32 Mill Street Net-Zero Energy Retrofit

Warrior Home
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WARRIOR HOME

Engineering Narrative

U.S. Department of Energy
Solar Decathlon 2023 Build Competition

32 Mill Street
Engineering Narrative
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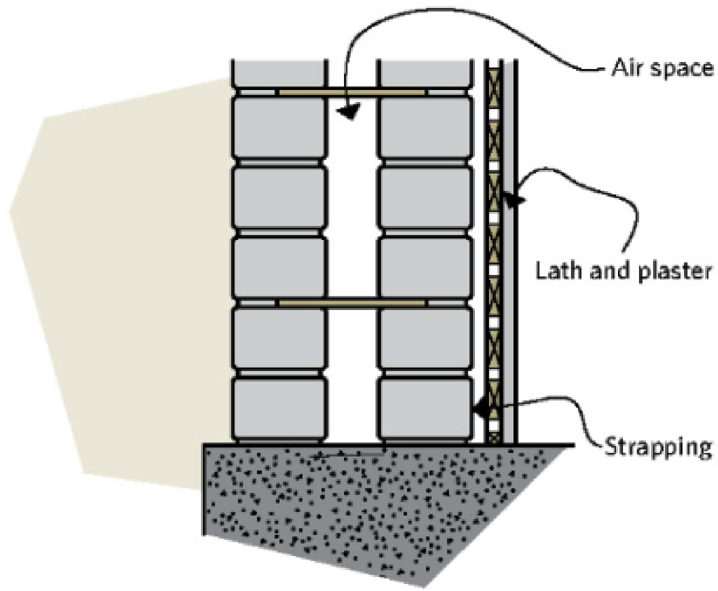
In partnership with the
KW Urban Native Wigwam Project

Engineering Jury

Building Envelope



The existing wall assembly was only a double wythe structural brick wall with a 2"x4" empty stud cavity covered with lath and plaster. This provided virtually no thermal resistance to the existing house and was one of the big improvements made in the retrofit design. Additionally, all of the existing non-dimensional 2x4 wood floor joists were bearing on the exterior brick wall which could cause issues regarding the freeze thaw cycle.

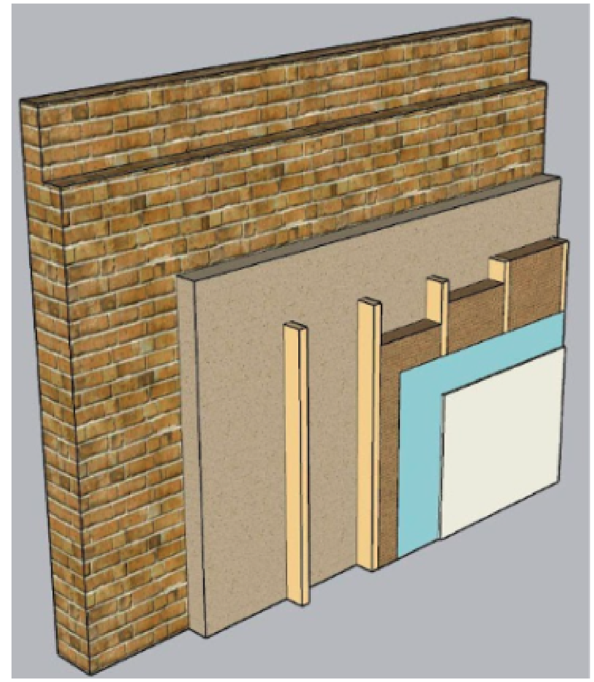
The team was unable to identify most of the connection details between the wall and the roof assembly before demolition. When going through the initial design, before demolition started, we used sample details from other historic buildings to help come up with the existing detail. In the existing roof attic space there was about a foot of blown in cellulose insulation. Upon initial investigation, it seemed that the attic space was originally designed to be a vented assembly, due to the location and type of insulation. After looking closer, the team realized that there were no soffit or attic vents installed, meaning it was an unvented space. This can cause issues with possible moisture penetration and its inability to dry out within the attic. Additionally, if cellulose is constantly being wetted by condensation and other moisture it can cause the insulation to settle, greatly diminishing the thermal resistance of the roof.

The foundation, both walls and slab, were completely uninsulated. The walls were made from rubble stone and the slab was poured concrete, meaning the foundation had limited thermal resistance. Additionally, the site is in a flood zone so that had to be taken into consideration when working on the retrofit design.

The first and second storey windows were double pane installed around 1990. The basement windows seemed to be original to the house as they were single pane windows and the frames were cast into the rubble wall foundation. When looking for window manufacturers it was necessary to re-do all of the window rough openings to ensure they do not hinder the energy efficiency of the overall building.

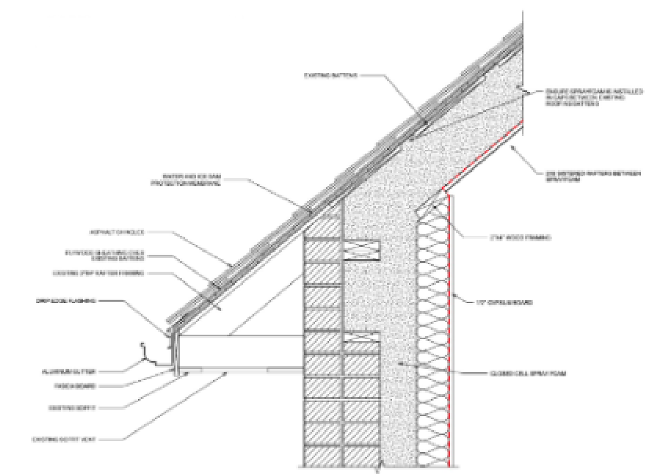
Building Envelope

Because the architectural team wanted to keep the look of the existing building facade, the building science team had no choice but to push the envelope in when designing the wall assembly. While this does limit the interior floor area, the team tried to limit the thickness of the wall while maximising its thermal resistance. These became two main goals for this specific area of the project. The wall assembly of the retrofitted house, from outside to inside, is planned to be as follows: the original double wythe brick, four inches of closed cell spray foam, 2”x4” stud wall insulated with mineral wool batt, vapour variable air barrier, and gypsum wall board with the owners’ choice of finishing.



This solution takes advantage of two different insulation types. The closed cell spray foam is more expensive but it provides higher thermal resistance which helps limit the interior floor area wasted by the wall assembly. While lower in thermal resistance, mineral wool provides fire resistance and is a cheaper option that comes in predetermined sizes that fit into the stud space, making it easy to install. Additionally, it is easier to install mechanical, electrical, and plumbing services in the mineral wool section rather than the closed cell spray foam. The addition of a vapour variable air barrier was to ensure that the assembly is airtight without preventing water vapour from being trapped within the wall itself. When designing the wall, we were initially concerned about applying spray foam directly on the brick because of the potential for moisture issues. After speaking with industry partners, it was determined that this would not be an issue because the exterior condition of the brick was in good condition so that it would be low risk for spray foam application.

The plan for the roof is for it to be converted into a vented assembly. The existing blown in cellulose insulation will be replaced with two feet of new blown in cellulose insulation. This is to ensure that any possible damaged original insulation is not in the newly renovated house. Spray foam will be installed at the connection between the wall and the roof to ensure the continuity of the thermal barrier between systems. Soffit vent, roof vents, and baffles will be included in the design to ensure full ventilation of the attic space, preventing any moisture from becoming trapped. The shingles were recently installed and in good repair but the roof sheathing will be checked thoroughly from the inside of the attic.

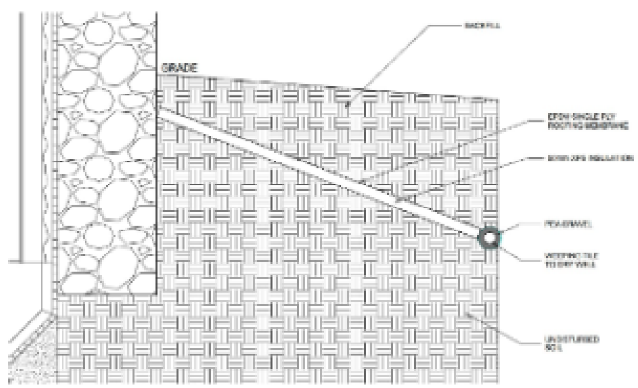


ROOF TO WALL CONNECTION
1:5

Building Envelope

Additionally, there are sections of the roof that do not have an attic space and instead are a part of a cathedral ceiling located above the stairs. These will have closed cell spray foam to keep the assembly as thin as possible to avoid taking away too much head room. This area of the roof assembly will still have soffit vent with baffles leading to the attic space to ensure full ventilation of the entire roof assembly.

The main goal for the foundation is to draw water away from the building in case of a flood or the possibility of any water ingress. The planned assembly of the retrofitted foundation wall, from outside to inside, is the existing rubble foundation wall, dimple board leading to a weeping tile and sump pump below the slab, two inches of closed cell spray foam insulation, 2”x4” studs, and gypsum wall board. The assembly for the new slab from outside to inside is two inches of gravel infill, two inches of rigid insulation, six mil polyethylene barrier, and the new concrete slab. On the top of the existing rubble wall a capillary break will be added in conjunction with skirt flashing at the transition between the double wythe brick wall and the rubble wall. An additional measure to prevent moisture infiltration. We plan to install a sheet of rigid insulation around the perimeter of the house extending about five feet out and three feet down. A single ply roofing membrane will be installed on top of the insulation sealed to the top of the rubble wall just below grade. The assembly will lead to an additional weeping tile covered in pea gravel, leading to a dry well. The purpose of this system is to lead water, within the soil, away from the foundation to limit it entering the foundation wall system. By attempting to reduce the water entering the foundation system it limits the strain that the foundation may have to take due to possible water ingress. Additionally, it helps to keep the foundation warm to limit the freezing in the wintertime.



Finally, the windows will be triple pane, argon filled complete with low-E coatings and thermally broken frames. We will be confirming that there is proper preparation of the rough openings to ensure that each window as a whole is performing at optimal levels.

Structural

The main structural material used was wood, which was used for all of the new structural elements in the project including floor joists, shear walls, etc. This choice of material was thought to be the most appropriate for the small residential nature of this project. The design basis used for the design and assessment of these wood members was CSA O86 “Engineering Design in Wood”. The existing masonry wall was assessed using the local masonry code, CSA S304 “Design of Masonry Structures”.

The loads that were considered in the retrofit were dead, live, variable, and wind loads. The dead loads consisted of the weight of the building and the structural components that were to be added. The live loads into account the occupants as well as the furniture that they would move in. The variable loads referred to the snow, rain, ice, or general debris that would sit on the roof. Once again, due to the smaller residential nature of the project, the seismic, permanent, crane, and expansion/deflection were ignored (in reference to OBC 4.1.2.1).

In collaboration with the architecture team, the house’s floor plan was redone while maintaining the home’s existing load bearing walls. Additionally, due to the existing stairs not being code-compliant (specifically between the basement and the first floor due to the angle of the stairs being over 45 degrees (according to OBC 3.4.7.5)) many of these stairs needed to be rebuilt to fit existing guidelines. These stairs, the partition walls, the beams, as well as the floor joists were reframed with newer pieces of lumber.

Upon inspection, minor cracks were found in the foundation wall. This indicated an underperformance of the wall, as reinforced concrete walls built to code should be able to withstand the effects of cracking (OBC 4.1.8.3). But, as the cracks were less than 2mm wide, they were classified as non-structural, meaning they could cause leaks but did not contribute to any structural deficiencies of the project. These cracks were most likely due to the differential settlement of the house, as the cracks at the top were wider than the cracks at the bottom. These cracks were addressed by injecting epoxy into the gaps, which sealed the cavities and prevented further water damage.

Structural

Benching (or bench pinning) was used to lower the floor of the basement. This was because it was cheaper than underpinning as well as quicker to construct. It also worked better with the site's granular soil conditions, as the soil was not strong enough for underpinning. Also, upon examination by out structural consultant, Tacoma Engineers, it was determined that benching was the most appropriate choice in terms of cost and labour. The rebar spacing and benching width was determined through calculations. This benching was done around the existing load-bearing wall of the basement with advisement from Tacoma Engineers.

Due to the added weight of the solar panels, it was necessary for the house's existing roof rafters to be sistered. Although the existing rafters were in good condition, sistering was needed for additional reinforcement. The existing roof rafters were inspected for mold prior to installing the newer rafters. In order to prevent the future molding of these joists, the roof was planned to be converted into a ventilated assembly in collaboration with the building envelope team. The solar panels were attached to the roof using a secondary c-channel steel structure, which helped to transfer the weight of the panel to the structure. This also allowed the weight of the panels to be more distributed than if the panels were bolted directly onto the rafters, as this would result in several point loads. The building envelope team also decided to place flashings directly underneath the bolts and the mounts in order to prevent vapour and rain leakage. These number of holes for bolts were also kept to a minimum to ensure as little thermal penetrations as possible.

The existing house included a porch, however it did not include a deck which was a want of our client, Kitchener-Waterloo Urban Native Wigwam Project (KWUNWP). New posts along with footings had to be installed for the construction of the deck at the back of the house. Formadeck vinyl deck boards was used as the decking material, which complied with the City of Kitchener's requirements. The spacing of the deck's joists were determined by its span. The wood for the porch was completely replaced with Formadeck vinyl deck boards as well due to rotting.

Energy Modelling

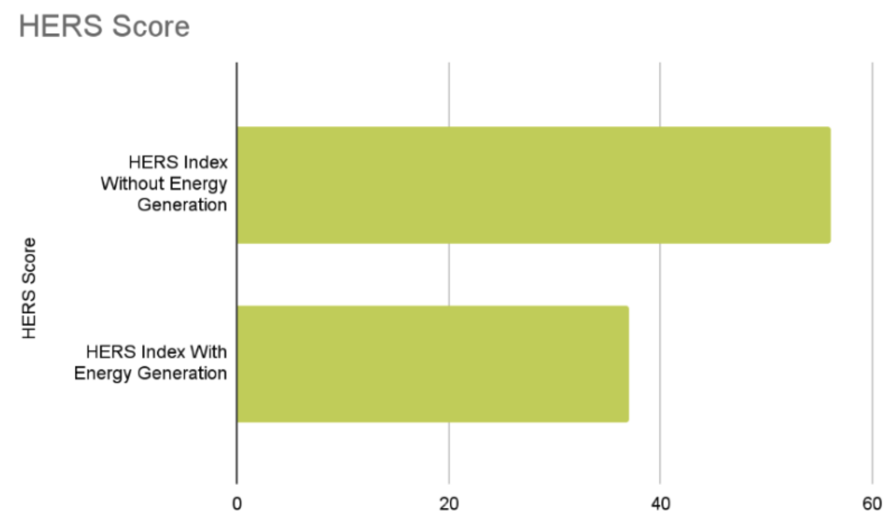
In order to create accurate energy models for the project, the design parameters of the house needed to be established, and the data was inputted into eQuest and Ekotrope. The model generated by the software helped to provide information regarding the annual and monthly energy consumption of the house post-retrofit and Home ENergy Rating System (HERS) scores. Table 1 below shows the major input parameters into eQuest, similar parameters are also inputted into Ekotrope.

The Ekotrope model was used to generate a HERS Score. The modeling software reported the Warrior Home design has a HERS score of 56 without PV implementation, and a score of 37 with PV.

The current Ekotrope energy model projected annual energy consumption of 11,463 kWh. Compared to baseline HERs homes, the energy use intensity (EUI) of the current retrofitted home design is projected to be 61.3% more energy efficient.

Table 1: Energy Model Inputs

Design Parameter	Warrior Home Design
Conditioned Area	1200 ft^2
Foundation Walls R-Value (RSI)	20
Above-Grade Wall U-Value (RSI)	0.022
Roof U-Value (RSI)	0.017
Window U-Value (RSI)	0.167
Slabs R-Value (RSI)	10
Window SHGC	0.3
Heating Equipment	Air Source Heat Pump (Electric, 10HSPF)
Cooling Equipment	Air Conditioner (Electric, 20 SEER)
Domestic Hot Water	Residential Water Heater (Electric, 3.48 Energy Factor)
Primary Lighting Fixtures	100% LED
ACH50 Infiltration Rate	1.0



Mechanical

For the building systems, we will be decarbonizing the home by replacing the existing natural gas equipment with a cold-climate air-source heat pump coupled with a heat recovery ventilator. Due to the asbestos found in the existing ductwrap, the ductwork will be replaced by an improved layout. Air will be distributed by a central air handling unit in the basement to avoid oversizing equipment. The heat pump features a backup 8 kW electric heater in the event of extremely cold temperatures below -22 degrees fahrenheit.

Bradford White Aerotherm Heat Pump Water Heater

GE/ Haier Connect Air-Source Heat Pump

HERO 150H HRV

HERO HS300 HEPA

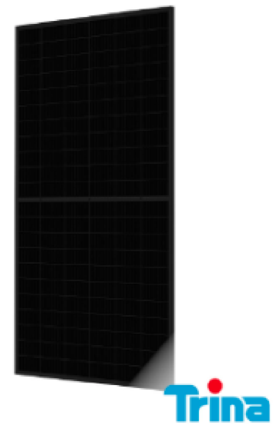
The HRV will utilize a hybrid ducted system with the AHU, with dedicated spot ventilation in the bathrooms and general return from common spaces for better air circulation. To improve the indoor air quality, a bi-polar ionization device will be installed at the AHU supply duct to filter out any pollutants and particulate matter.

While the systems are currently shown as floor-mounted in the basement, we are planning to steer away from conventional residential HVAC practices by elevating the equipment and using floor drains and a sump pump for flood resilience.

The domestic water heating will be handled by a heat pump water heater, serving low-flow water fixtures. All of the water appliances and bathroom groups are stacked to reduce plumbing lengths with a single sanitary stack and domestic water riser through the center of the home.

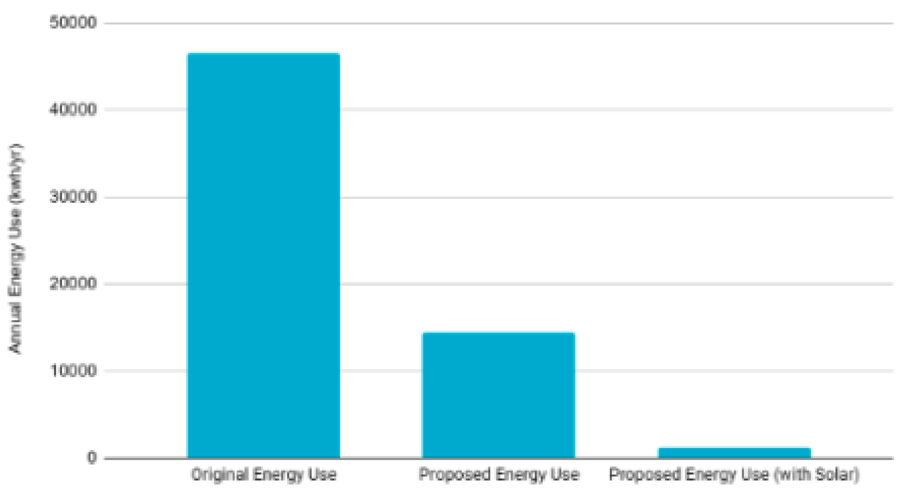
Solar

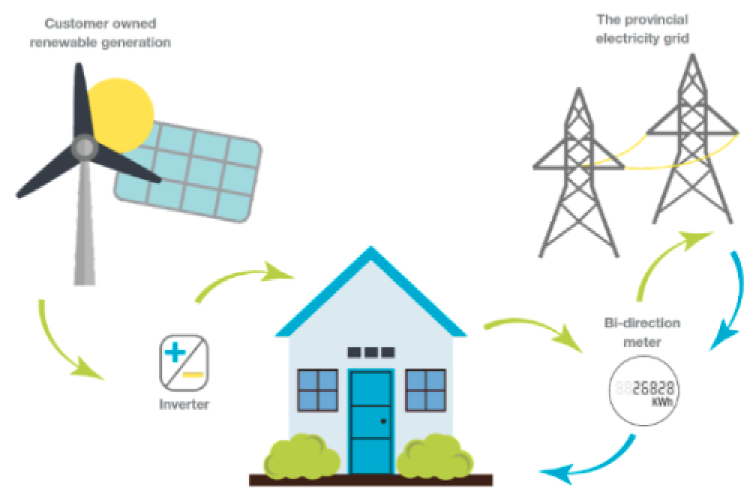
The proposed PV array is 10.9 kW. A total of 28 Trina Solar TSM 390 modules are to be flush mounted to the roof with a Fastrack aluminum rail system. The rail system is well suited for the somewhat complicated panel layout on account of the existing roof shape. A protective array perimeter meshing will be installed to provide physical protection from environmental factors such as high winds or falling debris and to deter animals from the array.



The array will be paired with a SolarEdge SE7600H 7.6 kW string inverter. The PV system does not include energy storage. The house will remain grid-connected with the use of a net-meter, allowing the home to draw from the grid when necessary. Using net-metering, we can maximize the benefit received from the energy generated on site and avoid the significant capital cost of a battery. Further, the majority of electricity in Ontario is generated from hydropower, which is considered a green energy source.

The system overall is estimated to produce about 11,000 kWh per year.





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WARRIOR HOME

Building Specification Summary

Property
32 Mill St.
Kitchener, MI

32 Mill St. (DRAFT)
Initial House Design - No solar

Organization
Warrior Home Solar Decat
Ankit Shah

Builder

Inspection Status
Results are projected

Building Information

Conditioned Area [ft²]	1,200.00
Conditioned Volume [ft³]	9,600.00
Thermal Boundary Area [ft²]	5,782.63
Number Of Bedrooms	3
Housing Type	Single family detached

Rating

HERS Index	56
HERS Index w/o PV	56

Building Shell

Ceiling w/ Attic	Target Roof insulation; U-0.017
Vaulted Ceiling	None
Above Grade Walls	Envelopoe D1; U-0.022
Found. Walls	Subfloor Target; R-20
Framed Floors	None
Slabs	Slab; R-10

Windows (largest)	U-Value: 0.167, SHGC: 0.3
Window / Wall Ratio	0.11
Infiltration	1 ACH50
Duct Lkg to Outside	Untested Forced Air
Total Duct Leakage	Untested

Mechanical Systems

Heating	Air Source Heat Pump • Electric • 10 HSPF
Cooling	Air Conditioner • Electric • 20 SEER
Water Heating	Residential Water Heater • Electric • 3.48 Energy Factor
Programmable Thermostat	Yes
Ventilation System	80 CFM (unmeasured) • 59.56 Watts (Default)
Whole House Fan	N/A

Lights and Appliances

Percent Interior LED	100%
Percent Exterior LED	100%
Refrigerator (kWh/yr)	170.0
Dishwasher Efficiency	467 kWh
Ceiling Fan	None

Clothes Dryer Fuel	Electric
Clothes Dryer CEF	3.0
Clothes Washer LER (kWh/yr)	152.0
Clothes Washer Capacity	4.2
Range/Oven Fuel	Electric

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