KEHL-0

RACE TO ZERO

ATTACHED HOUSING

VOLUME I

APRIL 3, 2018

UNIVERSITY OF WATERLOO

WARRIOR HOME

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1.0 Project Summary

The Kehl Street Development is a community being built by Habitat for Humanity in the Waterloo Region (HabitatWR). Kehl-0 is a 4-unit townhome within the Kehl Street Development project, which intends to bridge the gap between affordable housing and energy efficiency. While embodying HabitatWR's goals, Kehl-0 focuses on fostering and nurturing communities through its constructability and long-term adaptive design.

Relevance of Project to Goals of the Competition

The ever-increasing cost of energy and the growing demand for sustainability are leading the building industry towards more energy-efficient designs. This shift in the industry has placed a heavy burden on homes designed for the affordable housing market, which are currently built to the minimum code requirements. Warrior Home will provide practical and cost effective solutions to improve HabitatWR's current home design, while meeting the Net Zero Energy Ready requirements. Kehl-0 can potentially be implemented by HabitatWR in future developments, including one planned for 2021.

Design Strategy and Key Points

Warrior Home's approach is to improve the current HabitatWR design, which is based on the minimum energy performance requirements. Kehl-0 focuses on ease of constructability, affordability, and energy conservation, while following the net zero energy ready requirements. Kehl-0 will maintain a simple house geometry, and will ensure the continuity of the control barriers in the building enclosure. Fundamentally, Warrior Home will future-proof the design to allow families to live in their homes comfortably for many years, without the need for major retrofits.

Project Data

- Kitchener, Ontario, Canada
- ASHRAE Climate Zone 6A [1]
- Square footage per Unit 1116 ft^2;
  Lot Size per Dwelling Unit: 1346 ft^2;
  Total Lot Size: 5382 ft^2
- 2-Storey, 3 Bedrooms, 1 Bathroom, average 5 occupants per unit
- HERS 0 with PV, HERS 48 without PV
- Utility Costs (electricity): $57CAD/Month
- Utility Costs (water): $30CAD/Month

Technical Specifications

- Wall Insulation: 40 hr.ft^2.°F/BTU
- Foundation Slab Insulation: 12 hr.ft^2.°F/BTU
- Roof Insulation: 60 hr.ft^2.°F/BTU
- Window U-Value: 0.24 BTU/hr.ft^2.°F
- Window SHGC: 0.25
- HVAC Specifications: ERV, Mini-split heat pump system for heating and cooling
- Electric heat pump water heater with drain water heat recovery
- Solar PV: REC355 Twin Peak 2S72 module

1.1 Team Information

Warrior Home is composed of over 50 students from the University of Waterloo who have a passion for building efficient homes, stronger communities, and a better future. The interdisciplinary team is led by three managers, four design leads, and eight technical leads. The collective expertise of the team helps create effective and innovative designs that exceed all evaluation parameters of an affordable net zero energy ready home (NZERH). The team actively participates in the local community and has developed strong relationships with the University and industry, leading to valuable insight and guidance.

TEAM LEAD

Matt Roberts
4th Year Civil Engineering

JUNIOR PROJECT MANAGERS

Sharon Emmanuel
3rd Year Civil Engineering

Alison Kong-Foon
2nd Year Civil Engineering

DESIGN LEADS

Anita Cheng
BArchSci, MEng Candidate

Jeffrey Ren
1st Year Urban Planning

Sara Al Humidi
2nd Year Civil Engineering

Jasmine Zou
2nd Year Environmental Engineering

TECHNICAL LEADS

Saif Hashimi
2nd Year Civil Engineering

Galen Fernandes
2nd Year Mechanical Engineering

Ani Dharmarajan
3rd Year Civil Engineering

Rebecca Wong
3rd Year Mechanical Engineering

Daeun Yoon
3rd Year Civil Engineering

Sara Turner
3rd Year Environmental Engineering

Peter Oliveira
4th Year Civil Engineering

Michael Wong
3rd Year Environmental Engineering

1.1.1 Industry Partners

Habitat for Humanity Waterloo Region (HabitatWR) is a non-profit housing organization that builds simple, robust, and affordable homes. As our client, HabitatWR assists Warrior Home by providing information about their construction practices, business model, and finances. In return, Warrior Home aims to make improvements to their designs, and raise $80,000 for HabitatWR, $20,000 of which has already been raised.

Orchard Design has 20 years of experience in architectural drafting and design for single family residences and townhomes in urban developments. Orchard Design has provided Warrior Home with previous project drawings, specifications and insights on how to design affordable homes. As the current Architect of Record for HabitatWR, Orchard Design will be implementing aspects of the Kehl-0 design into a future 2021 development.

RDH Building Science Laboratories researches, tests, and analyzes building technologies to develop strategies for improving performance and functionality of buildings. RDH actively shares their knowledge and enthusiasm for building science with Warrior Home through mentorship, resources, consulting and software training services.

University of Waterloo (UW) is consistently ranked as one of the best engineering schools in Canada and is recognized around the world for its excellent reputation in the workplace. UW has internationally recognized researchers and professors in the field of architecture and building science. Warrior Home receives support from faculty members of the Civil, Environmental, and Mechanical Engineering Departments. Warrior Home is serving as the face for the new Architectural Engineering program being launched by UW in Fall 2018.

1.2 Design Constraints

Kehl-0 is located in the city of Kitchener, a fast growing city in Southern Ontario, Canada (Figure 1). A mid sized city that is part of the upper tier Regional Municipality of Waterloo (equivalent to a county), Kitchener has a population of approximately 233,000 people. Located roughly 100km southwest of Toronto and 130 km northwest of Niagara Falls, Kitchener is a well connected and easily accessible city. Served by VIA Rail and GO Transit, two crown corporations providing public transportation, it is possible to commute to Toronto in two hours or less. By car, highway 401, one of the widest highways in North America, connects Kitchener to Toronto. The city has a long history as a predominantly germanic manufacturing town, however, since then the city has diversified itself significantly. In addition to manufacturing; technology, finance and healthcare are all industries Kitchener is now known for. Recently, even technology giant Google opened an office in Kitchener.

Figure 1. Context Map

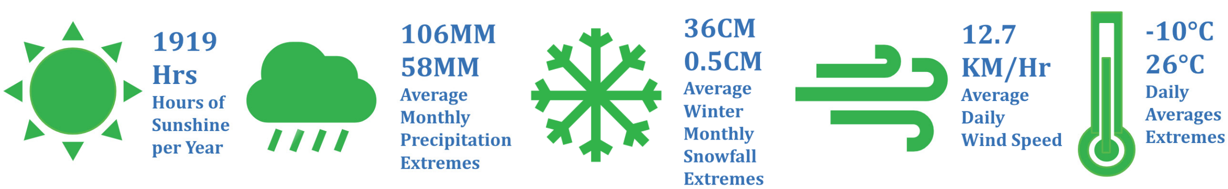


Figure 2. Climate Summary [2]

Cold and humid, the city is considered part of ASHRAE 6A climate zone [1] with temperatures that can fluctuate drastically throughout the seasons, as summarized in Figure 2. These weather conditions posed a challenge to Warrior Home to design a home that can withstand large amounts of precipitation (rain and snow) and an overall temperature difference of 64°F between the seasons.

Figure 3. Housing Types [2]

Kitchener has seen consistent and promising growth in the past few years. As the region developed into a centre for technology, the population has grown to become diverse and inclusive. As the city continues to grow, affordable housing is becoming an increasingly pressing issue for a number of residents. Warrior Home seeks to relieve the pressure of housing concerns for low income families by providing affordable and energy efficient housing solutions. As a result of the city's growth, building permits issued by the city have been increasing, with attached housing and apartments accounting for 60% of the growth in 2016 [3]. Compared to single family homes, attached housings are more efficient both in terms of space and energy consumption [xx]. An advantage of attached housing over apartments is the greater sense of community and a more amiable feeling of home.

[xx] RDH Building Engineering Ltd., Guide for Designin
Homeowner Protection Office, 2013.

1.2.1 Site Condition

The attached housing project is situated in the Southdale community of Kitchener, a predominately residential neighbourhood, well served by a number of amenities and established infrastructure.

Kehl-0 is located on a quiet residential street which connects to a major arterial, Ottawa Street, and conveniently feeds into the Conestoga Parkway. Well connected to employment and commercial centres, the site is also easily accessible via public transit. Although there is a presence of larger roads and highways nearby, a number of amenities such as restaurants, childcare and shops exist within a walking distance. A graphical summary showing the proximity of amenities is presented in Figure 4.

Figure 4. Neighbourhood Statistics [5]

Figure 5. Community Plan

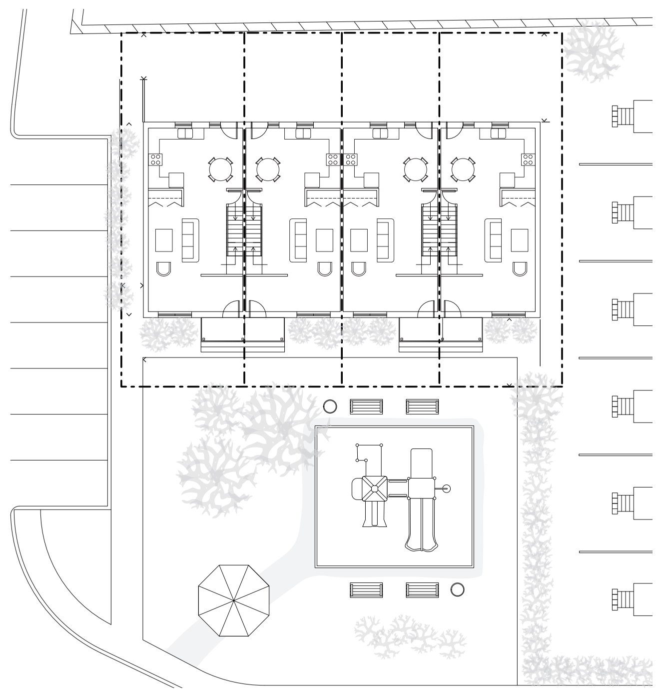


Figure 6. Site Plan with Community Park

Table 1. Site Statistics

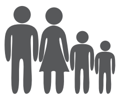
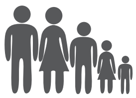
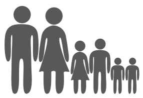
DESCRIPTION	AREA	
	m²	ft²
Lot Size	500	5382
Building Footprint	235	2529
Lot Area Per Unit		
End units	137	1475
Middle units	113	1216
Individual unit size	103	1116
Lot Coverage	47%	

Kehl-0's 4-unit, 2-storey, 4465ft² townhouse is part of HabitatWR's 45-unit Kehl Street "L" shaped build site (Figure 5). With this site, Warrior Home was challenged to maintain the integrity of the small building footprint and optimize energy efficiency. The building covers 47% of the total lot and is oriented north-east, allowing sun exposure along the width of each unit (Table 1). Surrounded by a residential area, Kehl-0 conveniently backs on to green space, reducing potential for noise and traffic. The plan features a community park, encouraging neighbours to interact and maintain an inclusive and safe environment (Figure 6).

1.2.2 Family Characteristics

Floor plans and interior spaces were designed based on families. With an average of five occupants per unit, occupants can range from single parent families to spousal families of three or more children. Table 2 contains a detailed summary of the hypothetical occupants for each of the four units.

Table 2. Family Characteristics

1		Family 1 has two energetic boys, one of which is in elementary school and enjoys reading and drawing, whereas the other son likes to listen to loud music. The parents work 9AM to 5PM jobs but are still engaging, hosting dinners for their large extended family frequently.
2		Family 2 has three children; one in university for volleyball, one in high school on the honour roll, and the last one requires lots of storage space for toddler needs. Both parents are very busy working long hours and occasionally bring work home.
3		Family 3 has four children. The youngest are twins and tend to cause a mess, while the other two are studious and active in their schools. Both parents are dedicated to their kids and work from home. The family enjoys getting together weekly for family boardgame night.
4		Family 4 is a single parent raising two kids with the help of a grandparent. The daughter has special needs and requires the house to be clean and simple; however, the son likes to have friends over. The grandmother stays at home and helps out but requires easy accessibility.

1.2.3 Design Strategies

Warrior Home has designed the Kehl-0 project to be in compliance with the Ontario Building Code (OBC) [6] and OBC Supplementary Standard SB-12 [7]. Additionally, Kehl-0 will meet the NZERH requirements as well as Energy Star Certification Version 3.1, EPA Water Sense and EPA Indoor airPLUS Program. Certification compliance will be confirmed using a performance path. A highlight of the design components in compliance with the mentioned relevant standards is provided in Table 3.

Table 3. Kehl-0 Design Highlights

COMPONENT		CURRENT HabitatWR	CERTIFICATION REQUIREMENTS[a]	PROPOSED DESIGN
ENCLOSURE	Basement Slab	n/a	R-10c[b]	R-12c
	Below Grade Wall	R-12b	R-19b/R-15c[b]	R-12b+R-20c
	Above Grade Wall	R-22b+R-5c	R-20b+R-5c[b]	R-20b+R-20c
	Ceiling	R-50	R-60[c]	R-60
	Window U-Factor	0.27	0.27[d]	0.24
	Air Tightness	3.53 ACH50	2.0 ACH50[e]	1.0 ACH50
Heating & Cooling System		92 AFUE gas furnace & no cooling	9.5 HSPF/15 SEER/12 EER air-source w/ electric or dual-fuel backup[e]	10.3 HSPF/18.8 SEER / 11.5 EER electric mixed mini-split
Mechanical Ventilation System		1.2 CFM/W; HRV with 60% SRE	1.2 CFM/W; heat exchange with 60% SRE[d]	1.3 CFM/W; ERV with 67% SRE
Water Heater		50-gallon conventional natural gas tank, EF=0.61	Electric systems, UEF = 2.0[e]	50-gallon electric heat pump, UEF=3.5
Lighting & Appliances		Homeowner selection	ENERGY STAR Qualified[d]	ENERGY STAR Qualified

[a]The certification requirements column displays the most stringent applicable requirement that must be fulfilled in order to achieve prescriptive certification for all programs of interest. Each value includes a reference to its respective program. For enclosure values; b=cavity (batt), c=continuous.
[b]2015 International Energy Conservation Code [8]
[c]Ontario Building Code [6] with Supplementary Standard SB-12 [7]
[d]DOE Zero Energy Ready Home Certification [9]
[e]ENERGY STAR, Version 3.1 [10]

1.3 Design Goals

Kehl-0 is designed to meet the Net Zero Energy Ready Home National Program Requirements set by the U.S. Department of Energy. Warrior Home's primary focus is to reduce energy consumption passively, through an effective building enclosure design. This design combines best practices for the region with building science principles to significantly reduce the HVAC loads. Most importantly, Kehl-0 represents a home designed to account for energy efficiency and affordability in all the design, construction, and occupancy periods of the building life.

INCLUSIVENESS

Since Kehl-0 is part of the Kehl Street Development, the 4-unit attached townhouse is designed to embrace inclusiveness and community-based design principles. By fostering a sense of community, homeowners will be able to feel safe, participate in joint environmental initiatives and enjoy their homes for many decades.

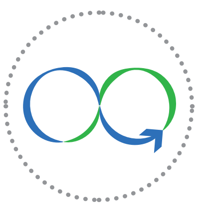
+ *maintain similar size to surrounding buildings*
+ *shared porch*
+ *community garden, park, gazebo*

EASY CONSTRUCTABILITY

HabitatWR builds homes with hundreds of volunteers who may not have any experience in construction. This poses a large limitation on the complexity of the building design. A simple rectangular geometry for the house would not only ease the methods of constructability, but it would allow for better energy performance.

+ *simple geometry: rectangular footprint with gable roof*
+ *reduced angles, joints, and areas of possible leakage*
+ *advanced framing: window openings line up with framing*
+ *design documentation/ manual to facilitate construction*

ADAPTABILITY



According to HabitatWR, families who move into their Habitat homes tend to occupy them for generations. In order to satisfy the needs of a growing family, Kehl-0 aims to future-proof areas around the home so that they can be easily renovated at a low cost (Figures 7a, 7b, and 7c).

+ *main floor closet can be converted into a water closet*
+ *den can be converted from play area to office space*
+ *basement can be renovated to include an additional bedroom*

Figure 7a. Den - Play Area

Figure 7b. Den - Future-Proof: Office

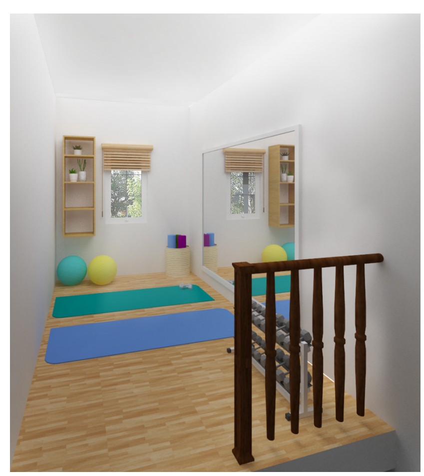


Figure 7c. Den - Future-Proof: Exercise Room

1.4 Building Enclosure

Warrior Home's affiliation with HabitatWR and its reliance on volunteer workers to build homes, were major considerations with regards to the design and material selection for the building enclosure and the structural design. Affordability, ease of construction for volunteer workers, and locally sourced materials to reduce the carbon footprint, were all important design factors.

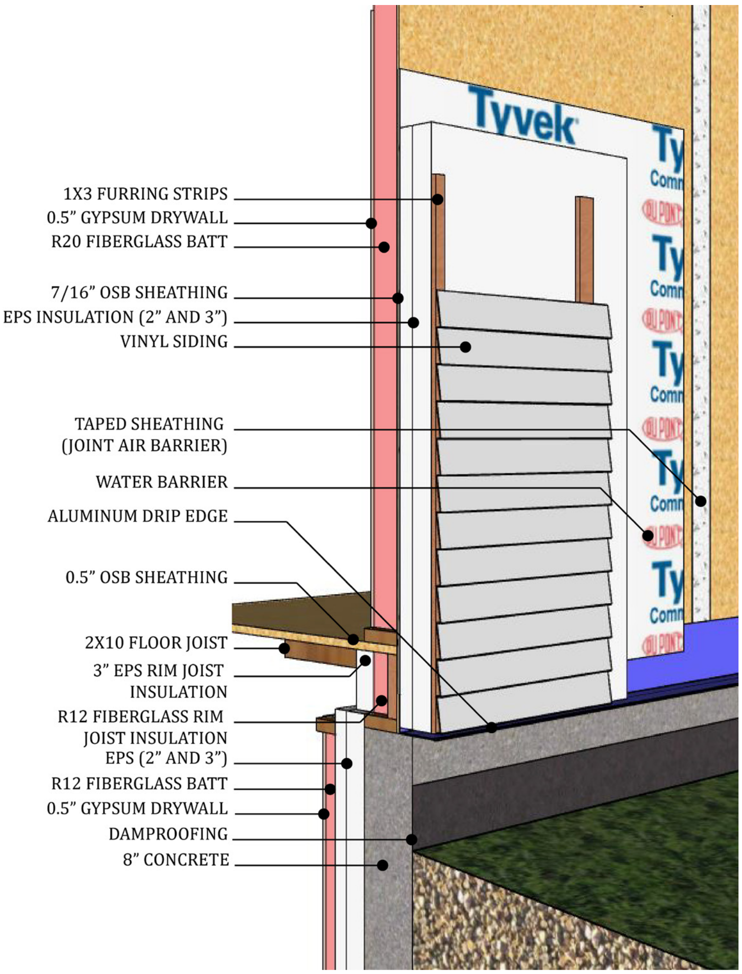


Figure 8. Layers of the Building Enclosure

Construction Instruction Manuals (Section 10) with notes and visual representations illustrated using SketchUp (Figure 8) and AutoCAD were created to provide directions for proper installation of typical problem areas including windows, control layers, and flashing details. In addition, Figure 9 shows an example of an instruction manual graphic regarding the first and second floor framing layout for constructability. As a result, volunteers will be able to gain knowledge in good building science and construction techniques.

With regards to the building design of the attached housing, it was decided that advanced framing, also known as optimum value engineering framing (OVEF), was the best method to frame the home. The major differences between standard framing and OVEF are the wall stud spacing, the roof and floor joist locations, and the configuration of the openings for windows and doors. By properly aligning floor and roof joists to the studs, loads can be transferred directly from the joists to the studs which allows home builders to frame with less material without compromising structural integrity, and reduces heat transfer through the walls of the home [1].

THERM software was used to analyze critical connections and identify areas of significant heat transfer, in order to reduce thermal bridging [2]. Additionally, hygrothermal analysis was performed using WUFI software, on the above grade wall, foundation wall, and foundation slab to determine the effect of heat and moisture transfer which indicate the durability and functionality of the building enclosure [3].

Section 1.4.1 is a cross section of the home, illustrating key building enclosure design components that would contribute to the overall design of a NZERH. In addition, the structural design of the home, using raised heel truss and advanced framing techniques, allow the use of additional insulation, further amplifying the performance of the building enclosure.

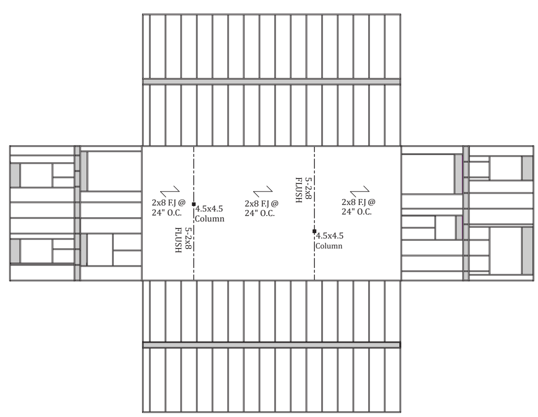
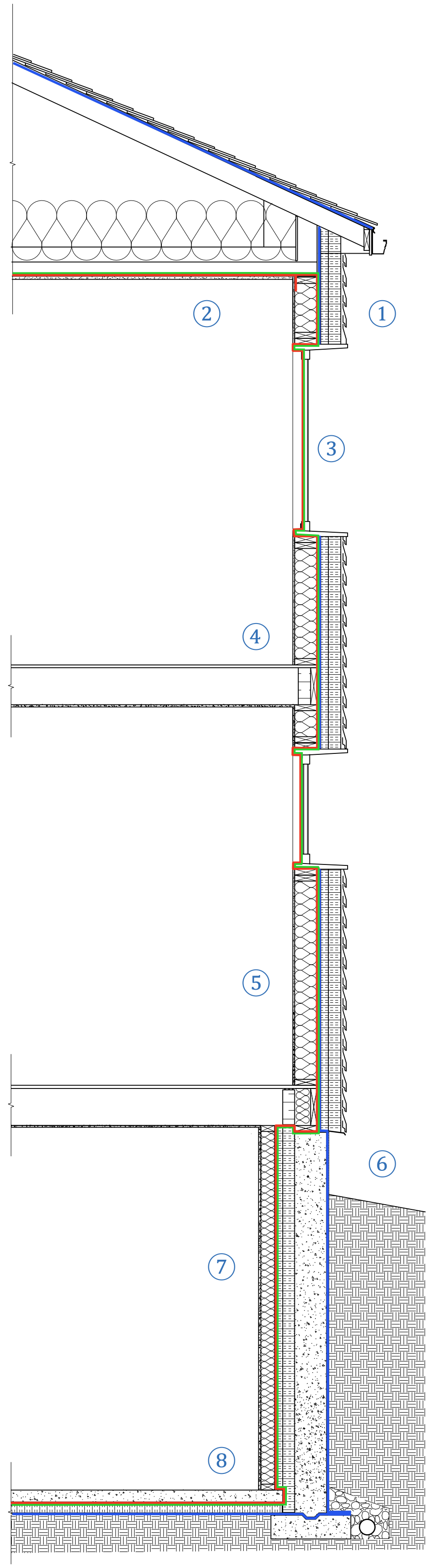


Figure 9. Knock Down Framing Plan (Appendix B)

1.4.1 Overall Wall Section

LABELED BARRIERS: **AIR, WATER, VAPOUR**
(SEE ANALYSIS PERFORMED IN SECTION 4.1)



① Roof to Wall

Raised Heel Truss with R60 blown-in fibreglass in the attic. Self Adhered (SA) ice and water shield underlayment for first 3ft of roof from eave to ridge. Synthetic underlay beyond first 3ft. Exterior EPS insulation would continue past the soffit a minimum of 3 inches, to minimize thermal bridging at the double top plate.

(THERM ANALYSIS)

② Enclosure Penetrations

Ceiling penetrations and wall penetrations air sealed using spray foam sealant.

③ Window Selection

Double glazed argon-filled casement windows with U-Value of 0.24 and SHGC 0.25. PVC frame with *SuperSpacer* glass spacer. Soft Coat LowE coating on surface 2 and Hard Coat LowE coating on surface 4. Casement windows were selected due to reduced air leakage compared to other operator types, and to maximize ventilation [4].

(THERM ANALYSIS)

④ Rim Joist

3" thick EPS insulation in rim joist cavities set in place using butyl caulking around edges.

⑤ Above Grade Wall Cross-Section

Vinyl siding fastened directly to 1"x3" furring strips. The furring strips create a 3/4" space behind the cladding, creating a back ventilated air space. 2 layers of exterior EPS insulation (2" & 3" each) with staggered seams reduces thermal bridging. Spun Bonded Polyolefin mechanically fastened to OSB sheathing as a water resistive barrier and OSB sheathing with taped joints using a suitable high-performance weather sealing tape as exterior air barrier.

(WUFI ANALYSIS)

⑥ Above Grade Wall to Foundation Wall Detail

3/8" gap between bottom of exterior insulation and top of foundation, creates weep holes for water behind the exterior insulation to escape [5]. Aluminum drip edge between top of foundation and bottom of exterior insulation to drain out water, with the mechanically fastened Spun Bonded Polyolefin overlapping the aluminum drip edge.

(THERM ANALYSIS)

⑦ Foundation Wall Cross-Section

Asphalt based dampproofing and a dimple mat installed on the exterior face of the concrete foundation. Dimple mat to continue over footing to prevent water entering between foundation wall and footing connection. 2 layers of EPS insulation (2" & 3" each) installed on the interior face with all the seams taped and the joint at the bottom sealed with butyl caulking, to ensure air does not leak through and condense on the cold concrete surface. 2x4 studs spaced 24" O/C with R12 fiberglass insulation will be installed adjacent to the EPS insulation and 0.5" gypsum drywall fastened on to the interior face of the studs.

(WUFI ANALYSIS)

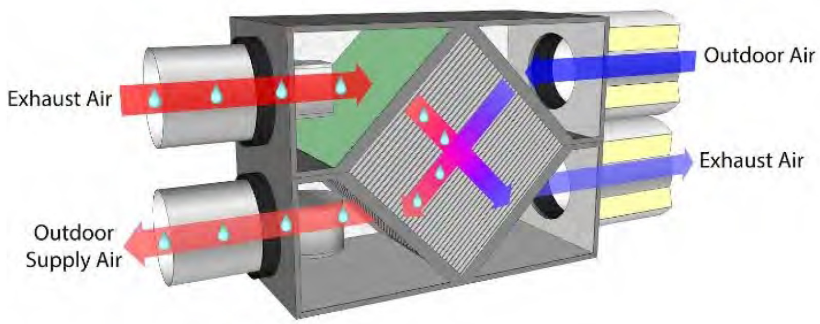
⑧ Footing to Slab Detail

6 mil poly vapour barrier placed directly against the underside of the concrete slab, with 3" thick EPS insulation located below it, on top of 4" thick gravel layer. The slab insulation to connect to the interior foundation wall EPS insulation, to minimize thermal bridging at the footing. Self-adhesive membrane, between top of footing and foundation wall, as a capillary break [6]. Weeping tile along the perimeter of the foundation at the footing level, with course gravel surrounding it. Filter fabric placed around the course gravel, to prevent fines entering the weeping tile [6].

(THERM & WUFI ANALYSIS)

1.5 HVAC System

To select the Heating, Ventilation, and Air-Conditioning (HVAC) system, the following factors were considered: energy consumption, cost to the homeowner, installation costs and occupant comfort. The best solution was determined to be utilization of a mini-split heat pump system. To provide ventilation and maintain suitable indoor relative humidity in the home, an energy-recovery ventilator (ERV) was selected. Figure 10 shows an ERV operation during winter showing exchange of heat and moisture within the cross-flow core.



[xx] RDH Building Engineer
Protection Office, 2015.

Figure 10. ERV Unit [xx]

The advantages of a mini-split heat pump system include minimized losses, good zoning control, and modular design. The U.S. Department of Energy states that duct losses can account for more than 30% of energy consumption for space conditioning [19]. Using a mixture of ducted and ductless indoor units, this system minimizes such duct losses. These systems simplify zoning of the house since the indoor units can be installed where needed, and allow heating or cooling in occupied zones. Proper zoning has been proven to save up to 25% in energy according to a study done by the University of Virginia [20]. The final design of this system will ensure even distribution of the conditioned air to each room. Based on the size of the home, multiple rooms can be served by one indoor unit and the conditioned air distributed throughout the zone by strategically placing ERV return grilles and ceiling fans.

1.6 Plumbing System

The plumbing design objectives are to reduce heat losses and wait times of the overall distribution system and increase energy efficiency of the water heating unit. This is being achieved by strategically placing the location of the mechanical room, kitchen, and bathroom, to be directly above each other to minimize the run of the distribution system. Additionally, a drain water heat recovery (DWHR) system and low-flow fixtures will be used to minimize the heating load and reduce water waste.

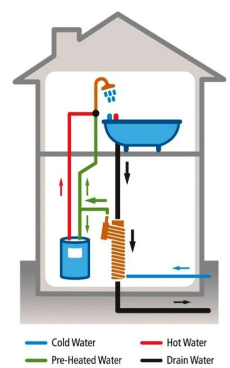


Figure 11. DWHR system diagram [24]

A DWHR system, illustrated in Figure 11, has the potential to reduce the energy needed to heat shower water by up to 50% [22]. DWHR exchangers (Figure 12) recover heat from the hot water utilized in showers to preheat the cold-water distributed to fixtures and the hot water tank. The DWHR system also increases the capacity of the water heater, thus allowing the water heating temperature to be lowered without affecting the capacity [23].

Figure 12. DWHR Pipe [24]

A heat pump water heater was chosen as the water heating unit since it is compatible with an electrical source, has a high energy efficiency, is ENERGY STAR certified, and can meet the water demand for the household [25]. Rheem Prestige Hybrid Electric heat pump PROPH50, UEF of 3.5 [26], was specifically selected, as it is designed to meet northern climate specifications.

1.7 Energy

The design of the house was refined through an iterative modelling process, based on optimal energy and cost efficiency. REM/Rate, BEopt (Figure 13), and eQuest were selected as modelling software to estimate the energy consumption and HERS score of the building. The HERS score for the Kehl-0 design is 48 without solar PV, and 0 with solar PV. The energy consumption of the home was reduced by 66%, resulting in an estimated annual consumption of 33,349 kWh, according to eQuest, without PV.

In order to offset the energy consumption of the building, a 31.24 kW solar PV system was selected as the optimal renewable energy source, due to its ease of installation, low capital cost, market availability, and reliable energy production. The array will be placed flush onto the south-west facing side of the roof, resulting in a 25° tilt angle. Using PVsyst, an average yearly generation of 36,996 kWh was estimated, resulting in a net-positive generation of over 3,600 kWh/yr. The annual end use breakdown for the building from eQuest is displayed in Table 4.

Table 4. Energy Consumption

END USE	CONSUMPTION		PERCENTAGE OF TOTAL (%)
	MMBTU/yr	kWh/yr	
Lighting	14.2	4,146	12
Appliance + Plug Loads	36.8	10,746	32
Heating	15.5	4,526	14
Cooling	8.8	2,570	8
Fans	23.5	6,862	21
Domestic Hot Water	15.4	4,497	13
Sub-Total	114.2	33,347	100
Solar PV Generation	126.7	-36,996	-
Total less Solar PV	-12.5	-3,649	-

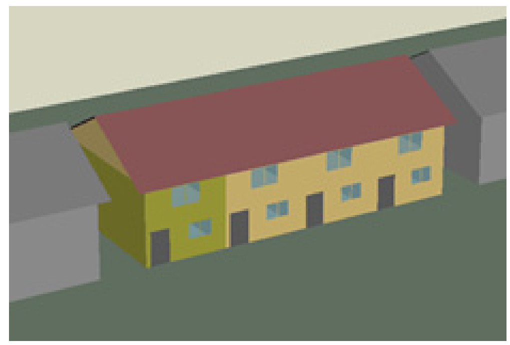


Figure 13. BEopt Model

1.8 Finances

Families selected for the HabitatWR program have an average annual family income of $59,000 CAD ($47,000 USD). HabitatWR mortgages require families to pay 25% of their monthly family income over an amortization period of 25 years; however families do not pay interest or a down payment. Using this information a monthly expense goal was set at less than $1,800 CAD ($1,440 USD) per month. Using the U.S. Department of Energy Financial Analysis Toolkit [27], Warrior Home established a cost of construction of less than $150,000 CAD ($120,000 USD) per unit and a sales costs of $260,000 CAD ($208,000 USD) per unit. Warrior Home made significant cost savings by avoiding complex construction geometry, maintaining a reasonable size, utilizing volunteers for construction and installing inexpensive finishes. Kehl-0 was able to significantly lower maintenance and utility costs, and was able to achieve an overall debt to income ratio of 35% without PV creating more disposable income for the homeowners. A cost summary is shown in Figure 14.

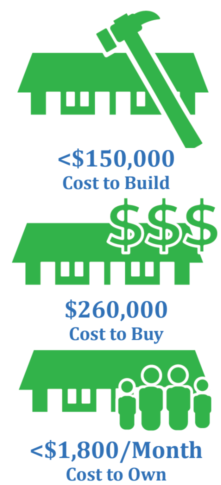


Figure 14. Cost to Build, Buy, and Own

1.9 Detailed Project Summary

Kehl-0 represents Warrior Home's initiative in bridging the gap between affordability and energy efficiency. Keeping HabitatWR in mind, the goals of this project focused on inclusiveness to the community, easy constructability, and long-term adaptability. Warrior Home's goal is to make a positive impact by helping families feel comfortable in their homes in an effortless and cost-effective way, in addition to creating an impact in the home design industry. Moving forward, the team will be running more detailed analyses, proving that the chosen technical specifications achieve net zero requirements and beyond.

al was

2.0 Architectural Design

The architectural design of Kehl-0 focused on maintaining the existing attached housing footprint while keeping HabitatWR's goals in mind. Although finding the connection between energy efficiency and affordability was the main focus, Kehl-0 pushes the limitations of a HabitatWR home. Essentially, Kehl-0 was designed to create a sense of community, be of easy constructability, and have long-term adaptability. A summary of architectural design concepts is shown in Figure 14.

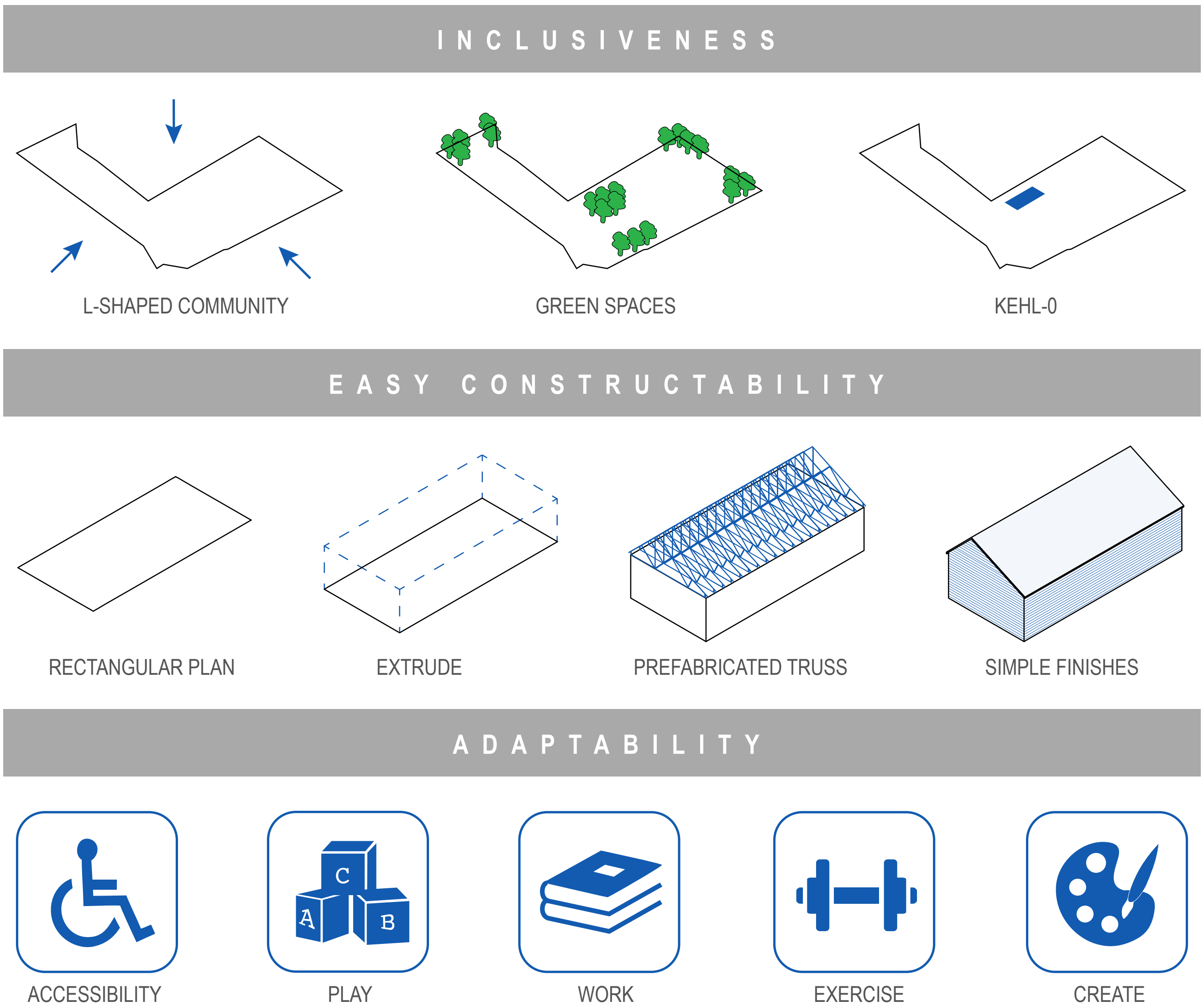
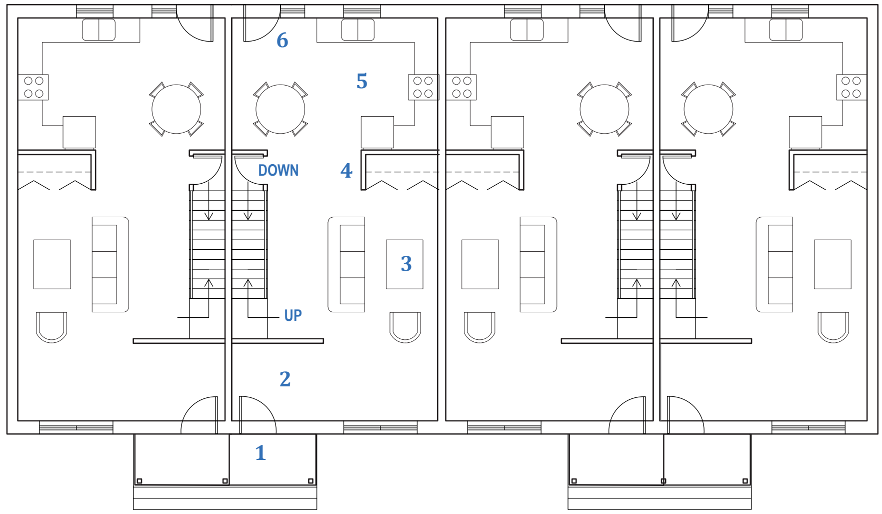


Figure 15. Architectural Design Concepts

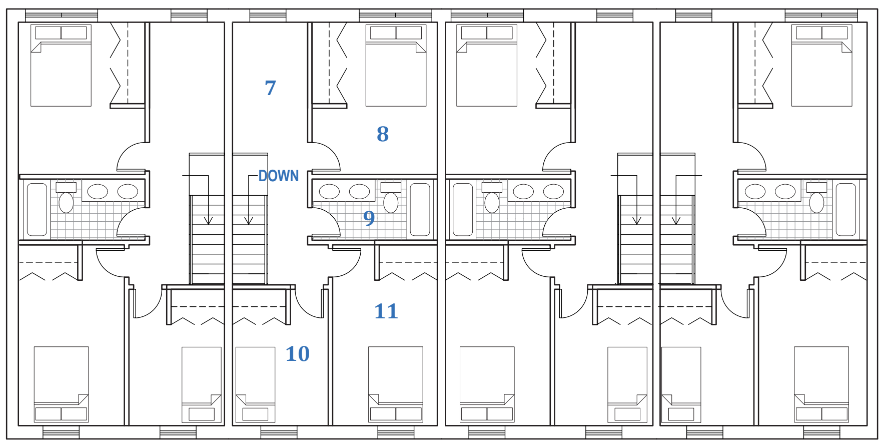
With an L-shaped community lot, Kehl-0 is part of a small, close-knit neighbourhood with pockets of green spaces to foster interaction and inclusiveness with neighbours. In the building scale, front porches are coupled to create interactions between neighbouring families. As the home is built by volunteers with a large range of skills, the obvious choice in design was to reduce complexity and maintain a simple yet tasteful design. Details from offsetting the gable roof angles to selecting modern finishes, make Kehl-0 a relevant design for many decades. Most importantly, a building that can cycle through generations without major rehabilitation or renovations is ideal for affordable housing. Keeping in mind that families grow with time, so do their need of space. Kehl-0 was designed to adapt to future-proofing needs. Providing an open floor plan, familes are able to organize their space to meet accessible, work, or creative needs.

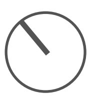
2.1 Floorplans

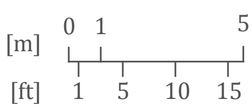
Ground Floor



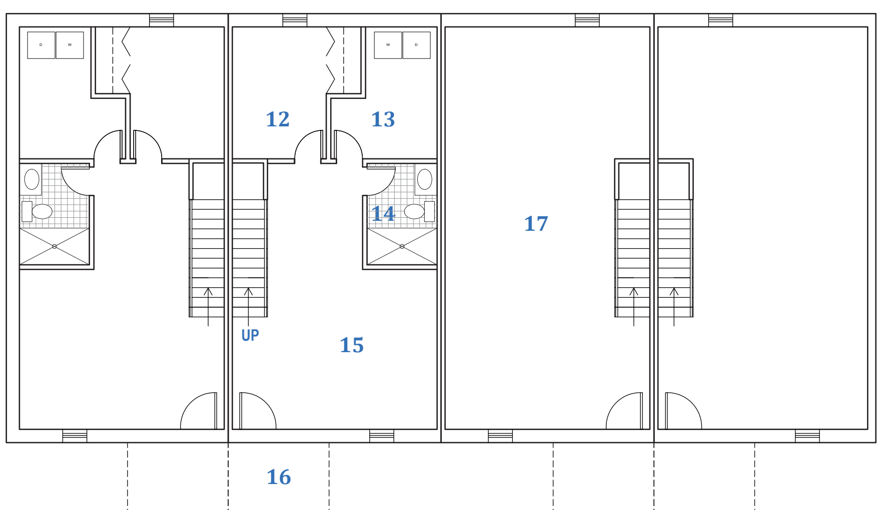
Second Floor







Basement



shared porch	1
main entrance	2
living room	3
closet/water closet	4
kitchen/dining room	5
back entrance	6
den	7
master bedroom	8
bathroom 1	9
bedroom 2	10
bedroom 3	11
bedroom 4	12
mechanical room	13
bathroom 2	14
living room	15
cold cellar	16
unfinished basement	17

3.0 Interior Design

Interior design incorporates all subdivisions of the interior of the house and allows for the optimization of the design goals of inclusiveness, constructability, and adaptability. A successful design can be easily altered to fit the family profile. With correct choice of materials and appliances, thorough analysis of electrical, and identification of lighting schedules, easy constructability is achievable. A wide range of future-proof compliance and accessibility options allow for achievable house adaptability. A successful design achieves these goals thoroughly and, in turn, allows for current and future satisfaction and comfort of the selected family profile.

3.1 Family-Oriented Design

The third family from Table 2 in Section 1.2.2 was selected to base all sample renders, furnishing, and floorplans. The design consists of one master bedroom for both parents, a shared room for the young twins, and one single room for each of the two older children. The oldest child resides in the basement room with extra space to work and study in the basement living room area. Renderings showing the furnished living rooms on the ground and basement levels are shown in Figures 16 and 17.

Figure 16. Ground Floor Living Room

Figure 17. Basement Living Area

All units include an open concept floorplan to promote family interaction and make small spaces feel larger. To create more open space on the main floor, it was decided that the girders which hold up the second floor would be supported by only a single column each. In order to ensure that this would be structurally feasible, a structural analysis of the girders supported by a single column was completed in SAP2000, using the maximum load either girder would support. Structural calculations can be found in Volume II.

3.2 Long-Term Adaptability

Future-proof homes are the key for innovation as they enable the homes to adapt to a changing family profile. The family chosen is one that may choose to alter the interior arrangements as their children get older. In the future, spaces can be rearranged due to family growth and desried activities. As the children grow, rooms can be rearranged to fit the family's needs. The den is currently set as a play room as it accommodates the two young twins. Later on, the den can be easily converted into an office space for the use of the parents to work from home. Future-proofing the den further would allow for the den to be converted into an exercise space to appeal to the parents as well as the two older children. The three suggestions for future-proofing the den were shown in Figures 7a, 7b and 7c in Section 1.3.

3.3 Accessibility Accommodation

Future-proofing a home is also subjected to future accessibility needs. Kehl-0 is designed to allow a family to continue to live at the same place as they age or are suddenly introduced to accessible needs.

A form of accessible adaptability is seen in the alteration of the den to be encompassed within the master bedroom. The den now becomes attached to the bedroom and the closet is moved further to accommodate for more accessible mobile space. The bathroom now has two access doors. One door is accessible to the remaining members living on the second floor, and one directly to the master bedroom for easy accessibility. This alteration can be seen in Figure 18.

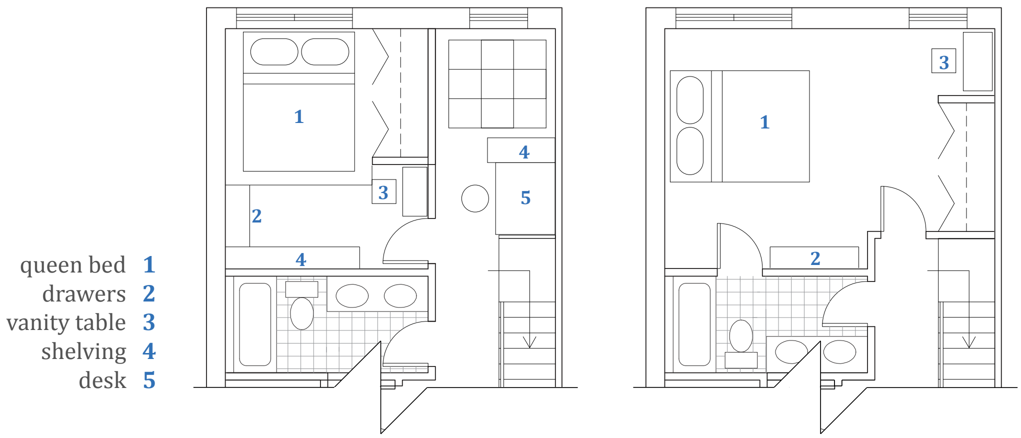
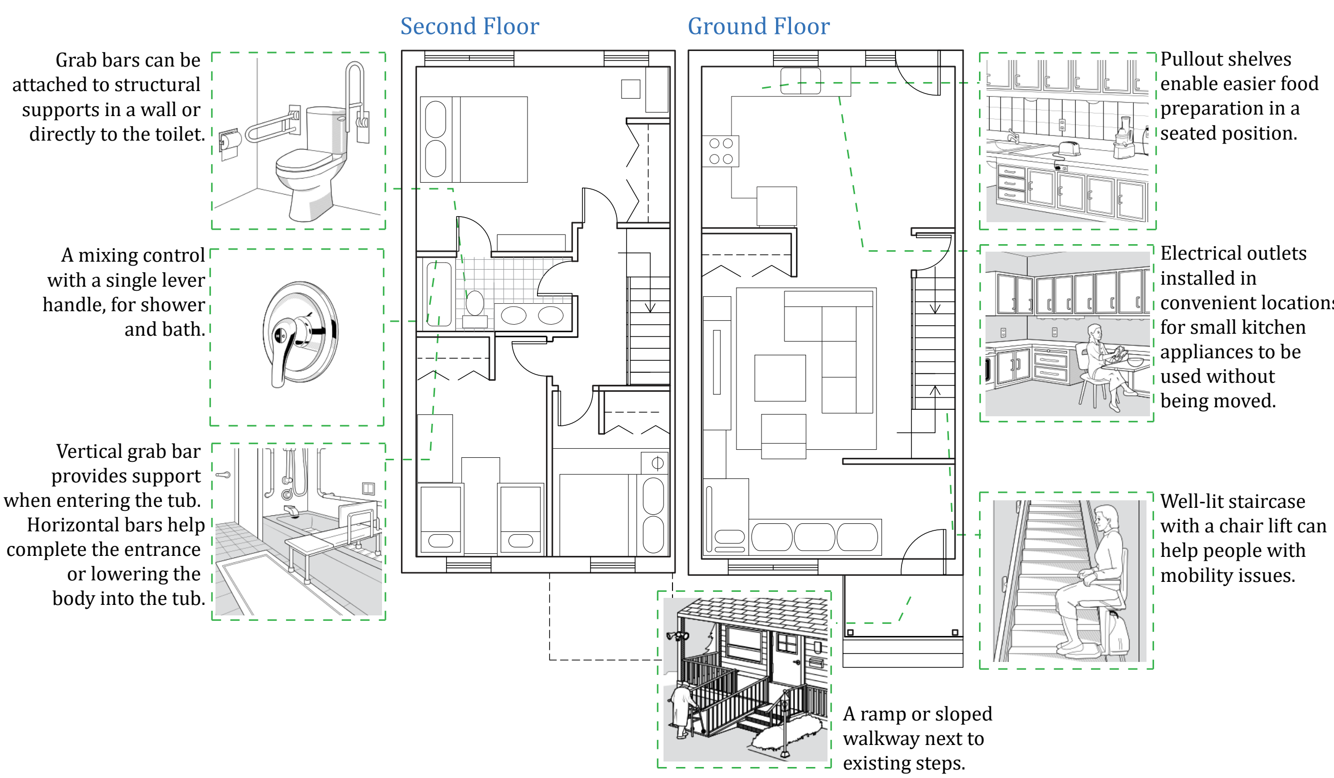


Figure 18. Before and After 2nd Floor Accessibility Renovations

Accessible design alterations can also be used for other conditions such as visual, mobility, auditory, and speech difficulties. Various accessibility adaptations can be found in Figure 19.



reference

Figure 19. Various Accessibility Accommodations

3.4 Materials Breakdown

To accommodate for the selected family, certain materials were chosen to comply with family design preferenaces, affordability, and energy efficiency. The focus was on visual stimulus, finances, indoor air quality, and user comfort needs. To comply with the design goals, the materials that were chosen are easily interchangeable with airPLUS compliant low-emission standards and products [2]. Furthermore, to satisfy both visual and comfort needs, simple and neutral-coloured materials were chosen to create a calm surrounding environment. Figure 20 highlights the materials chosen for the ground, second and basement floors.

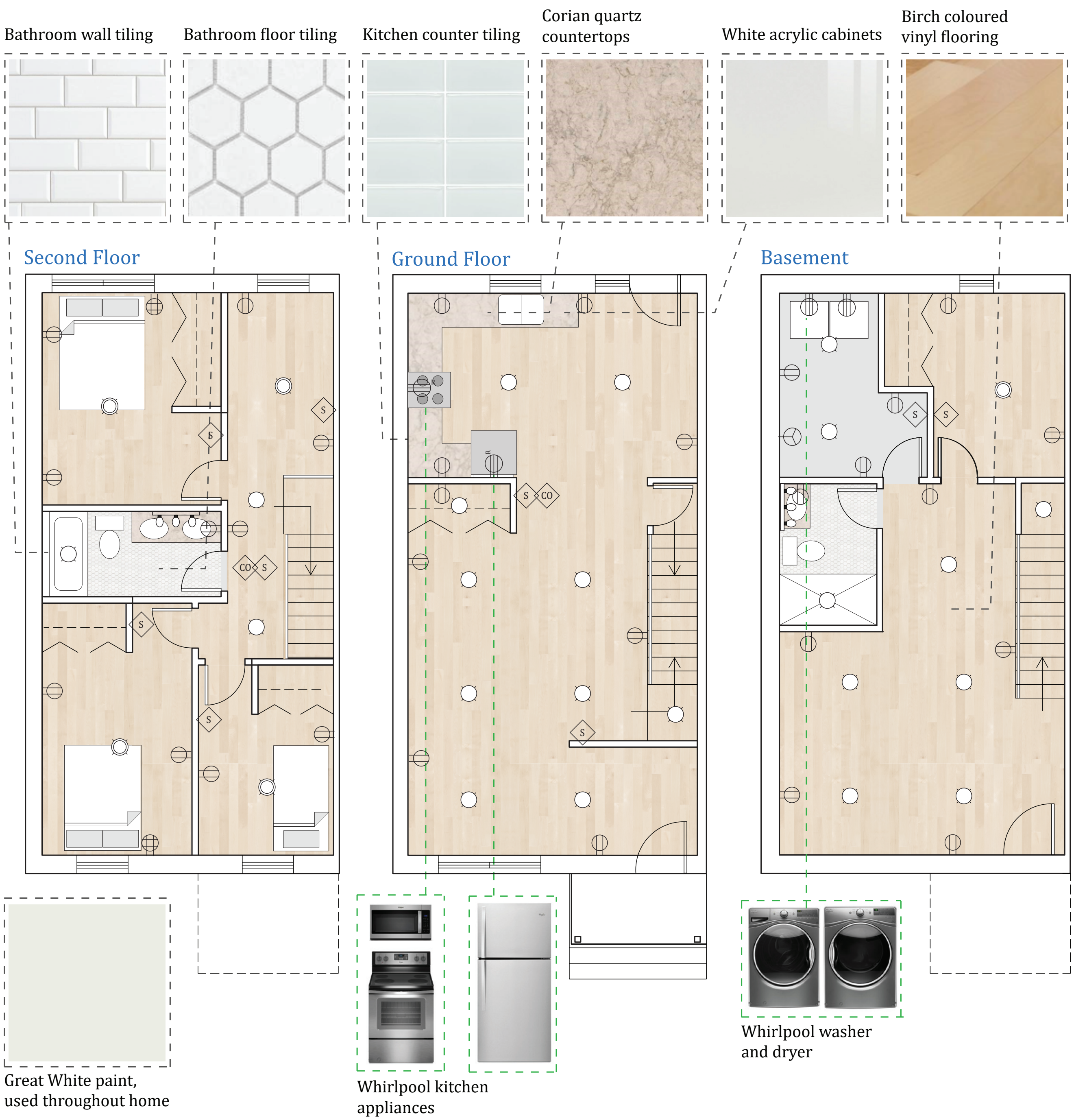


Figure 20. Materials, Electrical, Lighting, and Appliance Layout

Materials chosen are split into essential categories such as wood flooring, tiling, paint, and ceramics. All other materials in terms of interior fit-outs are subjective to family purchases. Birch coloured vinyl flooring is to run along all floor areas [3]. This flooring choice can be easily interchangeable with airPlus compliant hardwood plywood [2]. Ceramics consists of floor and wall tiling as well as countertops and cabinetry. White acrylic cabinetry were chosen for elegance and simplicity [6]. Corian quartz countertops were chosen for a simple aesthetic contrast [7]. Floor and wall tiles were chosen in white hues to allow for a neutral look [9]. Continuing with the neutral and simple theme, paint is a great white paint colour throughout the entire home.

3.5 Lighting Fixtures, Plug Loads, and Appliances

Electrical and lighting schedules have been chosen accordingly to comply with home aesthetics and mechanical, indoor air quality, finances and energy analysis. Figure 5 in Section 3.4 encompasses the lighting layout as well as the locations of the plug loads, fire alarms, and carbon monoxide detectors. Table 5 is a legend for Figure 19 in terms of electrical and lighting fixtures as well as their descriptive characteristics. The lighting fixture schedule can also be found in Appendix B.

Appliance choices are compliant with EnergyStar requirements [10]. Whirlpool is the commonly selected brand by HabitatWR. All other appliances are to be purchased separately upon owners' desire.

Table 5. Electrical/Lighting Schedule Legend

SYMBOL	FIXTURE	DESCRIPTION
	Potlight	Open trim, soft white, 15W, 1065 lumens
	Ceiling lamp	Soft white, 15W, 1065 lumens
	Multi-lights	LED strip lighting, 10W, 660 lumens
	Duplex Receptacles	20-amp sockets, 3 legs
	Fourplex Receptacles	20-amp sockets, 3 legs
	Range Receptacle	50-amp, 4 legs for range; 20-amp, 3 legs for microwave
	Dryer Receptacle	30-amp, 240V with 4 conductors, GFCI-protected
	Water Heater	
	Smoke Detector	
	Carbon Monoxide Detector	

3.6 Additional Homeowner Upgrades

Another large factor of home safety is a tangible security system for the home entrances. After extensive research of security system installations, an Ooma Door and Window Sensor is chosen to be the best option due to easy installation and cheapest price [11]. The system sends phone calls, app notifications, emails, and text message alerts to your smartphone wherever you are, which is perfect for a family with many children of all ages.

Additional owner options for energy efficient house systems, electrical, and lighting includes using smart home systems such as Amazon Echo. With Amazon Echo, it is possible to control the lighting and heating of the house to ensure energy and cost efficiency [12]. Philips Hue LED lightbulbs are Wifi-enabled lightbulbs that connect to a bridge, which can be controlled through a mobile application and moreover, systems like Echo [13]. Similarly, smart thermostats such as Ecobee3 can be used to reduce unnecessary heating [14]. Both systems can be programmed to reduce light and heating in a house, especially when not in use. Installation costs may seem high at first, but savings accumulate through the reduction of heat while not in use. This offsets the installation cost and renders the overall system as cost-friendly as standard LED and heating systems.

4.0 Building Envelope

The building envelope design took into consideration structural enhancements while maintaining the ease of constructibility, to improve envelope durability and energy conservation. With the introduction of advanced framing, the structural integrity of Kehl-0 was retained while improving thermal performance. Advanced framing replaces the conventional 2x4 studs spaced at 16 inches on center with 2x6 studs spaced 24 inches on center. Furthermore, other modifications were made, such as replacing double top plates with single top plates and using two stud corners [8]. Jack studs are used to support the headers of windows and doors are eliminated in favour of header hangers used to attach the headers directly to the king studs. The extra studs on either side of the openings are also eliminated. Advanced framing was selected for this project, primarily because it can reduce framing material costs by up to 30% [9] as it allows for more cavity insulation while reducing thermal bridging throughout the frame [9]. According to the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), advanced framing can achieve an improvement in thermal resistance compared to standard framing [8].

In addition, the use of a raised heel truss resulted in a reduction in thermal bridging at the roof to wall connection. When a roof truss's heel rests directly on the top plate of a building's top floor walls, this results in a space where no insulation can be fit at the roof to wall connection. With a typical design, the R-value of the attic insulation starts at R60 at the middle of the attic, and ends at R0 at the heel. By introducing raised heels in the roof truss, the space which was previously unable to fit insulation can be raised, so that the full 20 inches of insulation can be installed along the entire width of the attic, drastically improving the thermal control and increasing the overall effectiveness of the roofing insulation (Figure 21).

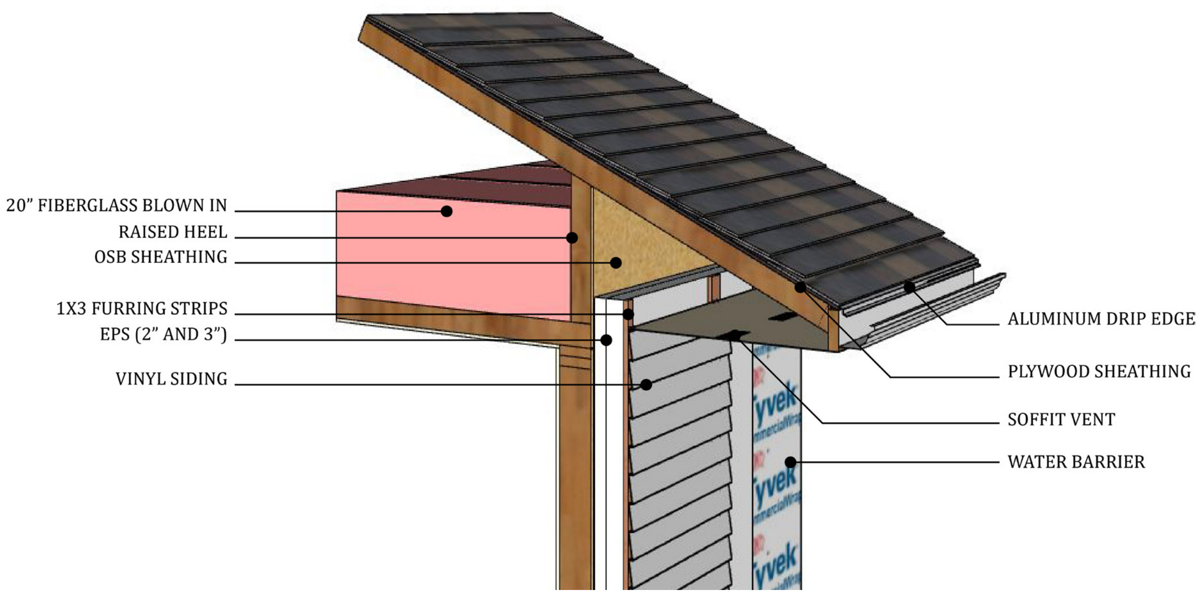


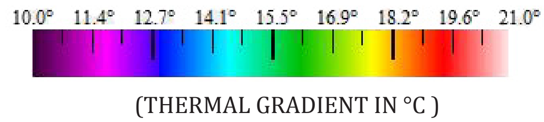
Figure 21. Roof-to-Wall Detail

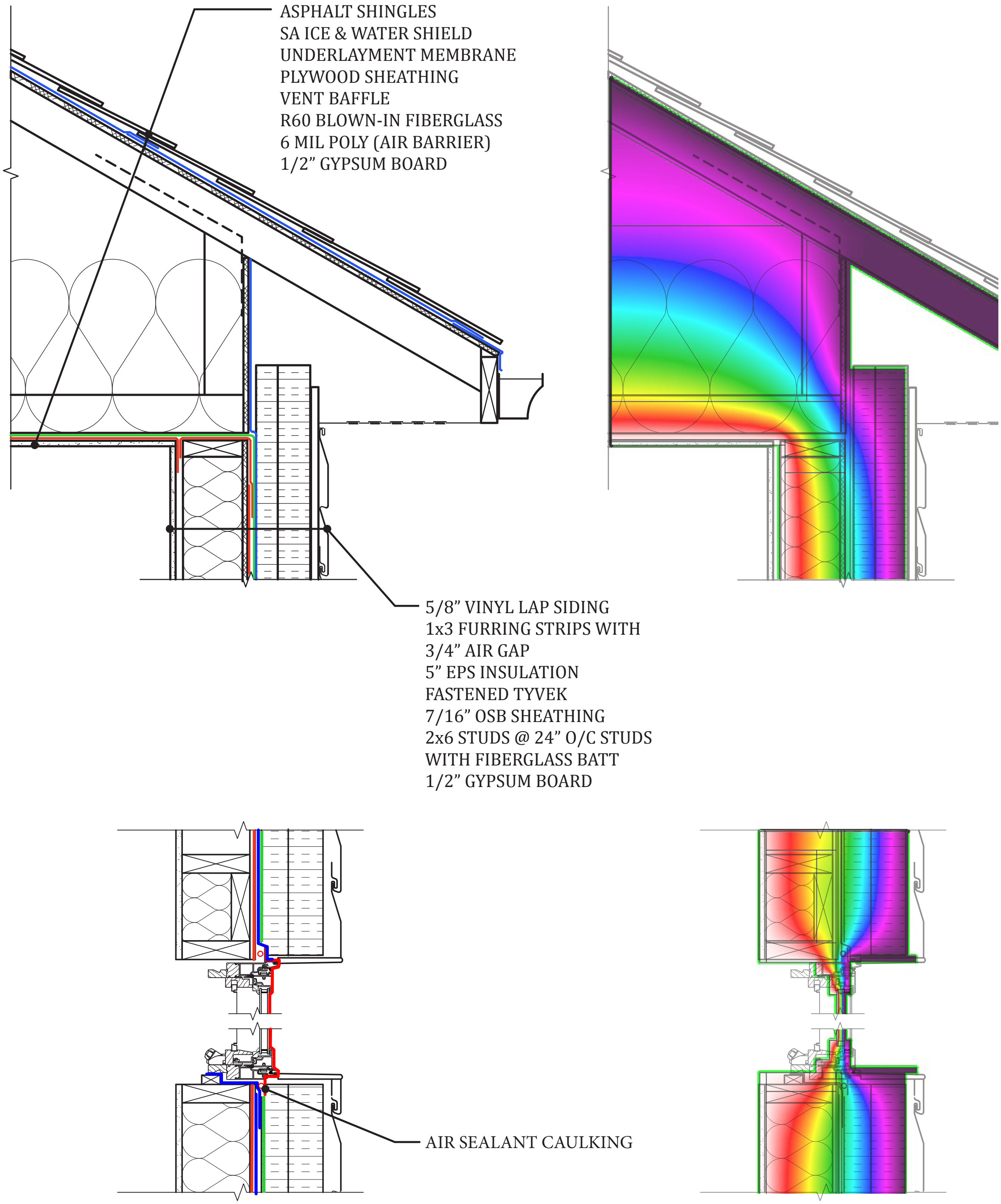
4.1 Heat Transfer & Hygrothermal Analysis

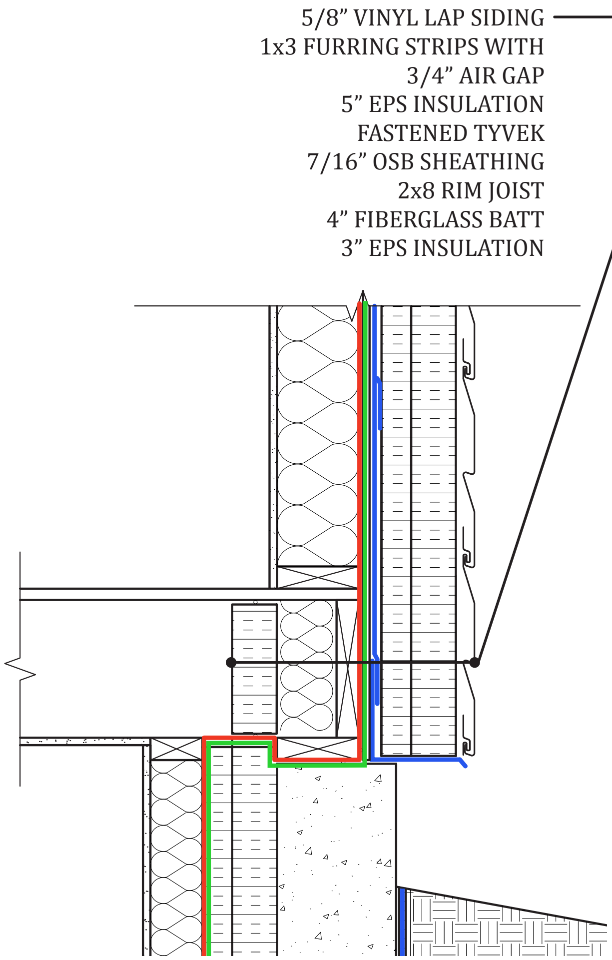
The THERM analysis used -18°C (-0.4°CF) as the above grade outdoor temperature with a relative humidity (RH) of 50%, and 10°C (50°F) with RH of 100% for below grade outdoor conditions. The indoor conditions were modelled as 21°C (70°F) and 50% RH for both below grade and above grade.

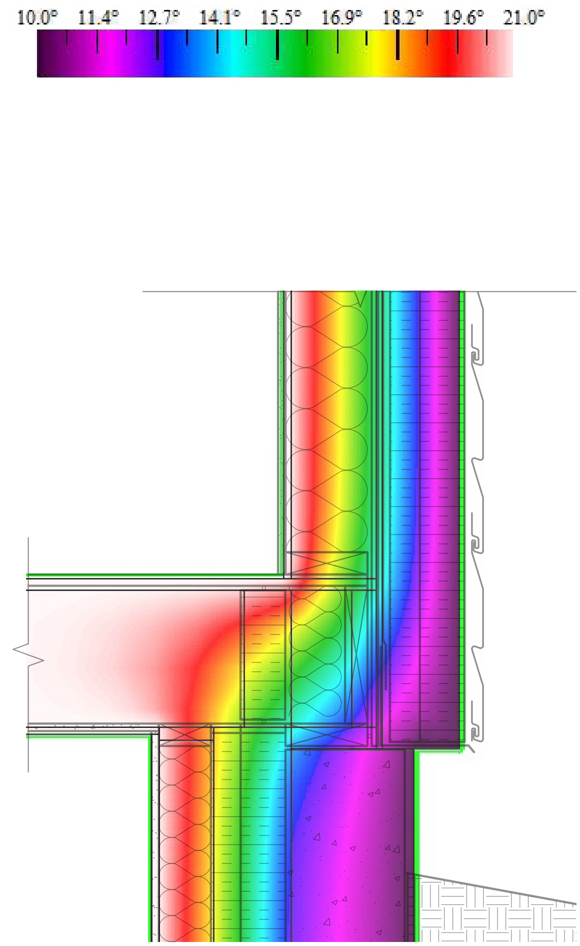
The WUFI analysis used a high moisture load sinwave function to model interior conditions and the Toronto Cold Year weather file to model the outdoor conditions for the above grade wall. The WUFI analysis for the below grade wall section and the slab used a high moisture load sinwave function to model interior conditions as well, and for the below grade outdoor conditions, a constant (RH) and temperature of 100% and 10°C (50°F) respectively, was used.

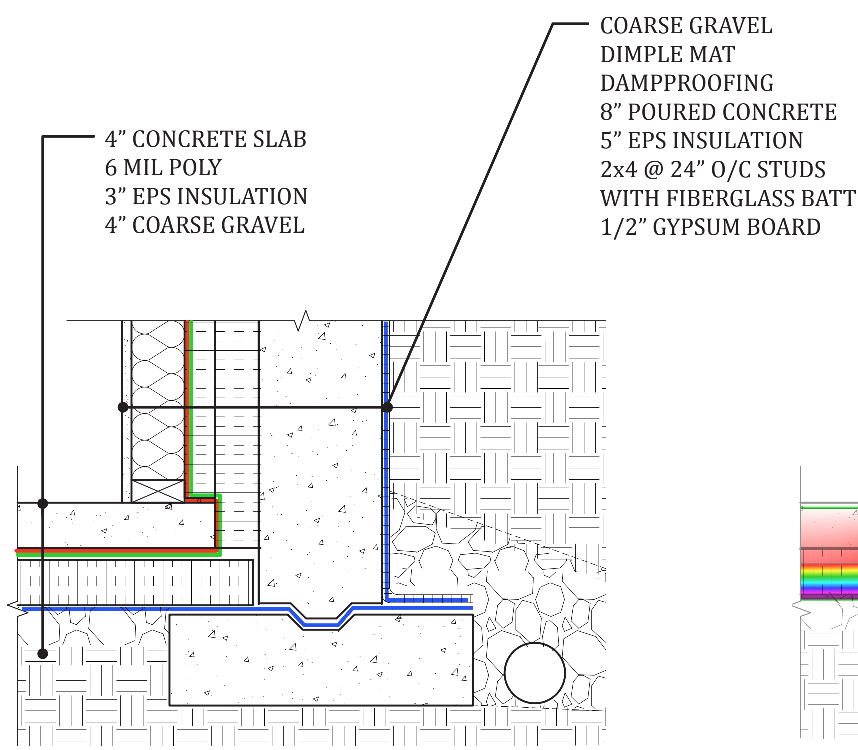
4.1.1 THERM Analysis

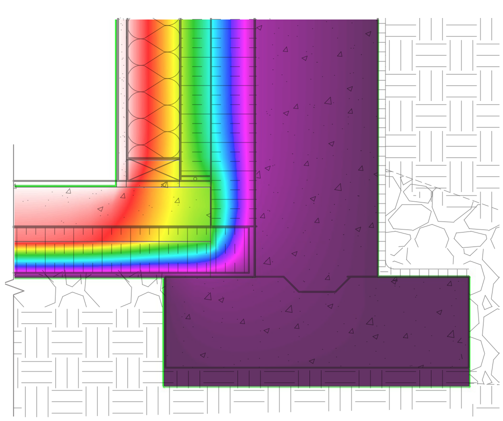





5/8” VINYL LAP SIDING
1x3 FURRING STRIPS WITH
3/4” AIR GAP
5” EPS INSULATION
FASTENED TYVEK
7/16” OSB SHEATHING
2x8 RIM JOIST
4” FIBERGLASS BATT
3” EPS INSULATION


10.0° 11.4° 12.7° 14.1° 15.5° 16.9° 18.2° 19.6° 21.0°


4” CONCRETE SLAB
6 MIL POLY
3” EPS INSULATION
4” COARSE GRAVEL
COARSE GRAVEL
DIMPLE MAT
DAMPPROOFING
8” POURED CONCRETE
5” EPS INSULATION
2x4 @ 24” O/C STUDS
WITH FIBERGLASS BATT
1/2” GYPSUM BOARD



4.2 WUFI ANALYSIS

The interior surface of the OSB sheathing is most likely the condensation plane for the above grade wall. Due to indoor air leakage, the condensation hours is zero. The moisture content of the OSB sheathing is less than 6% which is significantly lower than the 15% moisture content for mould growth in wood [1].

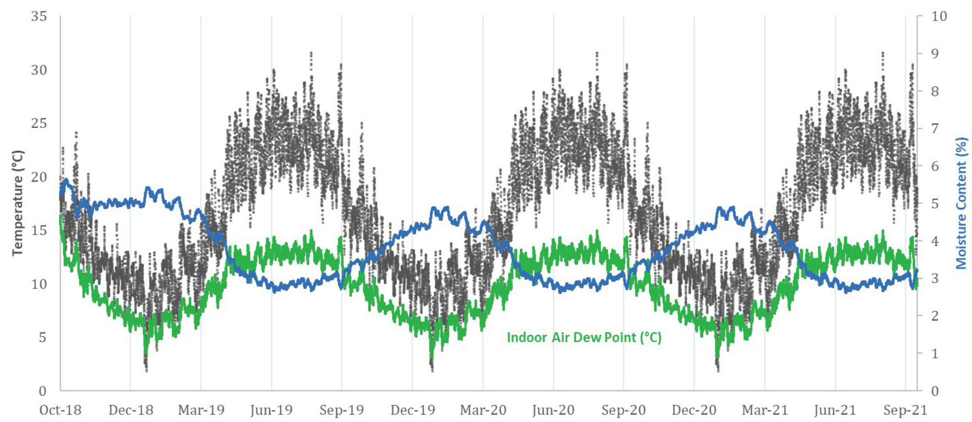


Figure 22: Above -Grade-Wall - Interior Surface of OSB Sheathing

The interior surface of the EPS insulation is the most likely condensation plane for the below grade wall because the EPS seams are taped, thus preventing air leakage condensation on the cold concrete surface.

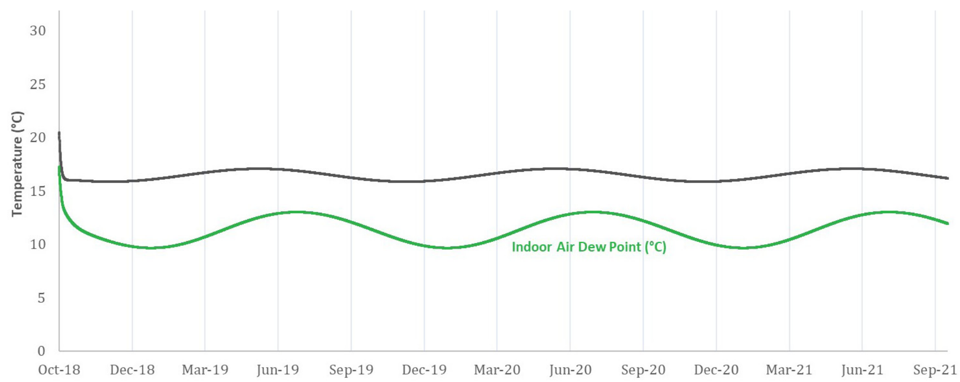


Figure 23: Below-Grade-Wall - Temperature of Interior Surface of EPS Insulation

The top of the concrete slab is the most likely condensation plane for the floor because it has no continuous air barrier on top, preventing indoor air making contact with it. The concrete itself is capable of handling relatively high levels of moisture, however, the materials (carpet, etc.) on top of the concrete slab may not be able to. As shown in Figure 24, the indoor air dew point is below the temperature of the interior surface of the concrete slab and therefore there is no risk of air leakage condensation.

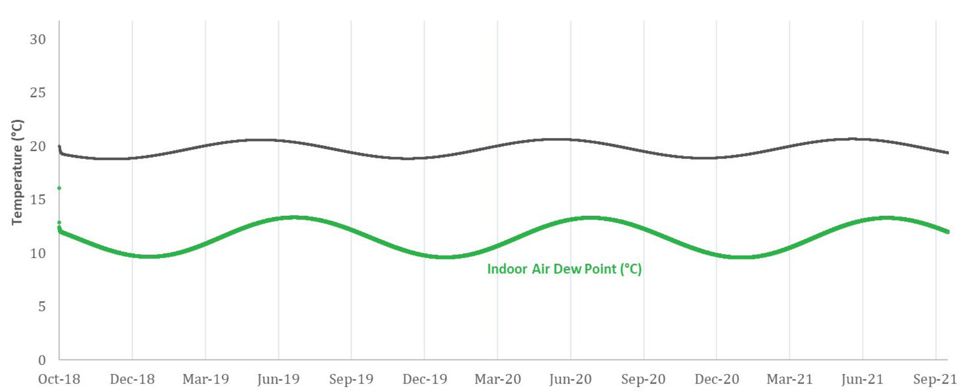


Figure 24: Below Grade Slab - Interior Surface of Concrete

5.0 Mechanical

The goals of the mechanical design were to maintain comfortable conditions using temperature control, humidity control, and distribution systems while minimizing energy consumption and cost to the homeowners. The winter outdoor design temperature was -18°C (-0.4°F), and the summer design temperature was 31°C (88°F) dry bulb (DB) and 23°C (73°F) wet bulb (WB) [1]. The selected system needed to operate efficiently in this temperature range. It was also ensured that the requirements of the OBC were met and that the mechanical design was user-friendly [2].

5.1 Selecting System Type

Natural gas furnaces were the most common type of heating system in Ontario in 2011 [3]. They have proved reliable for cold winters. As natural gas is a finite resource and harmful to the environment, this system was not preferred. Furnaces are also typically central forced air systems, which require ductwork that can account for more than 30% of energy losses in residential homes [4]. This type of system would also require a separate system to cool the building.

The selected option was a Mini-Split Heat Pump (MSHP) system. The advantages of a MSHP system include minimized losses, good zoning control, combined heating and cooling, and modular design. With the option between ducted or non-ducted indoor units, this system almost eliminates duct losses. A mixture of ducted and non-ducted units was used within the Kehl-0 home design to optimize the zoning of the home. Indoor units were installed within each zone to provide a system with zoned heating and cooling. Proper zoning has been proven to save up to 20.5% in energy according to a study by the University of Virginia [5]. The main disadvantage of a MSHP system is the initial cost which tends to be about 30% more than central systems, excluding ductwork [6].

As Canada has a cold climate, a large portion of building energy usage is spent on heating. Due to this, selecting the most energy-efficient heating system was the key to designing a NZERH. An energy consumption comparison of two systems was performed in REM/Rate using a preliminary design of the Kehl-0 project. The first system was a natural gas, forced-air furnace with a rated capacity of 22,000 British Thermal Units per hour (BTU/h), and an Annual Fuel Utilization Efficiency (AFUE) rating of 97%. The second system was a MSHP with a compressor capacity of 27,800 BTU/h at 8°C (47°F) and 18,300 BTU/h at -8°C (17°F), and a heating seasonal performance factor (HSPF) rating of 10.3. The difference in consumption was 72.3 million British thermal units per year (MMBTU/yr), as seen in Figure 25. Using less than half of the energy of the furnace, the initial cost of the MSHP system was justified for a family within the target budget range. For these reasons, the MSHP system was chosen.

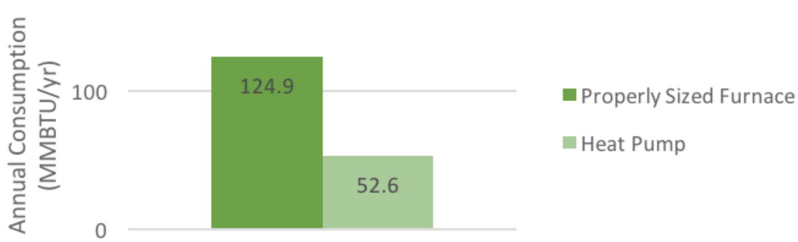


Figure 25: Annual Consumption Comparison

In addition to the space conditioning system, some form of energy recovery is essential to the Kehl-0 design. As the building enclosure is tight, a system to provide fresh air is important as well. Heat recovery ventilators (HRV) and energy recovery ventilators (ERV) provide both for residential homes. However, it was found that ERV's were able to better control the RH indoors in comparison to HRV's [7]. Therefore, an ERV was selected for use in the Kehl-0 project.

5.2 Specificying the Mechanical System

After deciding on a MSHP system type, an analysis of the heating and cooling loads was completed, followed by the zoning design of each unit, and equipment selection and placement. Each dwelling was designed to have an independent HVAC system to accommodate any differences in load requirements.

The Warrior Home Energy Analysis team provided a peak heating and cooling load analysis using a model of the Kehl-0 home in eQuest which can the found in Table 6. The indoor design temperatures were 22°C (72°F) for winter and 24°C (76°F) for summer, with the outdoor design temperatures as specified in Section 5.1[2]. The thermostat setbacks were 18°C (65°F) during winter nights and 29°C (85°F) during summer working hours. This analysis also took the heat recovery effect of the selected ERV into account. Full heating and cooling load data can be found in Volume II.

Table 6. Peak Heating and Cooling Loads

DWELLING UNIT	PEAK HEATING LOAD (BTU/hr)	PEAK COOLING LOAD (BTU/hr)
Unit 1	10,764	11,902
Unit 2	10,227	12,821
Unit 3	9,637	12,342
Unit 4	9,720	11,441

Figure 26 shows the zoning plan for each dwelling. Each zone aims to group together areas that would be occupied at the same time with similar activity levels. Locations of the units were coordinated with the ventilation supply and return to ensure a steady flow of fresh air throughout the home. A bi-axial ceiling fan was also placed in Zone 3 to assist the distribution of conditioned air. Zone 3 includes the second-floor den as it is expected for heat to transfer between the floors from the stairwell opening.

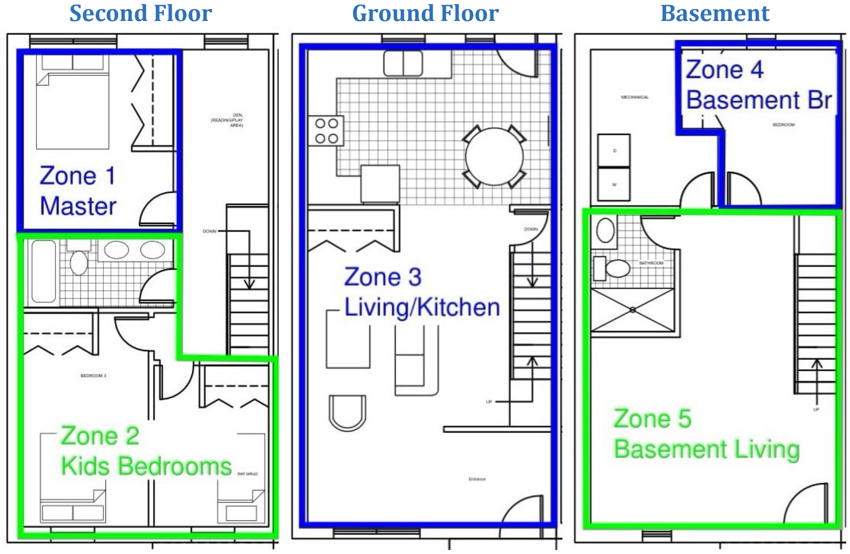


Figure 26. Dwelling unit zoning

With the majority of MSHP systems, the smallest outdoor units are sized around 18,000 BTU/h nominally [8], with the corresponding indoor units as small as 6,000 BTU/h nominally [9]. Most MSHP systems outdoor units also cannot accommodate Canadian winters as they are not commonly installed in the region. As the Kehl-0 home was optimized for energy usage the required heating and cooling loads were well below these values. To ensure that the selected system was not running at more than the required capacity, MSHP systems that incorporated inverter heat pump technology were selected. The final selections for mechanical equipment can be seen in Table 6. The total cost for the mechanical equipment and installation is estimated to be $8,000 CAD ($6,400 USD). A breakdown of the cost for each of the components in the system can be found in Volume II.

Table 7. Selected Mechanical Equipment [9]

UNIT TYPE	OUTDOOR UNIT	INDOOR UNIT	INDOOR UNIT	INDOOR UNIT
Model and Style	LG LMU300HHV Heat Pump [10]	LG LMCN077HV 4-Way Ceiling Cassette [11]	LG LMN078HVT Wall-Mounted [12]	LG LMDN096HV Low-Static Air Handler [13]
Nominal Capacity (BTU/h)	30,000	7,000	7,000	9,000
Locations Served	Rear exterior wall	Ground floor and Basement Living Room	Master Bedroom and Basement Bedroom	Two small bedrooms on second floor
Image				

With the inverter technology, the MSHP compressor adjusts its speed based on the system demand. This automated regulation allows for smooth transitions between shifts in demand and allows for operation of the system components at less than the rated capacity [14]. It was also important to select a system that had a mechanism built-in to accommodate winter weather conditions. As the outdoor temperature decreases, the heating capacities of the indoor units decrease, which was accommodated by selecting units that satisfy the load requirements even at low temperatures.

The LG outdoor unit was chosen because it features a factory-installed base pan heater and a heated outdoor coil base, allowing it to provide 100% of its heating capacity at -15°C (5°F) [10]. Being a larger model, four indoor units can be connected allowing for better zoning [16]. The indoor units were chosen according to each zone and were strategically placed to minimize refrigerant piping lengths, provide good coverage of the space, and stay out of the occupant's path. The basement units are fed from the same connection on the outdoor unit, so that only four connections are required. To control the indoor units, an LG AC Ez Central Controller was chosen for its compatibility with all the equipment. Each indoor unit comes with its own thermostat, and the central controller can be programmed with up to 8 schedules with operating mode, fan speed, louver direction, and temperature setpoint control for each unit [18]. There is also a holiday override which saves energy during extended unoccupied times [18]. A model of the mechanical equipment and layout is shown in Figure 27.

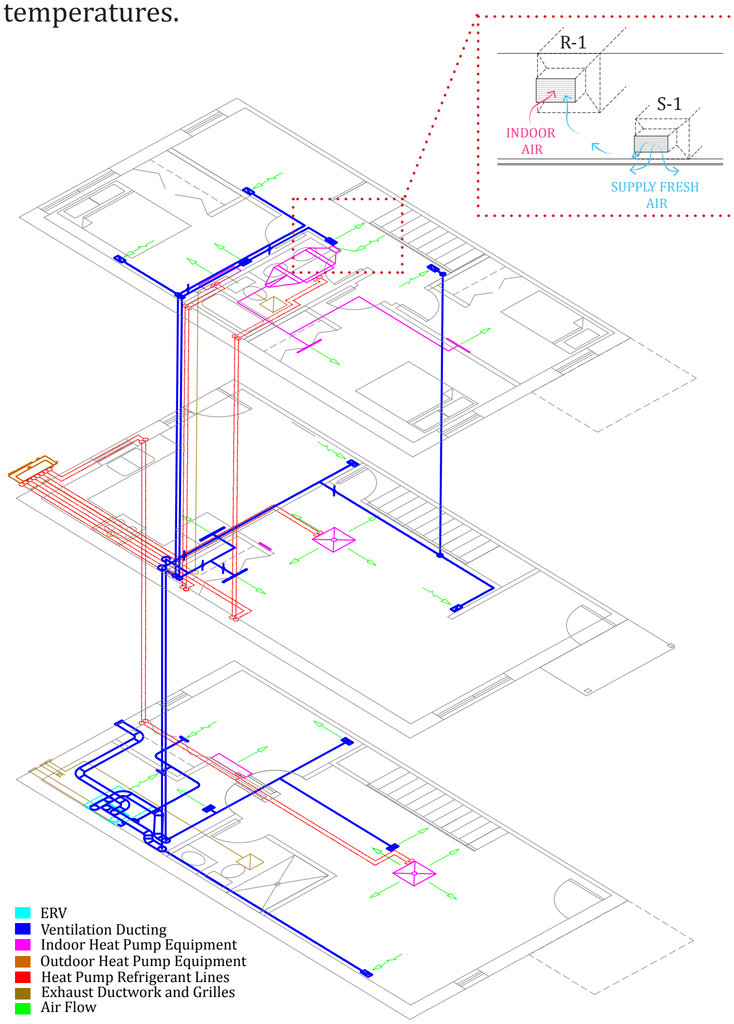


Figure 27. 3D model of Mechanical Layout

For the combination of outdoor and indoor units described, the HSPF rating is 10.3 and the heating COP is 3.3 when air enters the indoor unit at 21°C (70°F) DB and 16°C (60°F) WB, and with outdoor ambient conditions of 8°C (47°F) dry bulb (DB) and 6°C (43°F) wet bulb (WB) [17]. The SEER rating is 18.8 and the cooling EER is 11.5 when air enters the indoor unit at 27°C (80°F) DB and 19°C (67°F) WB, and with outdoor ambient conditions of 35°C (95°F) DB and 24°C (75°F) WB [17].

An optimized section of the design involved sending ventilation air to Zone 2. The ventilation supply grille was placed close to the return intake of the low-static air handler to feed fresh air into Zone 2. The zoomed-in detail in Figure 27 shows a view of this setup, where S-1 is the ventilation supply grille and R-2 is the air handler return. Using this method, the air handler serves ventilation and space conditioning purposes for those bedrooms, reducing the amount of ventilation ductwork.

After a mini-split system was selected and the design was optimized through the selection and placement of the units, the indoor air quality of the home was evaluated.

6.0 Indoor Air Quality

The goal was to provide and maintain acceptable indoor air quality based on ASHRAE 62.2 [xx] and the
2014 Ontario Building Code [6]. The additional cooling and heating loads due to ventilation were minimized through the use of an ERV.

6.1 Radon

The home is being built in Kitchener, which is not listed in the areas that are under special consideration for Radon in the OBC [1]. The region of Waterloo underwent a study by Health Canada to determine if the radon levels were above the allowable annual average of 5.4 picocuries/L (200 becquerel/m^3) [2]. The study found that about 4% of the homes tested had a problem where the radon levels were too high [2]. From this, it was assumed that radon could potentially be a large issue for Kehl-0. To comply with the Indoor airPLUS Construction Specifications, a 4" layer of gravel was added below the slab as a precautionary measure against potential issues that may occur in the future [3].

6.2 Material Selection

To comply with Indoor airPLUS requirements, low volatile organic compound (VOC) materials were used throughout the house. Zero VOC paint was used to paint the interior walls of the home and materials that would decrease the quality of the air, such as carpets, were avoided [4].

6.3 Required Ventilation

Taking a conservative approach, Equation 1 from ASHRAE Standard 62.2 (2016) was utilized to find the total ventilation required in the house [5].

$$\textit{Total ventilation} = 0.03 \times A_{floor} + 7.5\,(\textit{Number of Bedrooms} + 1) \qquad \textit{Eq. 1} \qquad [5]$$

$$\textit{Total ventilation} = 0.03 \times 1934\ \text{ft}^2 + 7.5\,(4 + 1) \approx 95\ \text{CFM}$$

A_{floor} was the dwelling unit floor area measured in ft^2 [5]. The total floor area was calculated including the exterior walls, which was determined to be approximately 1934 ft^2. There are a total of four bedrooms in Kehl-0. Using Equation 1, the total ventilation was calculated to be about 95 CFM.

Taking into consideration the ventilation that is needed in a home under the OBC, Table 8 summarizes the amount of ventilation required in each room in relation to Kehl-0 [1].

Table 8. Ventilation calculation using OBC regulations [6]

SPACE TYPE	VENTILATION RATE REQUIRED BY OBC FOR EACH SPACE TYPE		NUMBER OF CORRESPONDING SPACE TYPES IN KEHL-0	TOTAL VENTILATION RATE REQUIRED	
	CFM	L/s		CFM	L/s
Master Bedroom	21.2	10	1	21.2	10
Other Bedrooms	10.6	5	3	31.8	15
Living Room	10.6	5	1	10.6	5
Kitchen	10.6	5	1	10.6	5
Den	10.6	5	1	10.6	5
Basement	21.2	10	1	21.2	10
Bathroom	10.6	5	2	21.2	10
Laundry Room	10.6	5	1	10.6	5
			Total Ventilation	137.8	65

To comply with OBC standards, a total ventilation of 138 CFM was used as a requirement while choosing between different systems. As Kehl-0 has a very air tight building enclosure, a ERV mechanical ventilation system was specified to provide point source removal and fresh air distribution.

The criteria used to choose an ERV included the ventilation range, the sensible efficiency that the ERV would operate at (Table 9), and whether the ERV was Energy Star certified.

Table 9. Sensible Efficiency Range of the Selected ERV [7]

OUTSIDE AIR TEMPERATURE		NET AIR FLOW		SENSIBLE RECOVERY EFFICIENCY (%)
˚F	˚C	CFM	L/s	
32	0	51	24	76
32	0	81	38	72
32	0	119	56	67
-13	-25	74	35	60

In the product specifications, the recovery performance values do not go up to 138 CFM, with the closest value at 119 CFM, which has a sensible recovery efficiency of 67% [7]. This is greater than the 60% SRE that is required by the NZERH Prescriptive Program Requirements [8]. The ALDES E190-TRG model that was chosen also comes with an optional minimal efficiency reproting value (MERV) 13 filter [7], which would allow it to meet the minimal MERV 8 filter requirement by Indoor airPLUS [3]. The ERV has a range of up to 165 CFM, well in exceedance of the minimum requirements, allowing the user to select for more ventilation if required [7]. For example, if there were guests staying in the home, then the user can adjust the ventilation using the speed control to allow for everyone in the home to remain in an optimally comfortable state [7].

The ALDES E190-TRG model has multiple settings that can be used depending on the ventilation requirements of the house. The control panel was installed in the living room as it is an accessible location. The control panel included a speed control, a digital multifunction control, along with a slave mode switch so that occupants can turn on the ventilation manually [9]. Humidity control sensors were installed close to washrooms to detect the humidity in the air [9]. Depending on the level the occupants set the Humidity Control to, the ERV lowers the incoming outdoor air humidity to the desired levels [9].

In accordance with ASHRAE Standard 62.2 and OBC requirements, the exhaust fans chosen for the kitchen and bathrooms were 100 CFM and 50 CFM respectively. The models were selected because they are quiet while they are being run. The Air King ECV range hood creates less than 0.6 sones while being run at a continuous ventilation of 150 CFM [10]. The Delta GBR50 bathroom exhaust fan also creates less than 0.3 sones while being run at 50 CFM [11]. The low sone values allows for inreased comfort for the occupants as there is less noise being generated by the exhaust fans.

7.0 Plumbing

The design goals of plumbing were to maximize energy savings for the homeowners, reduce the size of the water distribution system and maintain occupant comfort. Also, the distribution system was designed to minimize heat losses and wait times associated with hot water distribution throughout the house.

7.1 Design Overview

Kehl-0's plumbing system combines low-flow fixtures and a highly efficient water heater to maximize savings to the home owners without sacrificing comfort. The architectural floor plans were also strategically designed, and placed the location of the mechanical room, kitchen, and bathroom, to be approximately above each other to minimize the length of piping needed for distribution. Additionally, a falling-film drain water heat recovery (DWHR) system was included in the Kehl-0's plumbing design to recover energy from warm graywater and preheat cold municipal water going into the water heater.

7.2 Hot Water Distribution System

A whole-house manifold system was selected for distributing water around the house, similar to the schematic shown in Figure 28. This system would equalize water pressure, such that several fixtures can be used simultaneously without dramatic changes in pressure or temperature [1]. The pipe sizes in this system are relatively small, so fixtures have their own dedicated pipes, which would reduce the amount of water that is wasted as well as the time taken to deliver hot water to fixtures. The 24 Port Polymer PEX Crimp Manabloc manifold has more outlets than required to allow for easy adaptability and future-proofing. Furthermore, installation costs are lower for a whole-house manifold system compared to conventional distribution systems [2]. The whole-house manifold has shut-off valves built into each of its outlets, which allows shutting off water to individual fixtures instead of shutting off water for the entire house. This is especially useful when conducting maintenance, or in cases of system failure.

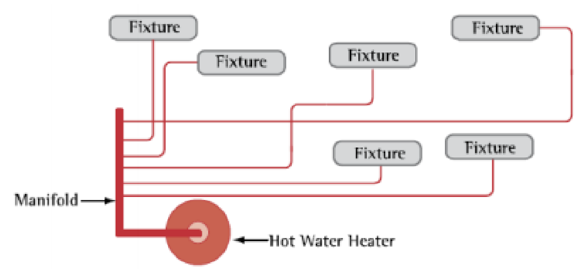


Figure 28. General Configuration of Typical Whole-House Manifold System [1]

Cross-linked polyethylene (PEX) pipes were chosen for the water distribution system in Kehl-0. Relative to metallic pipes, PEX pipes are cheaper and have lower thermal conductivity, reducing heat loss from the pipes [3]. PEX pipes are also easier to connect to the whole-house manifold, and their flexibility reduces the number of fittings required in the distribution system. To further minimize heat losses, all hot water pipes are insulated using ½" thick polyethylene pipe insulation with an R-value of 3.58 BTU/(hr °F ft^2).

7.3 Heat Pump Hybrid Electric Water Heater & DWHR

A 50 gallon, heat pump hybrid electric water heater (Model PROPH50 [4]) was selected for this design based on water consumption calculations shown in Volume II. PROPH50 is highly efficient and has an energy factor ranging from 3.55-3.70 uniform energy factor (UEF). The unit can either use indoor air (ductless) or outdoor air (ducted) for the operation of the heat pump. The minimum recommended temperature for the heat pump was 28°F (2°C); considering that the outside air temperature in Kitchener during winter can be lower than that, the ductless option was selected. The PROPH50 has a lifetime savings up to $5000 with a payback period less than two years [4].

An R3-60 DWHR unit with an efficiency of 53.3% was selected for the Kehl-0 design [5]. The model will save up to 35% on the homeowner's water heating costs by recovering heat from the hot water utilized in showers to preheat the cold-water distributed to the hot water tank [5].

7.4 Hot Water Fixtures

EPA WaterSense certified water fixtures were specified, which use less water than conventional water fixtures, and ultimately reduce the energy required to heat water for each of the units. These fixtures are itemized in Table 10.

Table 10. Tabular Summary of Selected Fixtures for DHW

FIXTURE	SPECIFICATION	CERTIFICATION	SPECIFIED LOAD (GPM)	ACTUAL LOAD (GPM)
Kitchen Faucet	Pfister Single-Handle Pull-Down Sprayer Kitchen Faucet, Stainless Steel F-529-7PDS	WaterSense	2.2	1.8
Lavatory Faucet	Pfister 2-Handle Widespread Bathroom Sink Faucet, Bronze F-049-SLYY	WaterSense	1.5	1.5
Showerhead	Pfister Single-Handle 3-Spray Tub and Shower Faucet, Brushed Nickel 8P8-WS2LRSGS	WaterSense	2.0	1.8

7.5 Hot Water Delivery System Calculations

Hot water calculations were conducted using EPA WaterSense flow rates. The maximum volume of water contained in a hot water supply pipe is calculated to be 0.31 gallons which is below the WaterSense total hot water volume limit of 0.5 gallons, and a maximum wait time below 11 seconds, which is within American Society of Plumbing Engineers acceptable performance. The volume and hot water wait time for each run is summarized in Table 11.

Table 11. Hot Water Volume and Wait Time Calculations [1]

FIXTURE	PIPE SEGMENT	PIPE DIAMETER (in)	WATER CAPACTIY (oz/ft) [1]	PIPE LENGTH (ft)	WATER VOLUME (gal)
Washing Machine	1	3/4	2.35	3.33	0.06
	2	1/2	0.64	15.83	0.15
			Total Hot Water Volume (gal)		0.21
Basement Sink	1	3/4	2.35	3.33	0.06
	3	1/2	0.64	2.5	0.02
			Total Hot Water Volume (gal)		0.09
			Hot Water Wait Time[1] (sec)		3.48
Basement Shower	1	3/4	2.35	3.33	0.06
	4	1/2	0.64	8.33	0.08
			Total Hot Water Volume (gal)		0.14
			Hot Water Wait Time[2] (sec)		4.77
Kitchen Sink	1	3/4	2.35	3.33	0.06
	5	1/2	0.64	25.6	0.025
			Total Hot Water Volume (gal)		0.31
			Hot Water Wait Time[3] (sec)		10.29
2nd Floor Sink	1	3/4	2.35	3.33	0.06
	6	1/2	0.64	21.6	0.21
			Total Hot Water Volume (gal)		0.27
			Hot Water Wait Time[1] (sec)		10.81
2nd Floor Shower	1	3/4	2.35	3.33	0.06
	7	1/2	0.64	22.5	0.22
			Total Hot Water Volume (gal)		0.28
			Hot Water Wait Time[2] (sec)		9.30

[1]Assumes a bathroom sink faucet flow rate of 1.5 gpm
[2]Assumes a showerhead flow rate of 1.8 gpm
[3]Assumes a kitchen sink faucet flow rate of 1.8 gpm

8.0 Energy Analysis

The goals of Kehl-0's energy analyses were to optimize an onsite renewable energy generation system and analyze the building's energy consumption, usage, and other key performance metrics.

8.1 Renewable Technologies: Solar PV

Solar photovoltaic (PV) technology was selected as the optimal renewable energy source, due to is superior performance, ease of installation, low capital cost, and reliable energy production [1].

8.1.1 Location and Climate

Kehl-0 is in a 6A climate zone with fluctuating temperature and weather patterns, requiring an extremely durable PV system. The colder, northern climate of the home does not diminish the potential for solar PV as the area receives levels of solar insolation of 5.1 kWh/m^2/day (1.62 kBTU/ft^2/ day) [2]. A Toronto Canadian Weather year for Energy Calculation (CWEC) file was used in PV power generation modelling as the closest comparison to Kitchener's climate and PV potential. Since Kitchener is only 90 km (55.92 mi) west of Toronto, the annual insolation values were calculated to be within 2% of each other.

8.1.2 PV Design Constraints

During preliminary modelling, a 30 kW array was proposed to be placed onto the south-west facing side of the roof, with a total roof area of 191 m^2 (2056 ft^2), and a resulting 25° tilt angle of the panels, as seen in Figure 29. Since there are four attached units, four systems of panels will need to be installed, restricting optimization of roof space. With a limited amount of space, the inverters will need to be strategically placed on the side of the roof, in a more shaded location. The front of the house is south-west facing, so the azimuth of the array is 225° from north (45° from south), rather than the optimal 180°. Another priority was to minimize first costs while also providing durable and high-quality equipment.

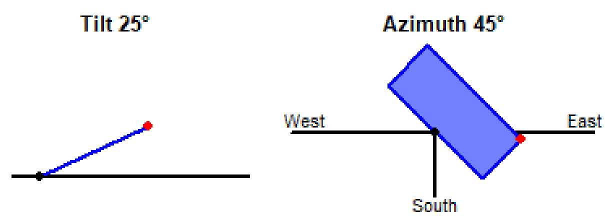


Figure 29. Tilt and Azimuth from PVsyst Fixed Tilt Schematic

8.1.3 Selected Equipment

The panels chosen for Kehl-0 were the REC 355 Twinpeak 2S 72 module (Figure 30) [1]. Due to their efficiency, quality, and price, these are the most effective [1]. The solar cells are made of 120 laser cut polysilicon, bolstering an innovative design that is reliable and will also provide enough energy to surpass energy consumed by the homeowners [3]. The cost of each panel is an estimated $252.50 CAD, coming to $22,220 CAD to optimally cover the roof with 88 modules, and overall $25,108 CAD including tax.

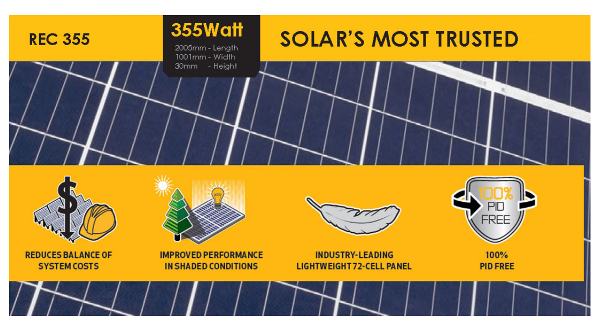


Figure 30. REC355 TP 2S72 module

In Table 12, the maximum design ratings of the PV system are shown. Additionally, the panels feature a weatherproof anodized black frame, which comes certified for salt mist and ammonia corrosion resistance, a 10-year product warranty, a 25-year power output warranty, and is 100% free of Potential Induced Degradation (PID) efficiency losses [3]. The REC TwinPeak modules' unique design also allows for the generation of electricity during times of partial shade, helping to melt snow during winter months, due to the generated waste heat, and allow for reliable power output all year long [3].

Table 12. Maximum Ratings of the REC Twinpeak 2S 72 Series

Operational Temperature	-40˚C to +85˚C (-40˚F to +185˚F)
Design Load (+)	3600 Pa (75.2 lbs/ft²)
Design Load (-)	1600 Pa (33.4 lbs/ft²)

The available roof space was maximized so that as many panels as possible could be incorporated. Each unit of the Kehl-0 building will have their own solar PV system. There will be 22 panels divided into two strings of 11 panels each, to 1 inverter per PV system. As seen in detail in drawing sheet Q100 in Appendix B, the panels will be placed in eight rows of 11 across the entire roof, totalling 88 panels for the whole building.

The inverter chosen for the system was the Sunny Boy 6000TL US 22 240V (Sunnyboy 6,000) model, as it is a cost-effective, high efficiency inverter [4]. Additionally, it is suitable in terms of temperature control, energy security, and flexibility within communication for the solar PV system [4]. The sizing of the inverter was optimized through PVsyst energy analysis. It was demonstrated that by oversizing the panel nominal power to the inverter power by using the Sunny Boy 6,000, the output is slightly higher than that of the regularly sized Sunnyboy 7,000 kW system. The smaller inverter model also has a lower first cost [5].

In addition to the panels and inverter, the racking chosen was from Kinetic Solar Racking and Mounting, a local and reliable solar racking company. Placing the panels in portrait orientation, rather than landscape, significantly reduces racking costs by $4,500 CAD. The entire racking system would cost approximately $6,555 CAD. One of the appealing features of the REC 355 Twinpeak 2S 72 module and the Kinetic Solar racking system is the industry-leading lightweight design. Ideally, the racking would be aligned with the roof trusses to improve structural integrity. As the panels will likely weigh less than the average winter snow load, the advanced framing detailed in Section 4.0, Building Envelope, will effectively carry the added weight of the panels [6].

8.1.4 Energy Output

During the early design stages, the maximum estimated energy production of the PV system was 37,622 kWh/year (128.4 MMTBU/year), calculated by fully populating the roof area and using the PV Watts energy analysis tool (Volume II). This number was estimated to match the predicted consumption of the four units during preliminary design. As the design process progressed, PVsyst was chosen as an enhanced modelling tool because of its detailed analysis that incorporates current products on the market.

PVsyst simulation results indicated that a 31.24 kW system offered 9.249 MWh (31.6 MMTBU) per year, per unit, totalling 39,669 kWh/yr (135.4 MMTBU/ yr) (Volume II). This estimation approximately validates the original prediction by PV Watts and confirms the suitability of the implementation of a PV system into the Kehl-0 design. A summary graph of the PV energy production from PVsyst can be seen in Figure 31.

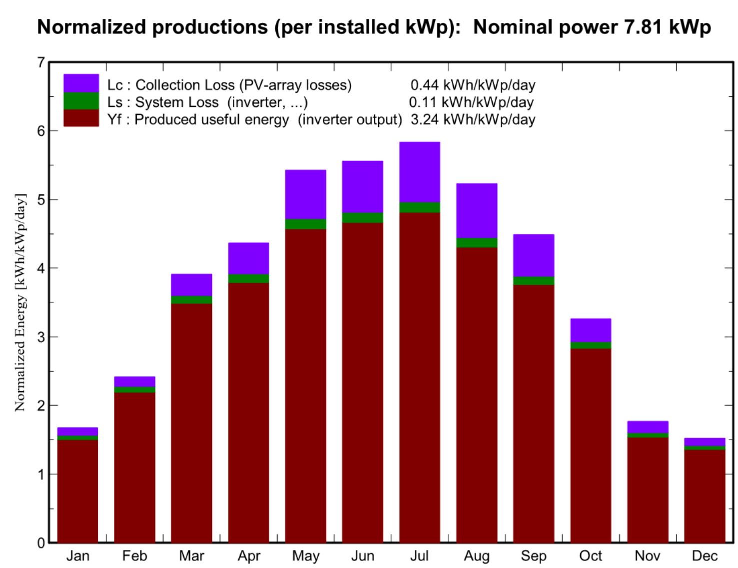


Figure 31. PVsyst Simulation Normalized Production Graph

8.2 Building Energy Modeling

An early design goal for the home was to create a comprehensive building energy breakdown, such that the energy usage of the building could be easily and accurately optimized. To achieve this, the design specifications were modeled using three different programs: BEopt, REM/Rate, and eQuest. These programs were used iteratively to reach a net zero energy (NZE) design, each with their own strengths and limitations. The design specifications of the house were input into all three models, with assumptions varying based on the level of detail and input requirements. These specifications are listed in Table 13.

Table 13. Design Changes

DESIGN PARAMETER	ORIGINAL BASE DESIGN	WARRIOR HOME DESIGN
Heating Equipment	Natural Gas Furnace 95% Efficient	Electric Air Source Heat Pump Heating COP: 3.35
Cooling Equipment	Single Units A/C	Electric Air Source Heat Pump Cooling COP: 3.35
Domestic Hot Water Tank	Natural Gas Boiler	Electric Heat Pump Water Heater EF: 3.5, 50% Eff. DWHR
Outdoor Air Delivery	Natural ACH	ERV, 75% Sensible Efficiency
Roof R-Value	31	60
Above-Grade Wall R-Value	27	40
Foundation R-Value	0	22
Window U-Value/SHGC	0.27/0.46	0.24/0.25
Primary Lighting Fixtures	Incandescent/CFL	LED
Water Fixture Flow/Flus Rates	Conventional	Low-Flow WaterSense
ACH50 Infiltration Rate	3.37	1.0

A complete summary of modelling assumptions, inputs, and details can be found in Volume II, however, noteworthy modelling assumptions include:

- For the BEopt and eQuest model, a Toronto weather file was used for the hourly simulations to ensure the design accounted for the local climate.
- A slightly reduced heating/cooling setpoint of 22/ 24°C (71/76°F) was implemented in the model.
- 1 ACH @ 50Pa was assumed due to improved building practices as outlined in Section 4.0.
- Drain water heat recovery could not be modelled with BEopt and eQuest; to reflect its impact, DHW energy savings of 30% were applied after the simulation was complete.
- Kehl-0 has limited humidification control, but a range of 25%-60% relative humidity (RH) was set in eQuest, to maintain thermal comfort; a RH setpoint of 40% was used in BEopt.
- Plug loads were calculated using information from national averages, and were determined to be approximately 1,000 kWh/unit/year (3.4 MMBTU/unit/year), as input into eQuest and BEopt.

Incorporating all design changes into the three modelling programs returned the outputs in Figure 32.

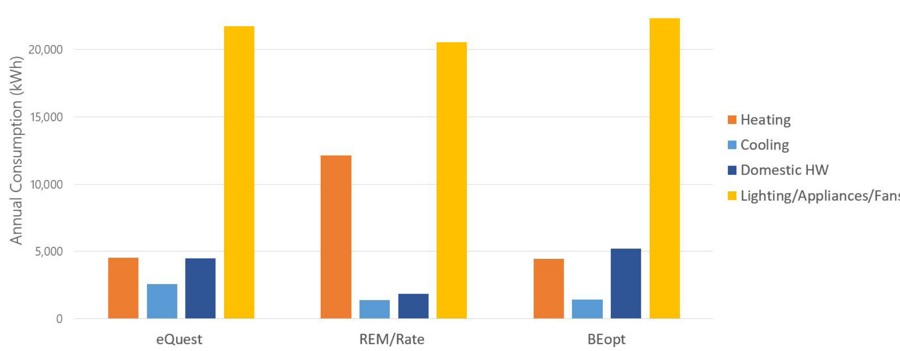


Figure 32. Kehl-0 Design Model Comparison

BEopt and eQuest are more detailed modelling software programs, due to their more intensive calculation engines and hourly simulations, and both offered similar end use consumption values (Volume II). eQuest was chosen as the most realistic simulation program, it has the most detailed inputs, including scheduling, airflow inputs, and zoning. The consumption values used in the remainder of this section and energy end-use breakdowns all contain annual eQuest simulated values for all units in Kehl-0, unless otherwise stated.

8.3 Estimated Annual Consumption

The annual energy consumption of Kehl-0 and baseline design was simulated using eQuest. The energy consumption results of the simulation are presented in Figure 33.

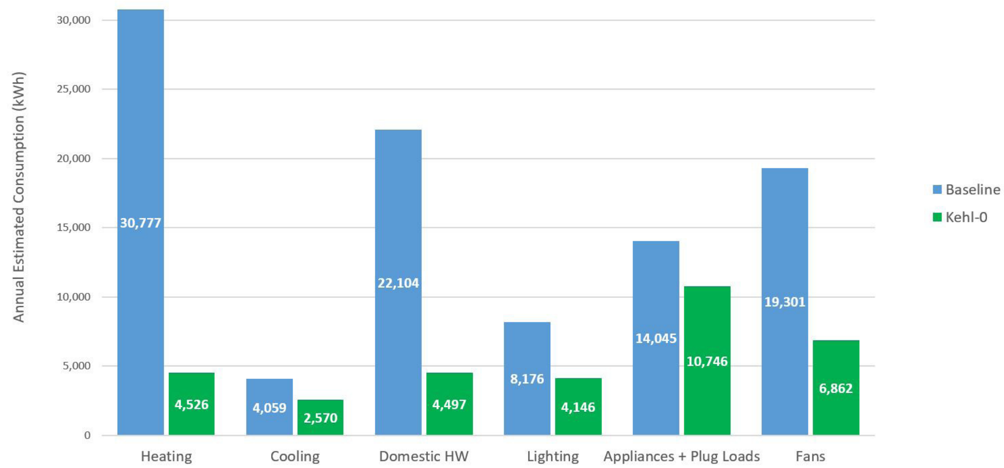


Figure 33. Baseline and Kehl-0 Design Energy Comparison

The design changes resulted in decreased energy usage in all aspects of the home. In particular, heating and domestic hot water usages were reduced dramatically, contributing to most of the energy consumption reduction. The total overall annual energy savings from the baseline were determined to be over 65,000 kWh (221.8 MMBTU); approximately a 66% reduction.

8.4 HERS Score

REM/Rate was used to generate a HERS score, which was computed with the energy efficiency measures displayed in Table 13. REM/Rate gave Kehl-0 scores of 48 and 0, before and after PV implementation, respectively (Appendix C). The progression of the HERS score with the various energy saving measures can be seen in Figure 6 below, using the corresponding REM/Rate total energy usage values.

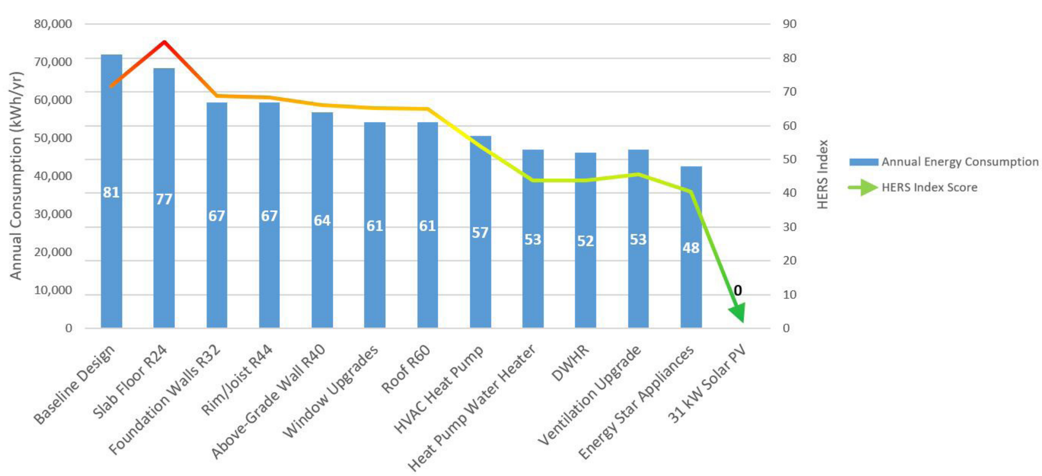


Figure 34. Progression of Design Iterations in REM/Rate

As seen in Figure 34, the design process led the design from its initial baseline HERS score of 81 to Kehl-0's score of 48. Finally, with the addition of solar PV, NZE-status was achieved, yielding a final HERS score of 0. It is noteworthy to mention that the score and energy consumption rise with certain upgrades; this is likely because of REM/Rate's calculation methodology.

8.5 Summary of Findings

After the design of the house was complete and the energy consumption was evaluated, the energy generation from solar PV was factored in to determine the net-energy consumption for the Kehl-0 design. As seen in Figure 35, the Warrior Home design surpassed the design goal of achieving net-zero, resulting in a net-positive generation of approximately 3600 kWh/yr (12.3 MMBTU/yr).

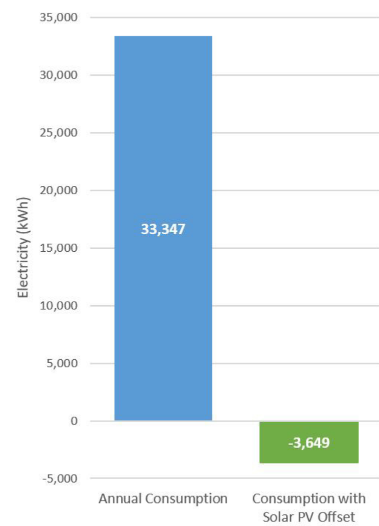


Figure 35 Net Annual Consumption

The energy usage intensity (EUI) of the Warrior Home was determined to be 53.96 kWh/m2 (17.11 kBTU/ft^2), which is a 62% improvement over the baseline EUI of 142.70 kWh/m2 (45.26 kBTU/ft^2). According to the Comprehensive Energy Use Database (CEUD), Ontario's residential EUI is approximately 200 kWh/m^2 (63.44 kBTU/ft2) [7]. Both the baseline design and Kehl-0 are well below this average.

Carbon emission factors were selected from the Canadian national inventory report to be 0.043 kg CO_2e/kWh (0.147 g CO_2e/MMBTU) and 1.899 kg CO_2e/m3 (53.774 g CO_2e/ft3) for electricity and natural gas respectively [8]. It was found that each unit from the baseline design was producing 2,878 kg per year of CO_2e, which was ultimately reduced to approximately 358 kg CO_2e/unit in the Warrior Home. This dramatic 88% improvement is largely due to the elimination of all sources of natural gas in the house, which emit over five times as much CO_2e per unit energy. According to the CEUD, the average attached home produces nearly 3500 kg CO_2e from natural gas alone, which is significantly above the emission rates for Kehl-0; the baseline design's carbon footprint was also below this average [7].

To provide a better understanding of the home's energy consumption, the end use breakdown of both the baseline and Kehl-0 were compared, as seen in Figure 37.

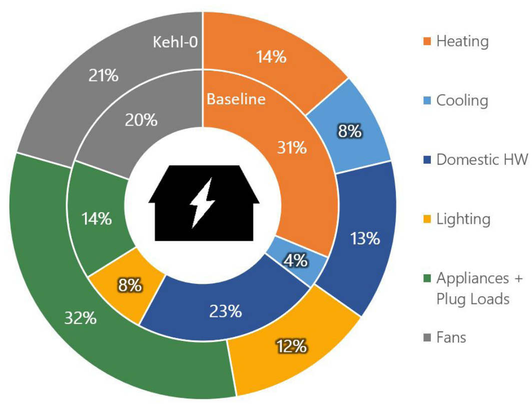


Figure 36. End Use Breakdown of Baseline and Kehl-0 Design

The fraction of energy that contributed to space heating and DHW drastically decreased, while the relative percentage of energy for appliances and plug loads more than doubled. This is an expected trend that is commonly seen in energy efficient homes; without a change in occupant behaviour, the consumption from appliance and plug loads cannot be reduced. The energy modelling assumptions for occupancy and plug loads assumed an average usage per occupant, however, appliance and plug load consumption can be greatly reduced by changing the habits of the occupants through education and environmental awareness. Key performance metrics of the Kehl-0 design can be seen in Figure 37.

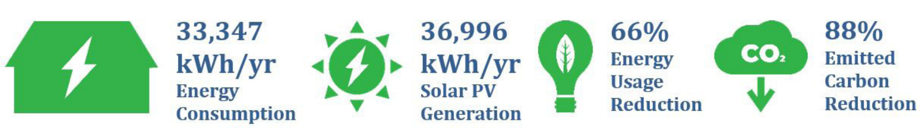


Figure 37. Energy Analysis Summary

9.0 Finance

Families selected for the HabitatWR program have an average annual family income of $59,000 CAD ($47,000 USD). HabitatWR mortgages require families to pay approximately 25% of their monthly family income (MFI) over an amortization period of 25 years; however, families are not required to pay interest on the principal amount or a down payment. Using this information, a goal for monthly payments associated with the home was set at less than $1,800 CAD ($1,400 USD) per month, which would keep the affordability below the target of 38%. Using the U.S. Department of Energy Financial Analysis Toolkit [1], along with data from RS Means and reliable companies, Warrior Home established a cost of construction without PV of $149,000 CAD ($119,000 USD) per unit and a sales costs of $260,000 CAD ($208,000 USD) per unit. Financial analysis was completed factoring in the installation of a photovoltaic (PV) system which added an additional cost of construction of $11,000 CAD ($8,800 USD).

Warrior Home was able to achieve significant cost savings by avoiding complex construction geometry, maintaining a reasonable size, utilizing volunteers for construction, using an advanced framing technique, and installing inexpensive finishes. Kehl-0 is expected to significantly lower maintenance and utility costs as well, currently anticipating an overall debt to income ratio of 35% without implementation of the PV system and 31% with the PV system. This will allow the family to increase their monthly mortgage payments so they can pay off their HabitatWR mortgage early.

9.1 Financial Assumptions

While completing the financial analysis of Kehl-0 , the following assumptions were made:

- Estimate was completed for all four units as one, assuming the home will be provided to the user with an unfinished basement, and the divided evenly to determine the average cost per unit.
- RS Means 2011 Student Version 1st Edition was used as the primary tool to determine an elemental estimate for assembly costs, with year conversions based on the Construction Price Indexes for new housing in the Kitchener-Cambridge-Waterloo area [2].
- Reliable and local companies were sourced or contacted to determine costs for detailed estimation. Where costs were found in USD, a conversion factor of 1.25 was used to convert to Canadian Dollars.
- Architecture, engineering, landscaping, land, site servicing, overhead, and general expenses were provided to Warrior Home by HabitatWR. The value provided was given for a specific number of units. The cost of this work for Kehl-0 was determined by averaging the costs evenly for all units.
- RS Means “Overhead & Profits” costs were used where work must be done by contractor and not by volunteers. This includes excavation, foundation, and MEP work.
- RS Means “Bare Costs” were used where work is completed by volunteers. The total cost of HabitatWR Overhead and General Expenses was added as a final line item under “other”. Included in this line item is the cost of full-time Build Site staff and cost for equipment.
- A discount rate of 6% was used for net present value (NPV) analysis.

9.2 Construction Costs

Figure 38 illustrates the breakdown of construction costs by each section. Overall, the cost per square foot of the constructed home was determined to be $122 CAD ($98 USD) per square foot, which is below the expected building costs of a new home in Southern Ontario provided by Rijus Home & Design, a firm located in the region [4]. Additionally, HabitatWR is provided ample materials from their sponsors, which can typically reduce construction costs by $30,000-$40,000 CAD ($24,000-$32,000 USD) per home, allowing for more leeway in terms of altering the design to make the home NZER.

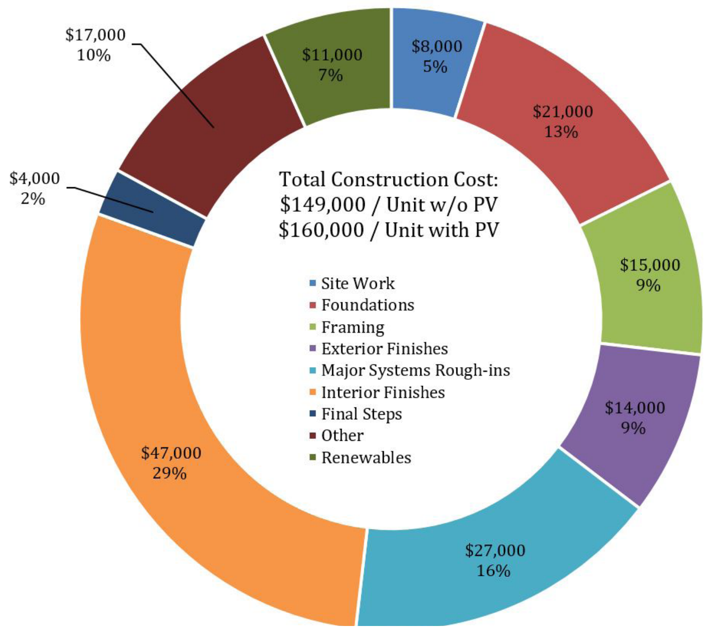


Figure 38. Construction Cost Breakdown with PV ($CAD)

9.3 Utility Costs and Mortgage Payments

HabitatWR offers its families the opportunity for home ownership, requiring no down payment and a 0% interest rate. Factoring in these unique circumstances, the expected monthly mortgage payment was determined to be $830 CAD ($670 USD), which is approximately 18% of the MFI. At 25% of the MFI the mortgage payment would be $1,230 CAD ($985 USD). This increased payment would lead to a debt-to-income ratio of 42% which is still within an acceptable homeownership rate.

The expected cost of electricity, without the PV system, was determined to be $57 CAD ($46 USD). This is significantly cheaper than the average Kitchener energy bill of $101 CAD ($81 USD) for electricity and $75 CAD ($60 USD) for natural gas [5]. Ontario has experienced some of the greatest increases in electricity costs compared with other Canadian provinces in recent years [6], however the Feed-In-Tariff program has allowed Ontario homes to sell electricity produced by solar energy to the provincial government at a rate of $0.29 CAD/kWh ($0.23 USD/kWh), and purchase it back at a rate of $0.08 CAD/kWh ($0.07 USD/kWh). This initiative has made implementing green energy solutions attractive to homeowners.

9.4 PV System

The Renewable Energy team working on Kehl-0 determined that the "REC 355 TwinPeak2S 72 Module Solar System" would be a viable option for the home. Using the PVsyst simulation tool, it was determined that the annual output for the system would be 9252 kWh per unit per year [7]. The warranty provided guarantees that the deterioration of the system production will not exceed 0.7% per annum, so this maximum deterioration was factored in to the calculation of savings over time with the PV system. This system would add roughly $11,000 CAD ($8,800 USD) to the total construction costs (per unit), based on cost information provided by Solar Electric Supply Inc. [8].

The PV system savings over the mortgage period was calculated using data gathered from eQuest en¬ergy modelling, which predicted that the Kehl-0 residents would require 8337 kWh per unit per year. Annual savings over time resulting from the PV system were calculated and it was determined that the costs of implementing the system would be recouped by the 4th year. The costs incurred with the PV system are significantly lower, with the NPV of the savings being $28,000 CAD ($22,500 USD). Net present value calculations are shown in Volume II.

10.0 Constructability

It takes hundreds of volunteers from all walks of life to build one HabitatWR home. A full-time site superintendent and site foreman manage this project from start to finish; a majority of the labour is completed by volunteers with little-to-no construction experience. Warrior Home adapted HabitatWR's unique construction practices to accommodate the challenges that come with managing a dynamically changing volunteer team. To promote this, a Construction Instruction Manual was created as a visual-aid to help volunteers in Kehl-0 construction, and includes an operations and lifestyle section.

To ensure that work is completed even in adverse weather conditions, framing is completed one unit at a time so that volunteers can work indoors in the first finished unit. Skilled tasks require a paid contractor to complete, and consideration was given to minimize their time on site and costs. Since the number of volunteers and their level of construction experience is unpredictable, the construction schedule, summarized in Figure 39, is longer than that of a typical house and multiple phases of work may occur at the same time.

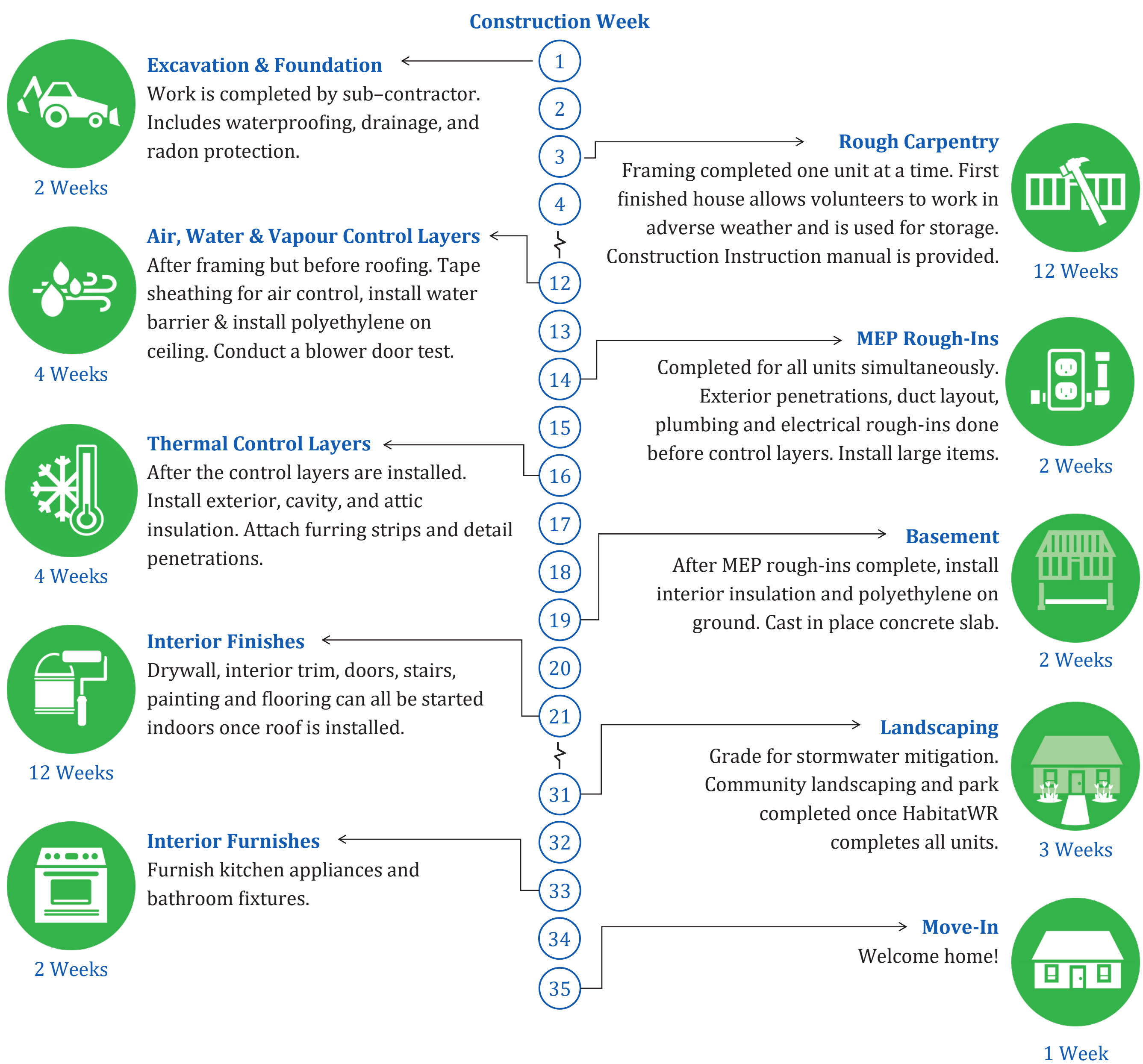
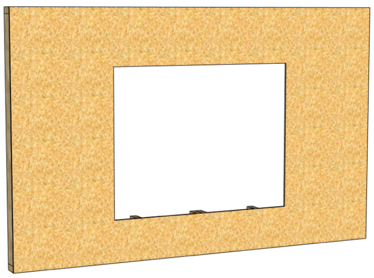


Figure 39. Construction Timeline

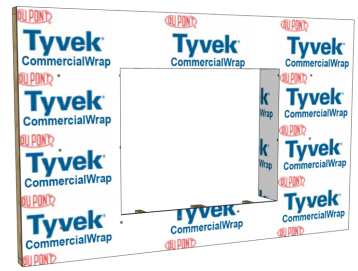
10.1 Construction Instruction Manual

Kehl-0 wanted to focus on the areas of where there were any penetrations introduced to the building enclosure. The window penetration was considered in detail to allow for better analysis for designing a NZERH. Figure 40 was prepared as a window installation guide for volunteers at the HabitatWR site. Each step highlights the necessary caulking and lapping applications to ensure a seamless transition between the building enclosure and the window.

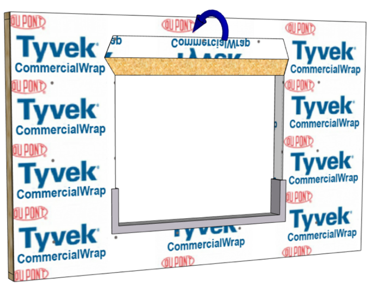


Step 1
Framing and OSB Sheathing.

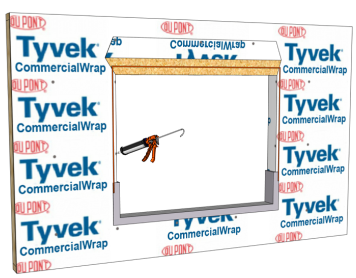
Step 2
Install water barrier and make a vertical incision halfway through window cavity.



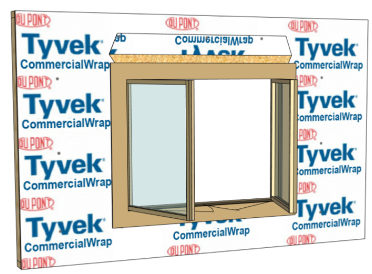
Step 3
Fold back and secure cut-out section of water barrier.



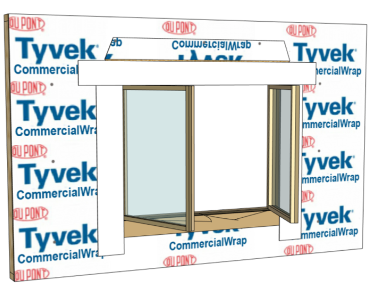
Step 4
Cut and fold water barrier as shown and install window sill pan flashing with a SA membrane back dam.



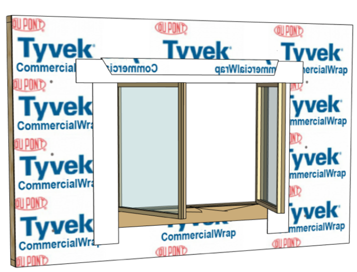
Step 5
Two small weep holes to be maintained at base of window to allow for drainage. Ensure weep holes are not blocked by sealant.



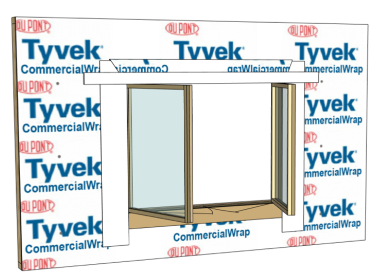
Step 6
Install flanged window.



Step 7
Apply flashing strips on jambs and header of window.



Step 8
Fold down top part of water barrier and seal with tape.



Finished Window Installation.

Figure 40. Window Installation Guide

10.2 Operations Manual

There are many incentives from the Government of Ontario for energy savings equipment and components for homeowners. The information in this section will be provided to the future home owner to outline operational suggestions that can save energy.

KITCHEN

- Use a microwave oven instead of a conventional large oven or microwave. This appliance is more energy-efficient. [6]
- Use a toaster oven or slow cooker to cook small quantities of food. Using these appliances can use up to 80% less energy than using a conventional oven for heating [6]

BUILDING ENCLOSURE

- Ensure windows, doors and air vents are fully closed when not in use or not needed.
- Seal around the window must be checked regularly to ensure no openings or holes.
- Ventilation fans must be used for short periods of time to prevent large amounts of air transfer from the outdoor environment to the indoor environment.

INDOOR AIR QUALITY

- For the ducted units and ERV duct work regularly check the seal the duck work properly to minimize the losses [15]
- Regularly clean the ERV and ducted unit filters so that they are running efficiently and do not have to work harder. As long as the insulation is intact, it does not need to be replaced. The users can do regular checkups to see if insulation is broken. Also, clean the ducted dryer filter regularly. [15]

MECHANICAL

- Ontario Building Code has recommended the heating and cooling set-points. As Warrior Home's design is equipped with mini-split heat pumps it is more efficient at delivering set-point temperature unlike conventional ducted homes. This is because each indoor unit serves a much smaller space, where less thermal stratification can occur.
- Change the thermostat setpoints to heat to 22 °C (71 °F) and cool to 24 °C (76 °F). Setpoints can be lowered in the winter and raised in the summer.
- Use ceiling fan in the living room running counter clockwise to help circulate cool air in the summer and clockwise to help circulate hot air in the winter [14].
- Automate heating and cooling with an "away" mode [15].

LIGHTING

- Replace incandescent lightbulbs with LED Energy Star rated lighting options. LED lightbulbs often last approximately 25 times longer than regular lightbulbs.

10.3 Lifestyle Manual

Simple initiatives and lifestyles choices pay out in the long-run as energy savings. As mentioned in Section 8.0 Energy Analysis, Kehl-0 allows the homeowner to choose lifestyles within the home. Suggestions of these lifestyles choices that lead to greater overall energy efficiency for the home are provided in this section.

KITCHEN

- Cook food in batches, to use the oven more when it is heated [5]
- Do not open the oven door while cooking, as heat losses translate to energy losses [5]
- Defrost food in advance by putting it in the fridge overnight. This cuts cooking time often in half. [5]
- Turn off the electric oven ten minutes before the completion of cooking, as the oven will stay at the temperature for approximately ten minutes after it is switched off. [5]

LIVING

- Purchase Energy Star Certified televisions of various brands including Artica, Avera, Samsung, Haier and JVC. Direct-lit LED, Edge-lit LED, or other LED televisions contribute big savings on long-term costs and environmental impacts [10]
- Buy unpackaged items. Reuse items and consider gently used options when it is possible.
- Dispose of waste in a responsible fashion and keep recyclable material out of landfills.
- Although the garbage tagging is not required in the Kehl-0 development, try to limit garbage to under one bag per week.
- Compost is another important factor to consider, kitchen waste and other compostable materials can be put in a backyard composter or a community composter that can provide fertilizer for the community garden.

UTILITY

Energy Star Certified central air conditioning units are designed to output a higher energy efficiency ratio and have higher seasonal energy efficiency ratios. Approximately 8% less energy is used in the Energy Star certified models compared to other conventional models. [4]

- Maximize on using natural ventilation instead of air-conditioning.
  Energy Star suggests a variety of brands of units that can be purchased.
- Keeping windows open at night and closing them during the day on hot summer days will allow for the cool air to circulate and reduce the overall temperature of the home during the day.

ELECTRICAL

- Avoid phantom power usage by plugging countertop appliances and electronics into a programmable power bar, or one you can turn off during the night. [15]
- Do not leave chargers plugged in as they still draw energy even when not in use. [15]

PLUMBING

- Take short showers instead of baths as the DWHR unit in place recovers energy from showers only.
- Wash clothes in cold wash to save energy.

11.0 Innovation Summary

Kehl-0 was designed to not only demonstrate good building practice to meet NZERH requirements, but also innovate and develop unique measures to improve the occupants' satisfaction and exceed energy requirements. One of the primary goals of Kehl-0 was to design a NZERH intended for subsidized housing that is both practical and affordable.

ARCHITECTURE

The architecture of Kehl-0 was designed to be highly adaptable for all types of families; to implement a generic design for unique families. The open-concept main floor minimizes the need for HVAC equipment and ductwork and encourages social interactions. The architecture was planned to be modular, such that any family could accommodate all their needs without significant renovation costs.

BUILDING ENCLOSURE

To prepare the home to be NZER, a high-performing envelope was implemented to maximize passive gains and minimize thermal bridging. This entails the use of insulation and fenestration that are well in exceedance of conventional deign, a low window-to-wall ratio, and a heavily insulated raised roof. Advanced framing techniques were also utilized to maximize space for insulation, while maintaining the structural integrity of the house.

HVAC SYSTEM AND PLUMBING

Mini-split ductless heat pumps were selected for their high-efficiency, zonal comfort control, modularity, and minimal ductwork. To further minimize ductwork, the ERV ducts were positioned such that the supply-air grilles on the second floor are located near the return-air intake for the primary indoor units, allowing the outdoor air to be circulated without the need of additional ductwork, grilles, or equipment. The manifold piping system will equalize pressure, which would allow occupants to use fixtures simultaneously without any significant impact to each other. Drain water heat recovery will be implemented to recover energy during showers.

INTERIOR DESIGN

Energy Star appliances will be installed in the home to maximize energy savings, while providing the occupants with reliable, feature-rich appliances. Smart LED lighting fixtures were chosen for their low energy consumption, long lifespan, smart home technology, and mercury-free assemblies. Low or zero-VOC finishes were selected to optimize indoor air-quality and increase occupant comfort.

RENEWABLE TECHNOLOGY

To maximize the amount of energy that can be generated by a residential solar PV system, the roof was optimized in order to increase solar gains by maximizing the south-facing roof. The panels also operate while partially shielded, increasing the number of operational hours under snowfall. The inverters have smart capabilities, allowing occupants to analyze real-time data from their PV system.

SUSTAINABLE LIVING

To guide and encourage the family to live a sustainable lifestyle, maximize the efficacy of Kehl-0, and lower their carbon footprint, a Construction-Instruction Manual is being provided. To truly exhibit a sustainable design, all uses of natural gas were eliminated from the home, ensuring that electricity would be the sole fuel source, which has a significantly lower carbon factor in Ontario.

extra page

USE FOR CONCLUSION!

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