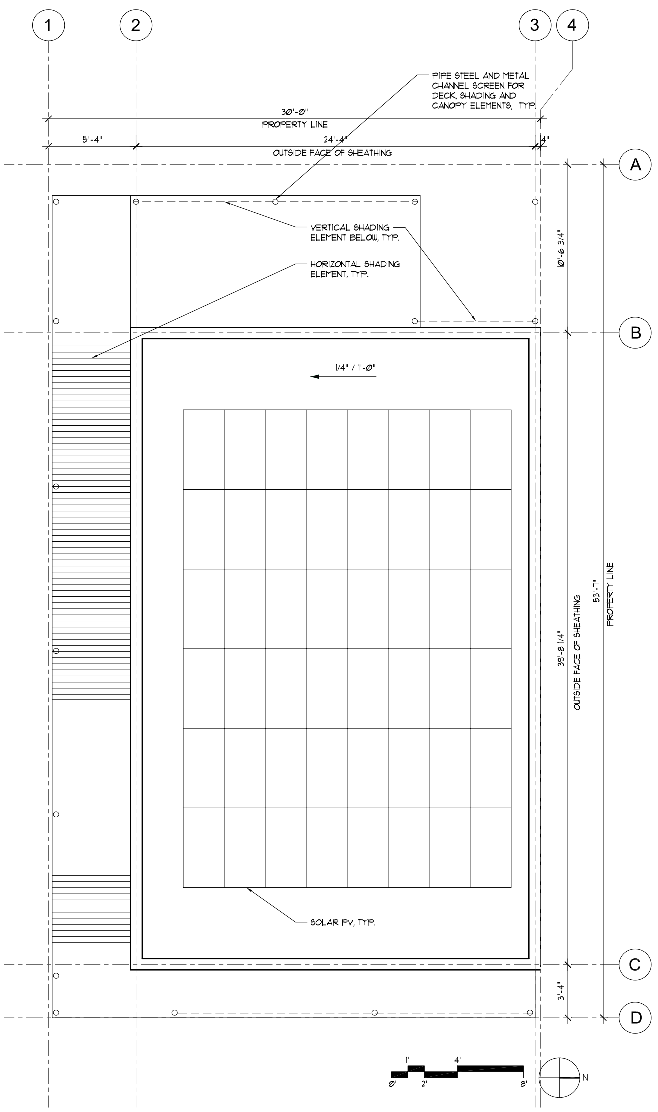


FIRST FLOOR PLAN



SECOND FLOOR PLAN

allow shading and overhead cover to be applied as needed depending on the alley lot orientation and building layout. In the case of our building, horizontal shading is provided on the south elevation over the windows at the first and second floors; vertical shading and privacy screening is provided at the east and west windows; overhead cover is provided at the front door and garage; and a deck is provided at the west side of the second floor.



ROOF PLAN

THE EXTERNAL FRAME

The flexibility of this independent external frame allows for different materials to be used for shading, decking and rain protection. Seasonal shade or year-round privacy could even be provided by plants, if conditions permitted. The independent structure could also be used to hang the heat pump compressor units, if space was not available on the roof or the ground. Rain water could be collected from the roof and other surfaces and directed to rain barrels hung from the structure. Solar panels could also be mounted to the structure, depending on site conditions.

The design team envisions this independent, exo-skeleton to be built with steel pipe and tube sections but other materials could also be used. The external frame of the building is decorative, as well as functional and allows the house itself to be constructed as a very simple, inexpensive box. This box could be mass produced and the frame could be customized to account for design aesthetic and budget.

BUILDING FORM

To maximize the usable space in the building, in response to the 20 ft. height limit for alley dwellings, and to simplify the building form to keep building costs low, the design team chose to create a flat-roofed building with a low parapet to screen the solar panels. For this site, the roof is pitched to the south to drain roof water to a gutter and downspout system and provide a beneficial angle for the solar panels. It is imagined the panels would be ballasted and stand on top of the low slope membrane roof without penetrating the enclosure.

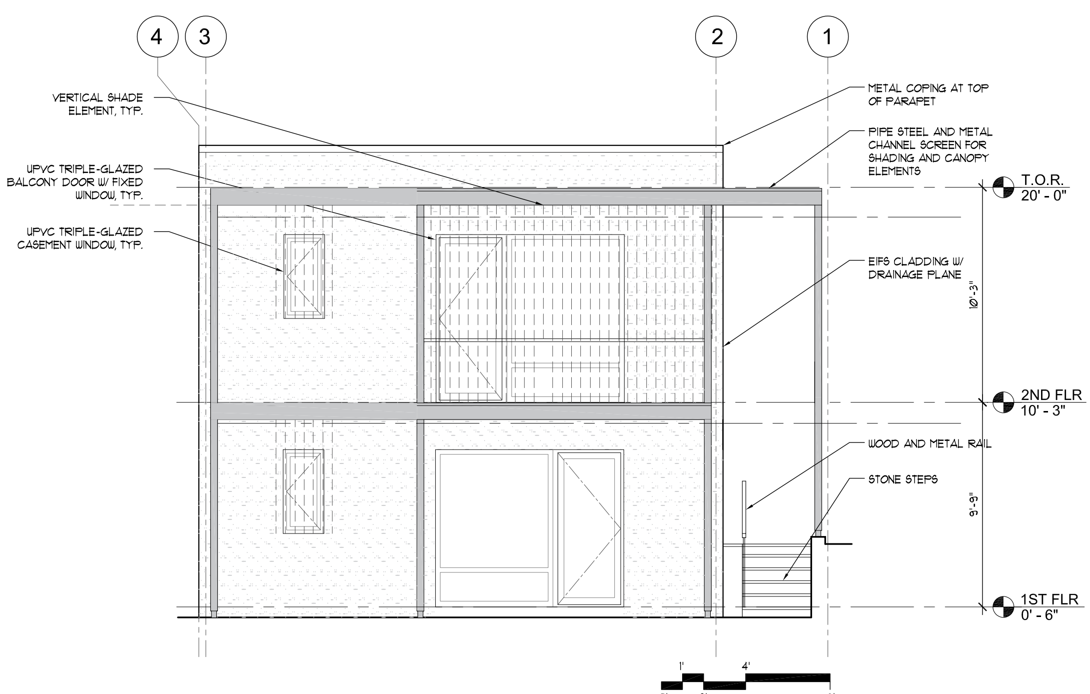
ADDITIONAL COST STRATEGIES

Keeping the building form very simple, with no overhangs, inside corners or unusual geometries is a good way to keep construction costs down. Some alley lots may require a different response but the lot in this study is large enough and orthogonally shaped to allow for the construction of a simple box. The pricing matrix shows the costs of different materials that were considered for this building and describes the energy, building science, and budget implications of the various options.

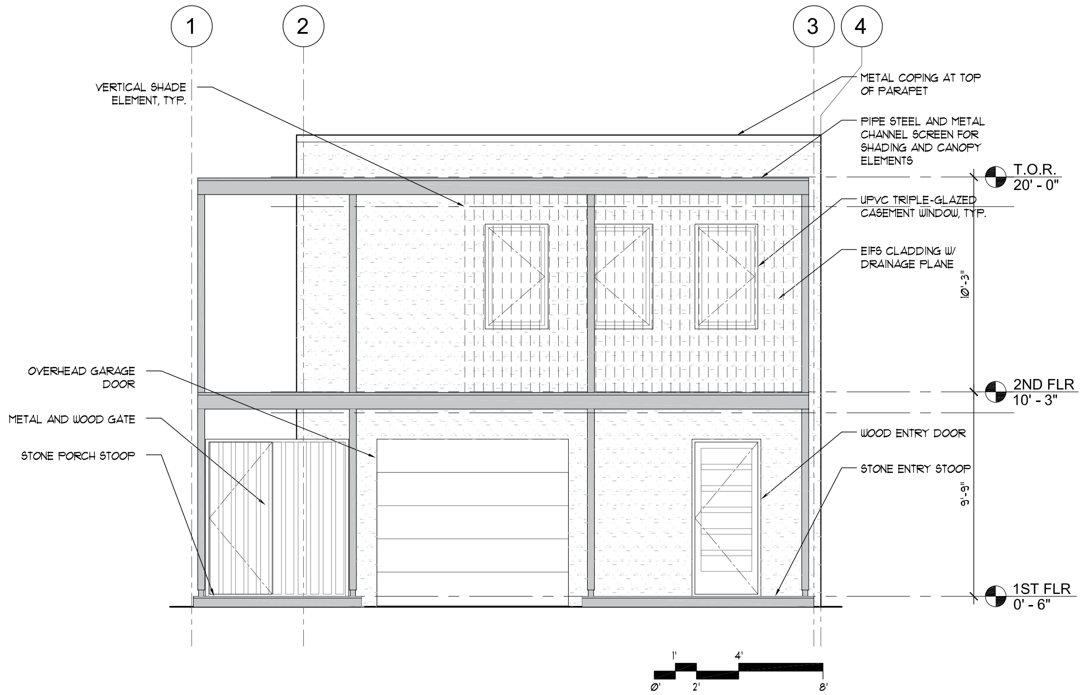
OFF-STREET PARKING

Another zoning requirement for alley dwellings is to provide one space for off-street parking. The design team feels this requirement may not be in-tune with current and future car use in the district. We have looked at two schemes related to parking and energy efficiency per square foot of habitable space. The first scheme provides the required off-street parking for one car by including an enclosed garage space inside the dwelling unit. We felt this approach, as opposed to an open car port, would give the dwelling unit usable space for storage or a workshop if the occupants did not need to park a car.

Because alley lots are sometimes quite small, providing a parking space that is not integrated into the building form, either inside the structure or below an upper portion of



WEST (REAR) ELEVATION WITH GARAGE

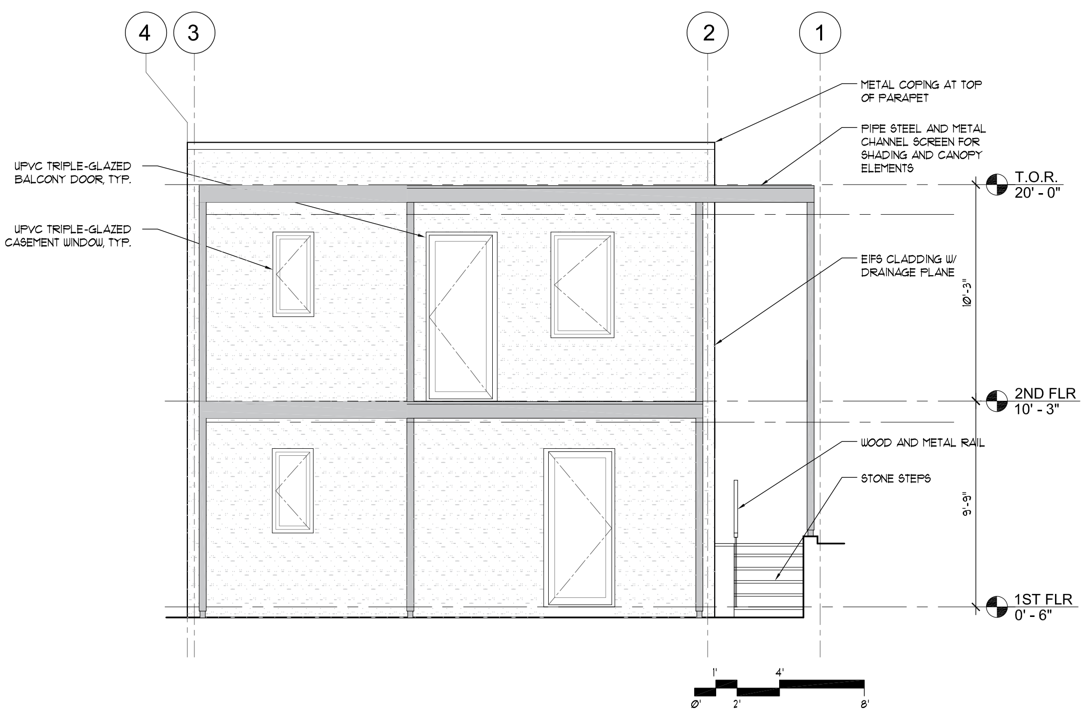


EAST (FRONT) ELEVATION WITH GARAGE

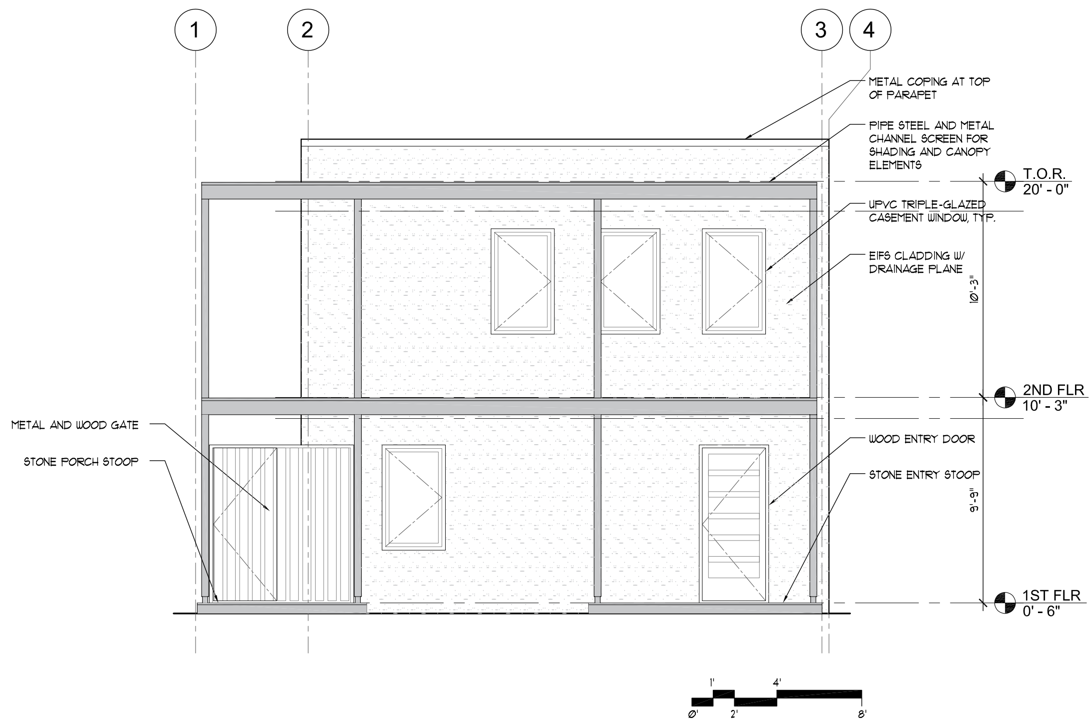
SOUTH (SIDE) ELEVATION WITH GARAGE

the house, would leave little room on the lot for the house itself. The interior garage space, or carport underneath the house, poses problems for the energy-efficient enclosure, as described in the energy modelling portion of this report.

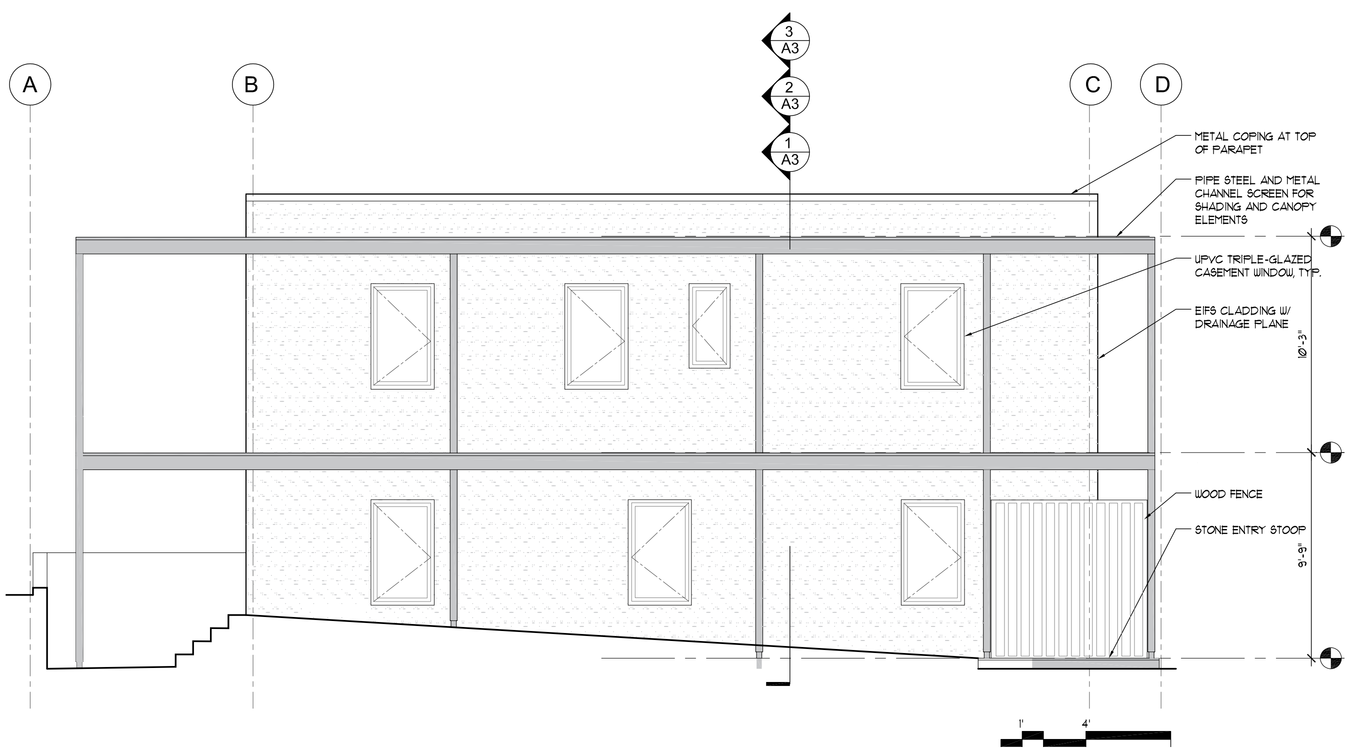
The design team provided a second schematic design that does not include off-street parking on the site. The second set of building elevations show this scheme, and also show a reduction in the size and number of windows. The energy impact of this scheme is described in the energy modeling section of the report.



WEST (REAR) ELEVATION WITH REDUCED WINDOWS - NO GARAGE



EAST (FRONT) ELEVATION WITH REDUCED WINDOWS - NO GARAGE



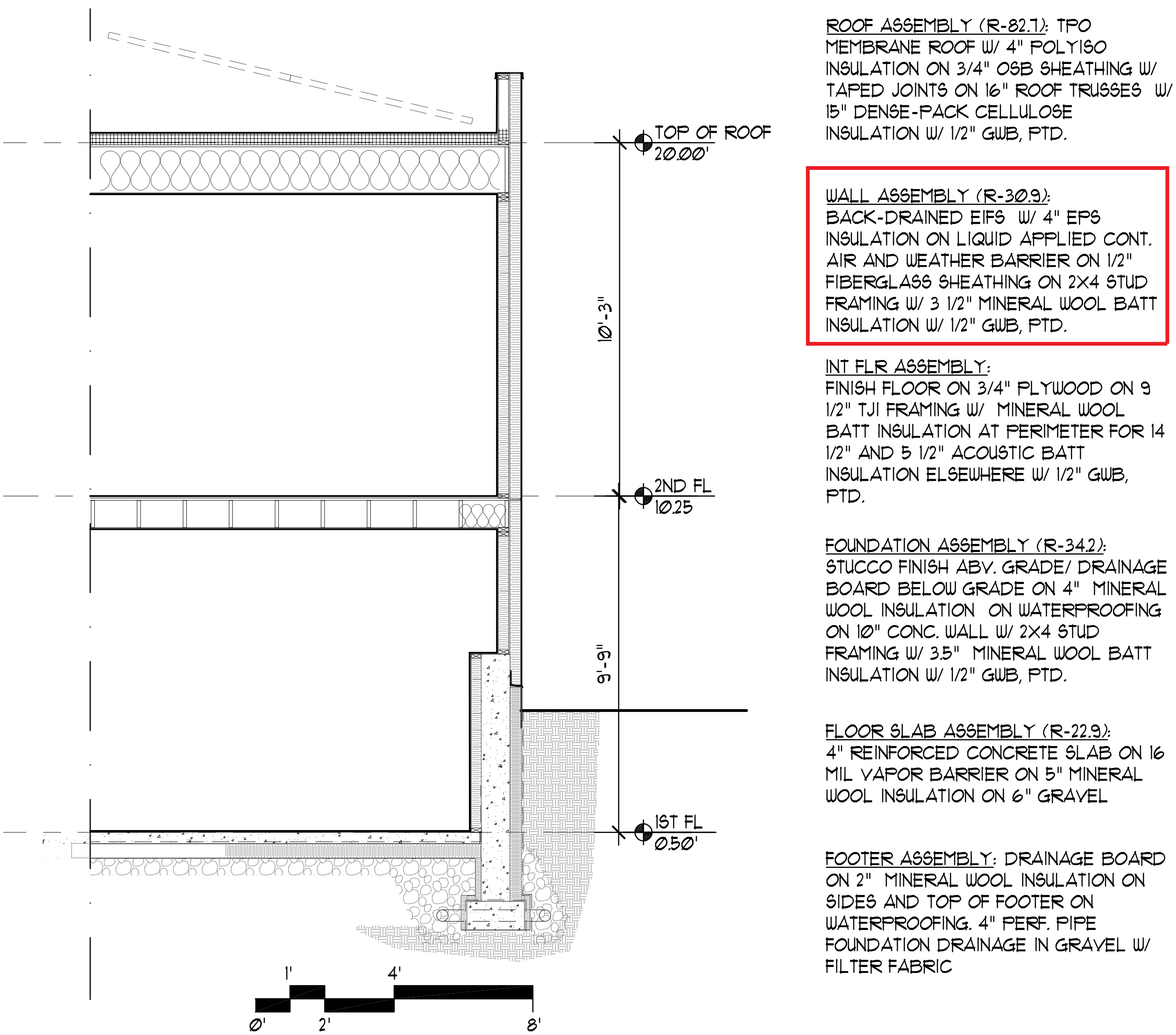
SOUTH (SIDE) ELEVATION WITH REDUCED WINDOWS - NO GARAGE

BUILDING SECTIONS

In order to begin the energy modelling, the design team needed to have a baseline case or cases to test. The building sections following show the schematic design for the slab and roof assemblies and three options for wall sections that are described in further detail in the energy modeling section of the report.

AIR SEALING THE BUILDING ENVELOPE

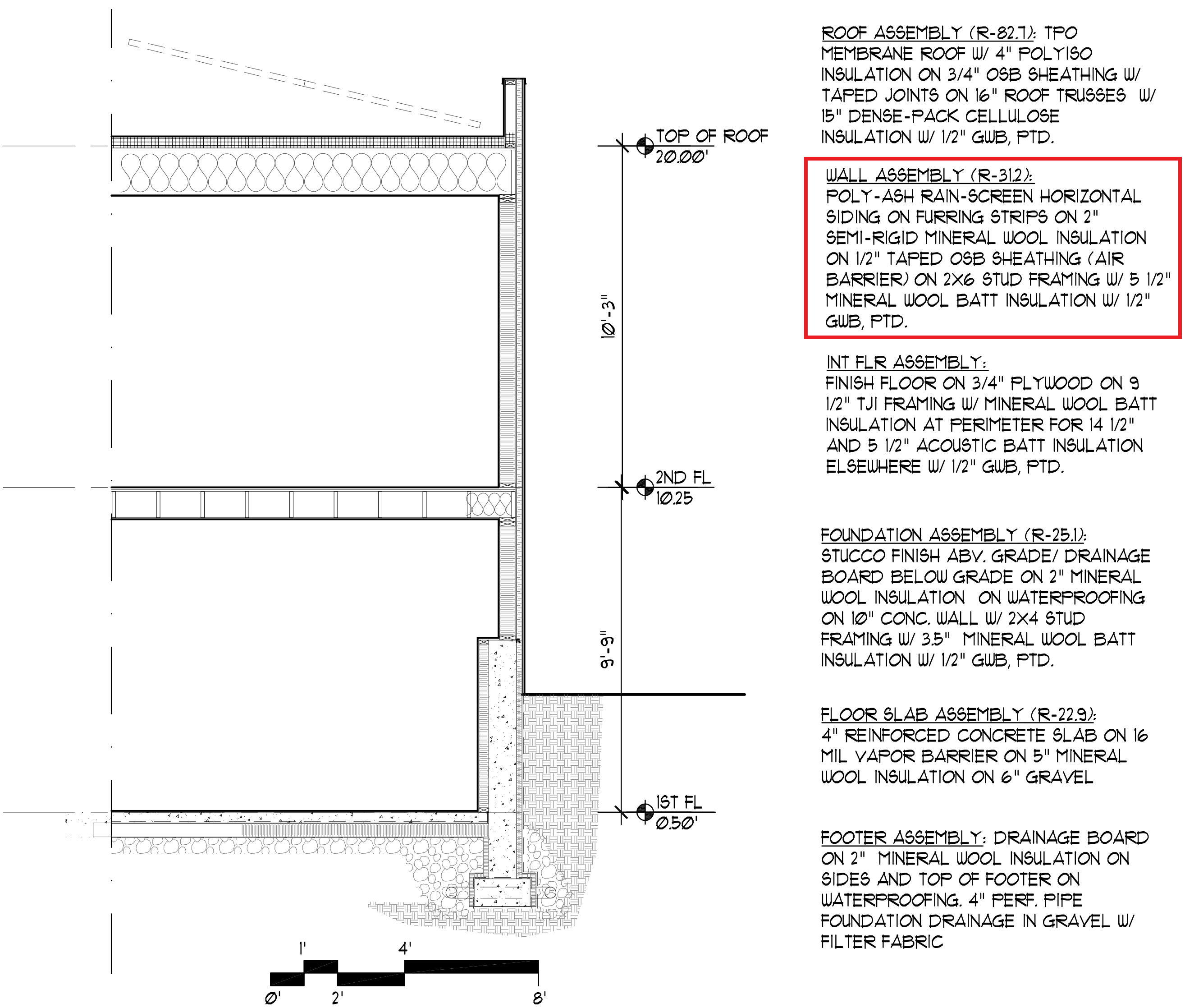
In addition to the wall, floor slab and roof assemblies described in the building sections, a zero-energy building needs to carefully consider the connections between the various assemblies, and at assembly penetrations, such as windows and doors, and mechanical, electrical and plumbing penetrations to ensure an air-tight enclosure with flashings that manage water.



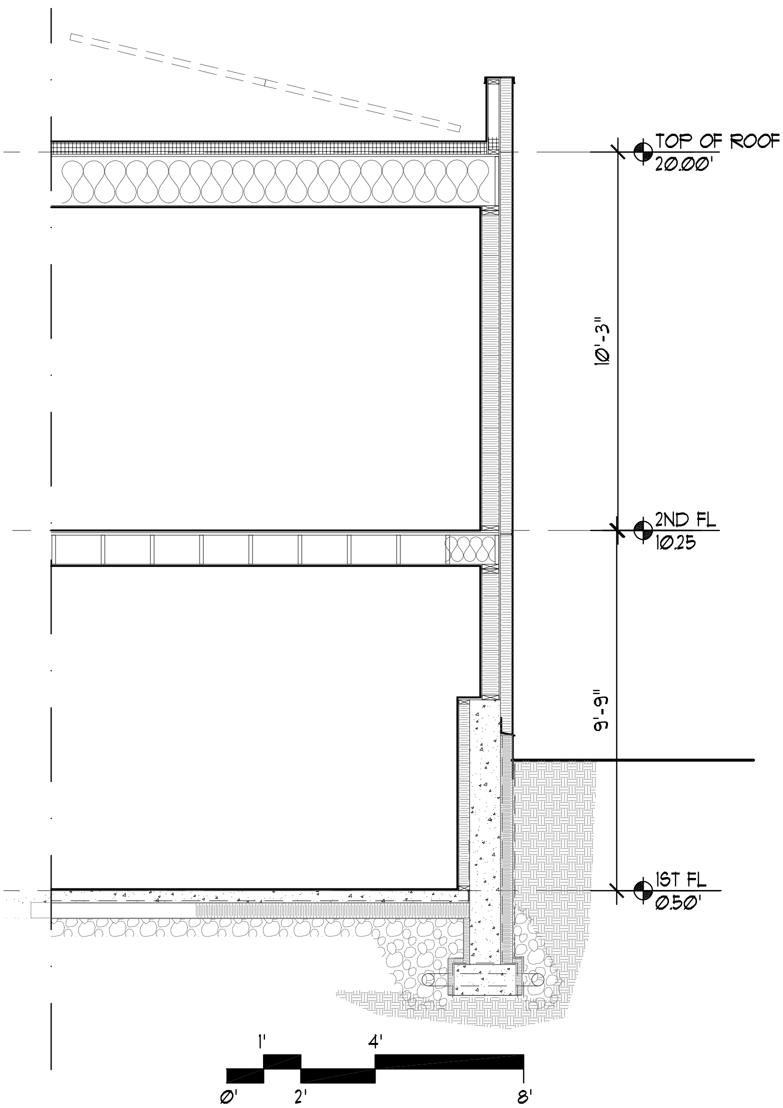
Building Section, Case 1 - 2x4 wall framing with 4” exterior insulation

THERMAL BRIDGING

When elements of the building, like an exterior deck, roof overhang, or a concrete footer in contact with the ground, interrupt or compromise the continuous thermal enclosure of the building, this is called a thermal bridge. Thermal bridges need to be considered to ensure there is not an excessive transfer of heating or cooling through the building envelope. Thermal bridges also need to be reviewed to ensure they do not create a risk of condensation within the building assemblies that could lead to material deterioration or mold growth inside the wall, floor or roof structure.



Building Section, Case 2 - 2x6 wall framing with 2” exterior insulation



ROOF ASSEMBLY (R-82.7): TPO MEMBRANE ROOF W/ 4" POLYISO INSULATION ON 3/4" OSB SHEATHING W/ TAPED JOINTS ON 16" ROOF TRUSSES W/ 15" DENSE-PACK CELLULOSE INSULATION W/ 1/2" GWB, PTD.

WALL ASSEMBLY (R-38.9): BACK DRAINED EIFS W/ 4" SEMI-RIGID MINERAL WOOL INSULATION ON LIQUID APPLIED CONT. AIR AND WEATHER BARRIER ON 1/2" FIBERGLASS SHEATHING ON 2X6 STUD FRAMING W/ 5 1/2" MINERAL WOOL BATT INSULATION W/ 1/2" GWB, PTD.

INT FLR ASSEMBLY: FINISH FLOOR ON 3/4" PLYWOOD ON 9 1/2" TJI FRAMING W/ MINERAL WOOL BATT INSULATION AT PERIMETER FOR 14 1/2" AND 5 1/2" ACOUSTIC BATT INSULATION ELSEWHERE W/ 1/2" GWB (CEILING), PTD.

FOUNDATION ASSEMBLY (R-34.2): STUCCO FINISH ABV. GRADE/ DRAINAGE BOARD BELOW GRADE ON 4" MINERAL WOOL INSULATION ON WATERPROOFING ON 10" CONC. WALL W/ 2X4 STUD FRAMING W/ 3.5" MINERAL WOOL BATT INSULATION W/ 1/2" GWB, PTD.

FLOOR SLAB ASSEMBLY (R-22.9): 4" REINFORCED CONCRETE SLAB ON 16 MIL VAPOR BARRIER ON 5" MINERAL WOOL INSULATION ON 6" GRAVEL

FOOTER ASSEMBLY: DRAINAGE BOARD ON 2" MINERAL WOOL INSULATION ON SIDES AND TOP OF FOOTER ON WATERPROOFING. 4" PERF. PIPE FOUNDATION DRAINAGE IN GRAVEL W/ FILTER FABRIC

Building Section, Case 3 - 2x6 wall framing with 4” exterior insulation

ENERGY ANALYSIS

PROJECT PARAMETERS

The energy analysis focused on three target goals. The first and primary was to determine whether the designed alley dwelling could achieve a yearly net zero energy balance given the constraints and orientation of the alley lot and the PV array capacity available on the roof. The second goal was to compare three exterior wall assemblies and their effective performance across various case set scenarios. The third goal was to target the Passive House Institute, United States (PHIUS) energy standard, PHIUS+ 2021 space conditioning criteria to determine the annual and peak heating and cooling loads. The first schematic design with an interior garage and maximum windows was used as our baseline in our energy modeling and analysis.

ZERO ENERGY TARGET

To establish the production capacity for a net zero energy balance equation, we sized a solar PV array given the roof area and site location using the NREL's PV Watts calculator. We used 75% of the available roof area, 688 sf, to determine a PV array size of 9.5kW which could produce an average 11, 432 kWh/yr. The predicted range for the PV system is 10,926-12,084 kWh/yr. This became our primary energy demand (site energy) target for the energy balance equation as we continued to evaluate our schematic design.

CALCULATING THE ENERGY DEMAND

To determine the primary energy demand of the schematic design, an energy model was developed using WUFI Passive V.3.2.0.1, which allowed us to asses the annual, monthly, and peak heating and cooling loads. The WUFI Passive energy modeling was set to Climate Zone 4A, using climate data from Washington DC, Regan AP VA. The building was set to an occupancy of three bedrooms, four persons, with one interior heating and cooling zone plus the garage as an attached unconditioned zone. The total envelope area of the baseline is 4,739 sf and the total indoor conditioned floor area (ICFA) is 1,256 sf, resulting in an envelope to area ratio of 3.77. With this information, the energy model can begin to calculate the building energy demand based on different building envelope assemblies.

ENERGY LOSSES AND GAINS

The baseline case set was broken into three cases

PV Array Sizing				
Available Roof area (75% of availabe roof sf)	688.5	ft2	64.0	m2
Size (PV Watts)	9.4	kW		
Total Energy Production (PV Watts Calculated)	**11,432**	**Kwh/Year**		

ABOVE: Calculations for a PV array based on 75% of the available roof area, using the NREL PV watts calculator

PROJECT OUTPUTS

	Cases	Building Volume (Gross)	Total Envelope Area	Area / Volume Ratio	Indoor Conditioned Floor Area (ICFA)	Envelope to ICFA Ratio	Window / Wall Ratio
TARGET	**PHIUS 2021 (Washington DC) - BASELINE**						
	PV Array Capacity						
BASELINE	**Case 1 - 2x4 + 4" c.i. Min Wool Ext Wall**						
	Case 2 - 2x6 + 2" c.i. Min Wool Ext Wall	15,896 ft3	4,739 ft2	0.30	1,256 ft2	3.77	0.13
	Case 3 - 2x6 + 4" c.i. Min Wool Ext Wall						
REDUCED WINDOWS	**Case 4 -** 2x4 + 4" c.i. Min Wool Ext Wall						
	Case 5 - 2x6 + 2" c.i. Min Wool Ext Wall	15,896 ft3	4,739 ft2	0.30	1,256 ft2	3.77	0.09
	Case 6 - 2x6 + 4" c.i. Min Wool Ext Wall						
TARGET	**PHIUS 2021 (Washington DC) - WITHOUT GARAGE, LARGER VOLUME (ADJUSTED TARGETS)**						
WITHOUT GARAGE	**Case 7 -** 2x4 + 4" c.i. Min Wool Ext Wall						
	Case 8 - 2x6 + 2" c.i. Min Wool Ext Wall	20,177 ft3	4,669 ft2	0.20	1,636 ft2	2.87	0.15
	Case 9 - 2x6 + 4" c.i. Min Wool Ext Wall						
WITHOUT GARAGE + REDUCED WINDOWS	**Case 10 -** 2x4 + 4" c.i. Min Wool Ext Wall						
	Case 11 - 2x6 + 2" c.i. Min Wool Ext Wall	20,177 ft3	4,669 ft2	0.20	1,636 ft2	2.87	0.09
	Case 12 - 2x6 + 4" c.i. Min Wool Ext Wall						

Cases	Annual Heating Demand (kBtu/ft2yr)	Annual Cooling Demand (kBtu/ft2yr)	Peak Heating Demand (Btu/hrft2)	Peak Cooling Demand (Btu/hrft2)	TOTAL SITE Energy			
PHIUS 2021 (Washington DC) - BASELINE	**7.8**	**9.1**	**6.6**	**3.6****				
PV Array Capacity							**11,432.00**	**kWh/yr**
Case 1	9.7	8.0	7.7	4.6	27,907	kBtu/yr	8,180	kWh/yr
Case 2	9.8	8.0	7.7	4.6	27,924	kBtu/yr	8,185	kWh/yr
Case 3	8.8	8.0	7.3	4.6	27,593	kBtu/yr	8,087	kWh/yr
Case 4	9.1	7.2	7.3	4.1	27,272	kBtu/yr	7,993	kWh/yr
Case 5	9.2	7.2	7.3	4.1	27,291	kBtu/yr	7,999	kWh/yr
Case 6	8.1	7.2	6.8	4.0	26,933	kBtu/yr	7,894	kWh/yr
PHIUS 2021 (Washington DC) - WITHOUT GARAGE, LARGER VOLUME (ADJUSTED TARGETS)	**7.0**	**8.1**	**5.5**	**3.2**				
Case 7	7.4	7.0	6.1	3.9	32,141	kBtu/yr	9,420	kWh/yr
Case 8	7.3	7.0	6.1	3.9	32,105	kBtu/yr	9,410	kWh/yr
Case 9	6.7	7.0	5.7	3.8	31,790	kBtu/yr	9,318	kWh/yr
Case 10	6.7	6.3	5.7	3.5	31,420	kBtu/yr	9,209	kWh/yr
Case 11	6.8	6.3	5.7	3.5	31,448	kBtu/yr	9,218	kWh/yr
Case 12	5.9	6.3	5.3	3.4	31,045	kBtu/yr	9,099	kWh/yr

ABOVE: Summary of energy analysis results per case set

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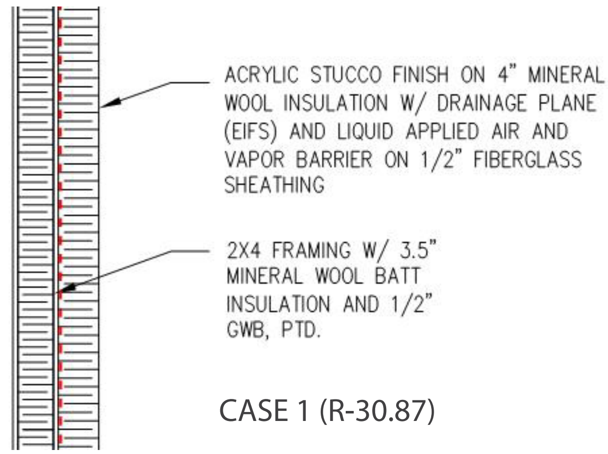
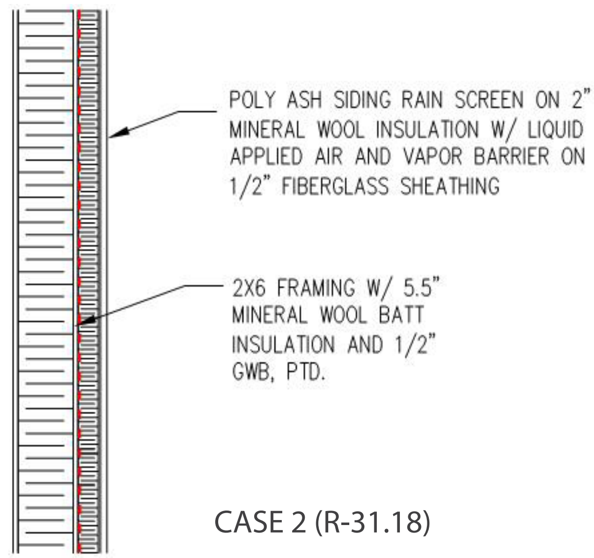
to evaluate the three exterior wall assemblies under consideration. All other envelope assemblies (slab and roof), and specifications for windows, exterior doors, and equipment remain the same for all cases. An economic triple pane passive house window was used for fixed and operable windows and doors across all cases. Shading factors that reflect the steel exterior shading structure of the schematic design were also included in the energy modeling.

BASELINE WALL TYPES

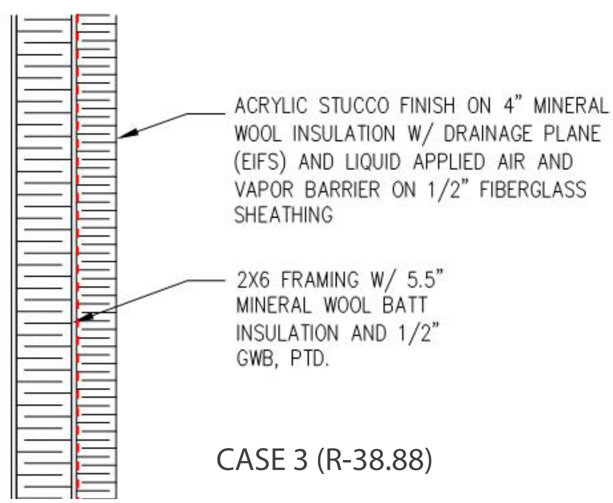
Three exterior above grade wall assemblies based on typical residential building standards for the DC region were determined and used to establish three cases within the Baseline Case Set. As mentioned previously, all other inputs remained constant in order to evaluate the impact each assembly has on heating and cooling loads. Assembly Case 1 is a 2x4 stud framed wall with 3.5" mineral wool batt insulation, ½" fiberglass sheathing with a fluid applied air barrier, plus 4" of exterior mineral wool board insulation, with a total R value of 30.87. Assembly Case 2 is a 2x6 wood stud framed wall with 5.5" mineral wool batt insulation, ½" fiberglass sheathing with a fluid applied air barrier, plus 2" of exterior continuous mineral wool board insulation, with a total R value of 31.18. Assembly Case 3 is a 2x6 wood stud framed wall with 5.5" mineral wool batt insulation, ½" fiberglass sheathing with a fluid applied air barrier, plus 4" of exterior continuous mineral wool board insulation, with



CASE 1 (R-30.87)



CASE 2 (R-31.18)



CASE 3 (R-38.88)

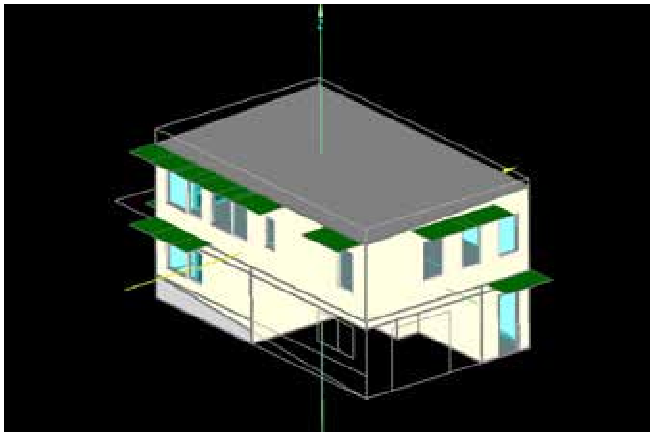
a total R value of 38.88.

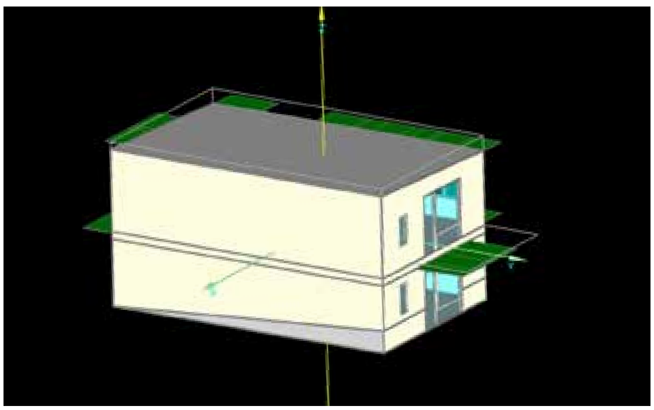
ENERGY MODEL RESULTS

The WUFI Passive modeling of the Baseline Case Set resulted in a total site energy demand for all three exterior wall assembly cases ranging from 8,087-8,100 kWhr/yr, which falls below our PV production target of 11, 432 kWh/yr. These results confirmed that our schematic design with the garage as an attached but unconditioned zone could achieve a net zero energy balance annually. The WUFI results for heating and cooling demands, however, did not demonstrate that we could meet PHIUS passive house standards with the baseline model, using any of the three exterior wall assembly types. The annual cooling demand, or load, was the only metric that met the PHIUS+ 2021 target criteria established for the project.

THE PHIUS+ PASSIVE HOUSE STANDARD

The design team used the PHIUS+ passive house standard to set design criteria because the PHIUS standard incorporates measures to guard against moisture problems within the wall (or roof, or slab) assembly which could create condensation problems. The standard also ensures comfort by eliminating causes of drafts and overheating. Other benefits of following the PHIUS standard are excellent indoor air quality and a quiet environment. Certifying a project to the PHIUS passive house standard





ABOVE: Images of Baseline Case Set model in WUFI Passive

Baseline Assembly R-Values		R VALUE
EXT WALLS	**Case 1** - 2x4 w/min wool batt + 4" c.i. min wool	30.87
	Case 2 - 2x6 w/min wool batt + 2" c.i. min wool	31.18
	Case 3- 2x6 w/min wool batt + 4" c.i. min wool	38.88
	Ext Wall below grade (4" c.i.) - CMU block wall with 4" c.i. mineral wool on exterior, 2x4 stud with 3.5" mineral wool batt insulation on interior	34.16
	Ext Wall below grade (2" c.i.) - CMU block wall with 2" c.i. mineral wool on exterior, 2x4 stud with 3.5" mineral wool batt insulation on interior	25.12
	Interior Walls at Garage - 2x6 stud cavity with 5.5" mineral wool batt insulation with 2" c.i. mineral wool on exterior	32.35
ROOF	4" Polyiso + 15" blown-in cellulose in ceiling joist cavity	82.70
FLOOR	Ground Floor - Insulated with 5" mineral wool below slab	22.90
	Upper Level Floor - Insulated over Garage	36.98

Baseline Windows and Door Values	Uw Value	Uglass Value	SHGC
Operable - Zola UPvc Window	0.2	0.09	0.53
Fixed - Zola UPvc Window	0.16	0.09	0.53
Door - Zola triple pane	0.28	0.09	0.53
Garage Door - not modeled in conditioned zone	N/A	N/A	N/A

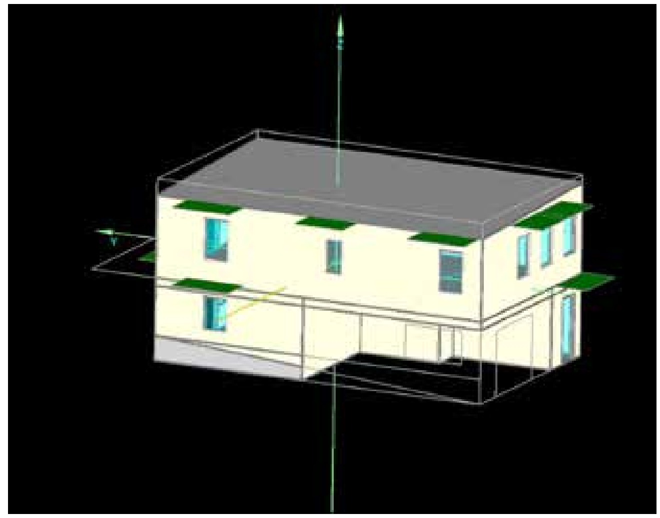
brings a an outside review of the project to flag potential problems and requires third party verification, ensuring that the planned features and functions are met.

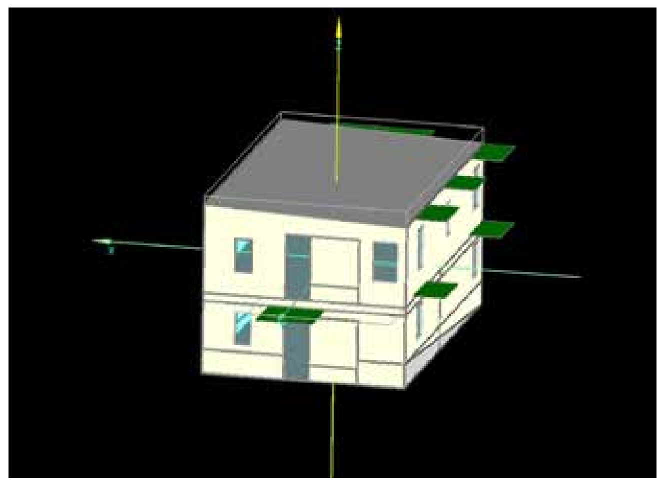
RESPONSE TO BASELINE RESULTS

Given that the baseline case did not meet the PHIUS passive house criteria established for the project, new iterations were developed from the baseline case set to evaluate what design measures might reduce the annual heating and peak heating and cooling loads.

REDUCED WINDOW SIZES

The next case set evaluated was a reduced window option in which the overall window to wall ratio was reduced from 12.8% to 8.9%. The Reduced Window Case Set minimized the total glazing to code minimum requirements in bedrooms and reduced window openings in the living room. The results of these cases showed that the annual and peak heating and cooling loads as well as the total site energy would lower, but the annual heating, and peak heating and cooling loads still did not meet the PHIUS+ 2021 criteria that we established as a target goal.





ABOVE: Images of Reduced Windows Case Set model in WUFI Passive

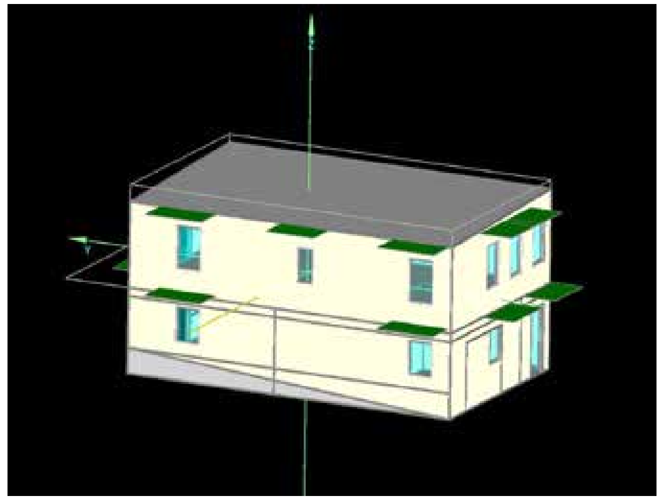
REDUCED ENVELOPE AREA

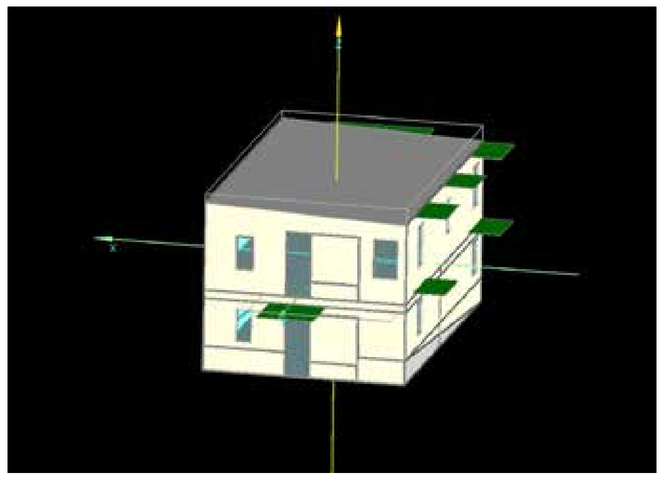
The third case set we evaluated focused on increasing the overall volume of the building by incorporating the garage of the schematic design into the conditioned space. The garage was made into an additional bedroom and some additional living space on the first floor resulting in an increased indoor conditioned floor area (ICFA) and a decreased envelope area. The new envelope to floor area ratio of the house without an internal garage is 2.87. The garage door was removed and a single operable window was added to the front (east) facade.

The WUFI Passive modeling of the Without Garage Case Set resulted in an increased site energy demand ranging from 9,348-9,420 kWhr/yr. This increase in site energy is due to the overall increase of the building volume and floor area, but still remains under our predicted PV production targets. The WUFI modeling of cases 7-9 showed lower annual and peak heating and cooling loads. Results show that case 9 meets the PHIUS + 2021 target criteria for annual heating and cooling, but none of these cases are able to meet the PHIUS+ peak heating and cooling targets.

HYBRID CASE SET

The final case set evaluated in WUFI Passive combined the two design measures previously modeled; reduce the windows and incorporate the garage into the conditioned area of the building. This case set, Without Garage + Reduced Windows, resulted in the building achieving the PHIUS+ 2021 annual heating and cooling criteria and the peak heating criteria, but not the peak cooling criteria. The design team believes the peak cooling criteria could be met for all cases by adjusting the window shading factors but this adjustment was not pursued due to time





ABOVE: Images of Without Garage + Reduced Windows Case Set model in WUFI Passive and scope constraints for this project. The overall primary energy demand ranged from 9,099 - 9,218 kWhr/yr., still under the predicted PV production targets. This case set demonstrates the impact that building size and glazing can have on the heating and cooling loads.

ENERGY MODELLING CONCLUSIONS

The results of the energy modeling demonstrate that the schematic design for the proposed alley dwelling can achieve an annual net zero energy balance and with any of the three exterior wall assemblies, in all of the case sets. Only the cases with a larger building volume, however, were able to meet most of the PHIUS + criteria. While achieving net zero is the primary goal, maintaining indoor comfort and mitigating moisture risks is a concern when designing small, well insulated, airtight buildings. Reducing peak heating and cooling loads to PHIUS+ passive house standards will ensure comfortable interior conditions throughout the year and manage moisture risk in the building envelope.

The main takeaways from the energy modelling are:

- compactness is important (reduced surface area)
- low window-to-wall area ratio is important
- a variety of wall assemblies can be used to meet the project goals.
- it is not enough to meet zero energy targets by providing sufficient PV panels to balance building loads - moisture management and occupant comfort must also be considered.

CONSIDERING VAPOR DRIVE

When designing and constructing very air tight, well insulated buildings, special care must be taken to prevent moist air from condensing within the building envelope. If conditions exist that may lead to moisture accumulating within the building envelope assemblies, the designer and builder must provide the ability for that moisture to dry out to avoid mold growth or deterioration of building materials. Following PHIUS+ standards will help avoid moisture problems. If a project is not following the PHIUS+ standards, extra care must be taken to ensure moisture is managed correctly. Best practices for locating insulation and providing vapor permeable materials, chosen according to climate zone, can avoid condensation problems. Performing hygrothermal analysis with WUFI Plus, or other software, can identify and avoid potential moisture problems.

PHIUS+ 2021
Performance Criteria Calculator v1

UNITS:	IMPERIAL (IP)
BUILDING FUNCTION:	RESIDENTIAL
PROJECT TYPE:	NEW CONSTRUCTION
STATE/ PROVINCE	DISTRICT OF COLUME
CITY	WASHINGTON DC DULL
Envelope Area (ft²)	4,739
ICFA (ft²)	1,256
Dwelling Units (Count)	1
Total Bedrooms (Count)	3

Space Conditioning Criteria		
Annual Heating Demand	7.8	kBtu/ft²yr
Annual Cooling Demand	9.0	kBtu/ft²yr
Peak Heating Load	6.1	Btu/ft²hr
Peak Cooling Load	3.6	Btu/ft²hr

Source Energy Criteria		
PHIUS+ 2021	3568	kWh/person.yr
PHIUS+ 2021 Source Zero	0	kWh/person.yr

ABOVE: PHIUS+ 2021 Criteria calculator set with Baseline Case Set parameters. The Performance Criteria Calculator is used to set the Space Conditioning Criteria for the project based on the location, building size and occupancy. Note how space conditioning criteria changed as shown in the Energy Analysis matrix on page 16-17 when the building volume and floor area changed.

RESULTS 11,432 kWh/Year*

System output may range from 10,928 to 12,064 kWh per year near this location.

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Value ($)
January	2.42	590	65
February	3.41	742	82
March	4.21	997	109
April	5.31	1,181	130
May	5.81	1,306	143
June	6.27	1,304	143
July	6.28	1,349	148
August	5.56	1,162	128
September	4.56	955	105
October	3.53	794	87
November	2.65	583	64
December	1.98	470	52
Annual	4.34	11,432	$ 1,256

Location and Station Identification

Requested Location	808 Carry's Way SE, Washington DC
Weather Data Source	Lat, Lon: 38.89, -76.98 2.2 mi
Latitude	38.89° N
Longitude	76.98° W

PV System Specifications *(Residential)*

DC System Size	9.5 kW
Module Type	Standard
Array Type	Fixed (roof mount)
Array Tilt	2.4°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

Economics

Average Retail Electricity Rate	0.110 $/kWh

Performance Metrics

Capacity Factor	13.7%

Sourced from https://pvwatts.nrel.gov

ABOVE: Estimated annual PV production results for a 9.5kW system, generated by the PV Watts calculator.

PRICING MATRIX

The Wall Assembly Type pricing tables on the following pages show a range of options for acceptable materials for framing, insulation, sheathing / air barrier and finishing systems. All options are compatible with the materials used in the energy modelling. The cost assumptions in our pricing analysis are based on experience-based costs and current materials pricing. They were compiled by Allen Built, Inc. in September 2021. Because material prices are constantly changing, these costs are not intended to show the absolute cost of materials and labor, instead they reflect relative costs. Relative costs will likely change, too, and architects and builders should run their own pricing calculations before making assembly and materials decisions. Our goal is to illustrate in general terms the relative cost-effectiveness of alternative ways to build walls that meet NZE goals.

BASELINE CASE-SET PRICING - MOST VAPOR OPEN

The Baseline Case Sets pricing table uses mineral wool insulation and glass mat exterior gypsum sheathing with a fluid applied air barrier. The exterior finishing options include an acrylic stucco finish and a poly-ash rain screen siding. In the mixed-humid climate of Washington DC, it is beneficial for a wall assembly to be very vapor permeable to allow any moisture that may get into the assembly to dry easily to one or both sides of the assembly.

Although the mineral wool board insulation is more expensive than an expanded polystyrene (EPS) board insulation, the design team included mineral wool as the exterior insulation in the baseline pricing set to simplify any fire-rating issues at the potential party wall assembly and because the mineral wool insulation seems to be a better deterrent to termite tunneling than EPS. The thermal qualities of both mineral wool and EPS are not reduced if the material becomes temporarily damp or wet and both are acceptable for contact with the ground. EPS and mineral wool insulation have a similar R-value of around R-4/inch.

The design team chose a fiberglass mat exterior sheathing in the baseline pricing set because this material is very vapor permeable and can dry to one side or the other if moisture is present on either side of the sheathing. The liquid-applied air barrier is compatible with the glass mat sheathing and can be visually checked to confirm a uniform and continuous coating of the wall surface. Accessory tapes and caulks that are used to transition between materials and around penetrations must be compatible with the liquid air barrier and the fiberglass sheathing.

The poly-ash siding is a dimensionally stable and water resistant material made from fly ash, a by-product of burning coal. The siding is made from 70% recycled materials and workable with standard carpentry tools. The 3/4" poly ash siding is a higher quality material than the thinner and less expensive fiber-cement lap siding and will better resist chipping and cupping. The polyash siding is able to be in contact with the ground and can cover the continuous insulation at the transition from above to below ground. The acrylic stucco is an integrated exterior insulating and finishing system (EIFS) and can be installed by a specialty contractor. Make sure to use an EIFS system with a drainage plane incorporated in the assembly, like a rain screen. The stucco can be applied over a mineral wool or EPS insulation substrate.

WALL ASSEMEBLY TYPE	MATERIALS	SQUARE FOOT COST	SF LABOR RATE	SF CONST. COST
2x4 stud wall w/ EIFS on 4" mineral wool	interior drywall	$0.75	$1.25	$2.00
glass mat sheathing and liquid applied air barrier	2x4 wood studs	$1.50	$2.00	$3.50
Baseline Case 1	3.5" mineral wool battt insulation	$4.25	$1.00	$5.25
	glass mat exterior sheathing	$1.25	$1.25	$2.50
	liquid applied air barrier	$1.10	$2.30	$3.40
	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	4" mineral wool semi-rigid batt	$6.25	$1.90	$8.15
	acrylic stucco finishing products	$6.00	$7.20	$13.20
			TOTAL SF COST	**$41.75**
2x6 stud wall w/ EIFS on 4" mineral wool	interior drywall	$0.75	$1.25	$2.00
glass mat sheathing and liquid applied air barrier	2x6 wood studs	$1.90	$2.00	$3.90
	5.5" mineral wool battt insulation	$5.10	$1.00	$6.10
Baseline Case 3	glass mat exterior sheathing	$1.25	$1.25	$2.50
	liquid applied air barrier	$1.10	$2.30	$3.40
	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	4" mineral wool semi-rigid batt	$6.25	$1.90	$8.15
	acrylic stucco finishing products	$6.00	$7.20	$13.20
			TOTAL SF COST	**$43.00**
2x4 stud wall w/ siding on 4" mineral wool	interior drywall	$0.75	$1.25	$2.00
glass mat sheathing and liquid applied air barrier	2x4 wood studs	$1.50	$2.00	$3.50
poly-ash siding	3.5" mineral wool battt insulation	$4.25	$1.00	$5.25
Baseline Case 1 - siding	glass mat exterior sheathing	$1.25	$1.25	$2.50
	liquid applied air barrier	$1.10	$2.30	$3.40
	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	4" mineral wool insulation	$6.25	$1.60	$7.85
	furring strips and screws	$0.75	$1.00	$1.75
	poly-ash siding	$3.80	$4.50	$8.30
			TOTAL SF COST	**$38.30**
2x6 stud wall w/ siding on 2" mineral wool	interior drywall	$0.75	$1.25	$2.00
glass mat sheathing and liquid applied air barrier	2x6 wood studs	$1.90	$2.00	$3.90
poly-ash siding	5.5" mineral wool battt insulation	$5.10	$1.00	$6.10
Baseline Case 2	glass mat exterior sheathing	$1.25	$1.25	$2.50
	liquid applied air barrier	$1.10	$2.30	$3.40
	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	2" mineral wool insulation	$3.10	$1.60	$4.70
	furring strips and screws	$0.75	$1.00	$1.75
	poly-ash siding	$3.80	$4.50	$8.30
			TOTAL SF COST	**$36.40**
2x6 stud wall w/ siding on 4" mineral wool	interior drywall	$0.75	$1.25	$2.00
glass mat sheathing and liquid applied air barrier	2x6 wood studs	$1.90	$2.00	$3.90
poly-ash siding	5.5" mineral wool battt insulation	$5.10	$1.00	$6.10
Baseline Case 3 - siding	glass mat exterior sheathing	$1.25	$1.25	$2.50
	liquid applied air barrier	$2.10	$2.30	$4.40
	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	4" mineral wool insulation	$6.25	$1.60	$7.85
	furring strips and screws	$0.75	$1.00	$1.75
	poly-ash siding	$3.80	$4.50	$8.30
			TOTAL SF COST	**$40.55**

Wall Assembly Type pricing - Baseline Case Sets

ALTERNATE MATERIALS PRICING

All assemblies in the Alternate Wall Assembly Types pricing matrix are deemed by the design team to have a low risk for condensation in the assembly with the ability to dry out. The condensation risk is generally avoided by using a minimum amount of continuous exterior insulation which is now required by the ICC building codes.

LOWER- PRICED OPTIONS

The pricing table Optional Materials, uses EPS rigid foam insulation and OSB (wood fiber) sheathing with taped joints as the air barrier. The exterior finishing options include a rain screen with fiber cement lap siding and an acrylic stucco on an EPS insulating substrate. The assembly materials in pricing table - Optional Materials, are provided as an economical alternate to the materials in the Baseline Case table.

EXTERIOR INSULATION

EPS insulation is readily available from building supply stores, is easy to work with on site and is less expensive than mineral wool. If fire rating is an issue, EPS may not be an available option. When used in an EIFS assembly, the site preparation work on EPS includes levelling and sanding the material prior to installing the stucco base coat which results in lots of tiny particles of EPS blowing off the site or settling in the earth around the building. This is very difficult to contain or collect for clean up. The type and class of EPS used in a EIFS application must be compatible with the vapor permeability called for by the EIFS.

CAVITY INSULATION

Dense-pack cellulose is a low cost, easy to install material with a low carbon footprint. The insulating value of cellulose insulation is reduced if the material is damp or wet so care should be taken to ensure any temporary moisture in the assembly has a way to dry out. Fiberglass insulation was not included in either pricing option. In both dense-pack and batt form, fiberglass insulation has a good R-value and maintains its thermal properties when damp and is thus, worthy of consideration in a NZE wall assembly. The price for fiberglass falls between cellulose and batt mineral wool.

SHEATHING

OSB taped sheathing provides a cost effective way to create an air barrier and is readily available and easy to work with. The OSB is not as permeable as fiberglass mat sheathing so will not dry as easily to either side if moisture develops inside the wall cavity. The air tightness of the material is dependant on the sheathing quality and the correct application of the tape which can get wrinkled during application creating possible air gaps, or the tape may not be fully adhered to the sheathing if the surface is not properly prepared (also true of a liquid-applied air barrier). High quality tape are advised for long-term durability. The taped joints should be inspected before they are concealing behind the finish system.

FINISHING SYSTEMS

An EIFS system on EPS insulation is less expensive than one on mineral wool boards, though may be more susceptible to degradation from termites or rodents. The fiber cement rain screen siding is likewise less expensive than the poly-ash option and is also thinner and less durable.

ALTERNATE WALL ASSEMBLY TYPE	MATERIALS	SQUARE FOOT COST	SF LABOR RATE	SF CONST. COST
2x4 stud wall w/ EIFS on 4" EPS	interior drywall	$0.75	$1.25	$2.00
taped OSB and dens-pack cellulose	2x4 wood studs	$1.50	$2.00	$3.50
	3.5" dense-pack cellulose insulation	$2.50	$0.00	$2.50
Alternate Case 1	OSB with taped joints	$2.25	$1.25	$3.50
	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	4" EPS insulation	$1.05	$1.00	$2.05
	acrylic stucco finishing products	$6.00	$7.20	$13.20
			TOTAL SF COST	**$30.50**
2x6 stud wall w/ EIFS on 4" EPS	interior drywall	$0.75	$1.25	$2.00
taped OSB and dens-pack cellulose	2x6 wood studs	$1.90	$2.00	$3.90
	5.5" dense-pack cellulose insulation	$3.10	$0.00	$3.10
	OSB with taped joints	$2.25	$1.25	$3.50
Alternate Case 3	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	4" EPS insulation	$1.05	$1.00	$2.05
	acrylic stucco finishing products	$6.00	$7.20	$13.20
			TOTAL SF COST	**$31.50**
2x4 stud wall w/ siding on 4" EPS	interior drywall	$0.75	$1.25	$2.00
taped OSB and dens-pack cellulose	2x4 wood studs	$1.50	$2.00	$3.50
fiber-cement siding	5.5" dense-pack cellulose insulation	$3.10	$0.00	$3.10
	OSB with taped joints	$2.25	$1.25	$3.50
Alternate Case 1 - siding	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	4" EPS insulation	$1.05	$1.00	$2.05
	furring strips and screws	$0.75	$1.00	$1.75
	fiber-cement siding	$2.40	$3.90	$6.30
			TOTAL SF COST	**$25.95**
2x6 stud wall w/ siding on 2" EPS	interior drywall	$0.75	$1.25	$2.00
taped OSB and dens-pack cellulose	2x6 wood studs	$1.90	$2.00	$3.90
fiber-cement siding	5.5" dense-pack cellulose insulation	$3.10	$0.00	$3.10
	OSB with taped joints	$2.25	$1.25	$3.50
Alternate Case 2	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	2" EPS insulation	$0.70	$1.00	$1.70
	furring strips and screws	$0.75	$1.00	$1.75
	fiber-cement siding	$2.40	$3.90	$6.30
			TOTAL SF COST	**$26.00**
2x6 stud wall w/ siding on 4" EPS	interior drywall	$0.75	$1.25	$2.00
taped OSB and dens-pack cellulose	2x6 wood studs	$1.90	$2.00	$3.90
fiber-cement siding	5.5" dense-pack cellulose insulation	$3.10	$0.00	$3.10
	OSB with taped joints	$2.25	$1.25	$3.50
Alternate Case 3 - siding	air barrier assocaiated caulks and tapes	$1.85	$1.90	$3.75
	4" EPS insulation	$1.05	$1.00	$2.05
	furring strips and screws	$0.75	$1.00	$1.75
	fiber-cement siding	$2.40	$3.90	$6.30
			TOTAL SF COST	**$26.35**

Alternate Wall Assembly Type pricing - Optional Materials

PROJECT ACTIVITIES

PHELPS HIGH SCHOOL ENGAGEMENT

One of the goals of our project is to take the knowledge we've gained through our research and help put that information into the hands of the future generation of architects, engineers, and builders. We have developed a two-part approach to working with the staff and students at Phelps High School, which we will carry out in the fall and winter of 2021-2022. Our work will help prepare students to participate in the NZE design and construction that will be standard in the District with the anticipated new energy codes.

BUILDING SCIENCE SEMINAR

The first component of our outreach and engagement effort with Phelps High School will be a series of interactive seminars with students that cover topics integral to our research. The seminars will be a combination of lecture and discussion, with some hands-on elements, depending on the topic. The goal will be to expose students to new and advanced ideas in topical areas they are already familiar with, including building design, building systems, and construction materials.

We will finalize the specific lineup of seminars with the Phelps team in Fall 2021. Currently, we anticipate seminars covering the following topics:

- Introduction to Net Zero buildings
- Principles of Passive House construction
- High performance wall assemblies and materials
- HVAC systems for Net Zero/Passive homes

We will align the seminar topics with Phelps' core course for Freshmen and Sophomores that provides in overview of a wide range of topics central to the architecture, construction, and engineering curriculum. One or more members of the project team will lead each seminar, walking students through the basic concepts for each topic, describing essential resources (e.g., training materials, codes), and providing applied examples, including from the grant research.

Refer to Appendix A for the Phelps Curriculum Plan

CONSTRUCTION WORKSHOP

The second component of our outreach and engagement is a workshop in which we work with Phelps students in a hands-on setting to construct wall assembly mock-ups based the designs we developed through the grant research. Mock-ups are a useful tool for constructing buildings, and they are also an educational device.

We will build two wall assemblies over one or two sessions that give students an opportunity to see how a building goes from design to construction, and to have the opportunity to interact with the materials—conventional and specialty—that go into a wall assembly to support a Net Zero home. The mock-ups will be half- or full-size corner wall sections with window openings. This allows us to show details for corners, window installation and transitions, exterior insulation, vapor, and water management, and cladding. Students will work in teams to build the mock-up, applying the materials the same way they would in the field on an actual structure.

Once the mock-ups are complete. We will coordinate with Phelps to determine how best to make the mock-ups available for other Phelps classes and students. We will coordinate the format and timing of the workshop with the Phelps team.

ANALYSIS AND RECOMMENDATIONS

Our research assessed the feasibility of alley lot dwellings that meet NZE goals and explored alternative design approaches based on cost and performance. Here we derive observations and conclusions from our case study that are relevant to those in the District looking at producing housing on vacant alley lots in ways that support climate change and energy savings goals. Each owner, designer, and builder will face unique circumstances, but we believe these insights will be broadly applicable and can make it easier and more cost-effective to design high performance houses on alley lots.

START SMALL AND SIMPLE

Alley lots offer multiple advantages when it comes to producing cost-effective, high performing homes.

- Alley lot sizes, characteristics, and zoning requirements are conducive to relatively smaller, simpler structure, which will be more cost-effective to build than other housing types.
- Most alley lots are rectangles that support taking a standard NZE building design and scaling it up or down, based on the specific lot size and configuration.
- The simplicity of an alley dwelling's compact shape makes it easier for builders with less experience constructing NZE structures to achieve the necessary air tightness requirements and to install continuous insulation.
- There are hundreds of vacant alley lots throughout the District, providing some of the best opportunities to construct additional single family housing that meets NZE goals.

AGGREGATE DEVELOPMENT

Alley lots also come with challenges, which work against the goals of maximizing housing and reducing costs.

- Alley lots often involve complex and expensive utility connections, which can raise the cost of projects substantially. If multiple alley lots could be developed at one time, infrastructure costs could be shared and mobilization costs reduced.
- Alley lots can be challenging when it comes to access for construction activity and storing and staging construction materials. Phasing construction across multiple lots can help provide space for construction activities.

ELIMINATE THE PARKING REQUIREMENT

- Zoning for alley lots requires including space for parking, which will mean reducing living space and occupancy or increasing the total size (and cost) of the building. We have shown in the energy analysis how including the parking space within the building (or building overtop the parking space) increases the envelope surface area of the occupied space and makes it harder to meet energy goals because of a greater area where space conditioning can be lost to the outside.
- With the rise in car share and alternative mobility options, as well as a greater density of services within

walking distance, the design team sees a trend in the District away from car ownership and feels the alley lot parking requirement may be outdated.

CONSIDER OPTIONS FOR COST AND CONVENIENCE

Some of the desirable design and materials choices we highlight in our analysis may pose challenges for project teams, and we have tried to highlight alternative options.

- Some builders or subcontractors may not be willing to provide EIFS (or other) finishes on small scale projects with constrained site access. In this case, a rain screen assembly is an effective (and cost-effective) alternative.
- While there are important benefits to exterior wall insulation related to the thermal enclosure and moisture management, assemblies with substantial (>2") exterior insulation can be challenging to build. Our analysis shows that in our climate, structures can meet NZE goals with a minimal amount of exterior insulation making them more cost-effective than ones with more exterior insulation.

UNDERSTAND THE CHALLENGES

Our research highlight some specific challenges—and solutions—for NZE alley dwellings, which we emphasize to anyone pursuing this type of project.

- Alley dwellings will often be relatively small, which reduces energy use and cost, but it also puts added pressure on carefully designed and built structures. Because the building envelope area to floor area ratio is small, and internal loads are low, losses of heating or cooling through the envelope need to be more carefully controlled than in a larger building.
- Window and door openings need to be carefully considered for size, R-value and shading. In particular, minimizing the use of windows—both in response to code and livability—is critical to achieving high thermal performance, which will improve comfort, reduce energy costs, and allow HVAC systems to be smaller, making them more cost-effective, not to mention the reduced cost of the window package.

EXTERNAL SCAFFOLD STRUCTURE

- The scaffolding / screen element is critical for the minimized alley dwelling form to provide needed solar shading and bulk-water management. We have not fully described this element in this report, but we feel it could be deployed in different ways to have the same benefit of protecting the envelope from water and shading it from unwanted solar gain. We also recognize the need to carefully consider the cost of this element, something we did not address in the report.

SHARE THE KNOWLEDGE OF NZE BUILDINGS

Finally, we offer more general observations and advice for owners, architects, and builders looking to take on an NZE alley dwelling projects, based on our research and collective experience. Namely, recognize that architects and builders may not be familiar with the types of techniques required to design and construct and NZE home. Architects may not be familiar or accustomed to the techniques and assemblies necessary to construct high-performance structures. Providing an architect with resources, such as this report, can support better, more effective designs.

LOOK FOR TRAINING OPPORTUNITIES

Similarly, builders may need support or training with the types of methods and materials that are increasingly standard in NZE construction. Builders may not be familiar with installing air barriers in a way that avoids gaps in coverage, and training may be useful to emphasize the importance of avoiding air leakage in a high-performance building. Additionally, builders may not be familiar with installing rain screen cladding through more than 1" of exterior insulation. Installing windows in these assemblies is also more complicated to ensure good air-tightness and water management. Builders will need to familiarize themselves with rigid insulation, using long screws that can support the cladding farther from the building sheathing, and window installation options and techniques. Architects and builders may not be familiar with using more permeable sheathing materials such as glass-mat exterior gypsum and the assembly requirements of these materials.

CONSIDER PRE-FABRICATION

Given the challenges of on-site construction and the relative simplicity of alley dwellings, another approach worth exploring is off-site construction methods. This could include factory assembling the exterior envelope elements, which can help with the quality control and shorten on-site construction time lines. Approaches like panelized construction are not commonly used in the District, particularly due to site access restrictions, but alley lots may be a appropriate application, if access to the site with large panels is not an issue.

CONCLUSIONS

The District needs more housing to satisfy current and projected population growth. To meet the District's climate goals, that housing needs to be energy efficient. Ideally, that housing should also help address the high cost of housing in DC. Alley dwellings that meet NZE targets can support all of these goals.

Additional housing stock helps lower prices, and the District has hundreds of buildable, vacant alley lots. Moreover, alley lots are less desirable than street-front lots and therefore less expensive to purchase. The form of alley dwellings are by nature simple and therefore accessible for inexperienced designers and builders to achieve NZE. We are not proposing that NZE alley dwellings will directly support "affordable housing," rather we are suggesting that a NZE single family dwelling on an alley lot can be more cost-effective than a NZE building on a street lot because it has a more simplified form and the lot prices are lower. NZE alley dwellings can also reduce the total cost of ownership (or occupancy, if rented), given lower utility bills.

This study has shown that alley dwellings with compact, simple geometries are capable of achieving NZE operation. There are a variety of materials to choose from for building wall assemblies that contribute to NZE structures. These materials are commonly used in building construction and broadly available. Techniques for installing continuous insulation and providing good air-tight detailing can be learned by first-time builders of NZE structures.

Because of their small size and small proportion of housing stock in the District, NZE alley dwellings may not be the building type that provides the greatest energy efficiency benefit to the city, but their simplicity and potential low construction cost make them a good building type for inexperienced NZE builders to start out with. Increasing the number of NZE structures in the District through the construction of NZE alley dwellings raises awareness of and experience with NZE building techniques and can help expand the construction of NZE structures across all building types.

Our building science seminars with Phelps high school will be built around their CTE Foundation Course, a core course that provides students with an introduction to a range of important architecture and construction concepts, technologies, and methods. Across six weeks of the CTE course, the grant team will conduct a series of interactive seminars on topics that align with the CTE curriculum. Table A.1 outlines the curriculum, indicating the CTE topic from the Phelps core course, the relevant building science topic(s), and the lead for each topic. In most cases, the seminars will be conducted by two or more members of the grant team. Throughout the series we will emphasize new and emerging technologies and products and use hands-on examples whenever possible. We will also use the Net Zero Alley Dwelling developed for the grant as an example of how to apply the concepts to a local housing example.

1. Introduction to Net Zero/Passive House
- Overview of Net Zero energy and Passive House approaches
- Basic requirements for NZE/PH
- Design challenges and common solutions
- Examples from the District of Columbia

2. Building science construction math
- Overview of the role of math in high performance design and construction
- Applications:
- HVAC calculations
- Air sealing and air tightness
- Insulation and thermal management
- Example: Net zero alley dwelling design

3. High efficiency HVAC systems
- Overview of the role of HVAC in high performance buildings
- Challenges to effective HVAC
- Common and emerging HVAC technologies

4. Wall assemblies for high performance structures
- Design principles for wall assemblies
- Common designs and their pros/cons
- Example: Net Zero alley dwelling
- Construction approaches and challenges
- Innovative products and tools

5. Energy modeling and analysis
- Overview of the role of energy modeling
- Principles and metrics
- Software and technology
- Example: Net Zero alley dwelling

6. High performance architectural principles
- Review of NZE/Passive design requirements
- How to approach an NZE/Passive design
- Technology to suppose
- Common challenges
- Example: Net Zero alley dwelling