REEP House
a Near Net Zero Century Home Retrofit

City of Kitchener, Waterloo Region, Ontario

Introduction

REEP House for Sustainable Living is a deep retrofit of a single family century home in Kitchener which was completed in late 2010. The overall goal for the project was a 90% energy reduction, to make the house “near net zero” energy with the addition of renewable energy sources. Project Managers REEP Green Solutions (originally the Residential Energy Efficiency Project) also wanted to achieve a LEED for Homes Canada Platinum Rating while providing a comprehensive showroom of green home retrofit options. In addition to the REEP House project, a nearly identical house next door called the 30/50 House was renovated by REEP, achieving a 50% energy reduction for a budget of $30,000 or less.

Context and Rationale

In Waterloo Region alone, there are over 15,000 homes built prior to 1940 which have uninsulated walls, original windows, outdated mechanical systems and poor air tightness. This number increases to over 80,000 regional houses in need of significant energy retrofits when including houses built prior to 1970. If every home built prior to 1940 was retrofitted to the REEP House standard, the Waterloo Region would see an annual energy use reduction of almost 816 million kWh (3 million GJ) and a carbon emissions reduction of over 130,000 tonnes. In addition, each of these homes would then be net zero ready, as technology and market acceptance evolves for alternative energy products. The retrofitting of existing homes is even more relevant when we consider also that each home embodies roughly 300 MWh of energy in its construction alone. The potential for efficient re-use is enormous.
Ownership and Management of REEP House
The driving force behind REEP House retrofits is REEP Green Solutions, a community-based not-for-profit organization that delivers environmental programs and services to Waterloo Region residents, with a focus on spurring uptake of energy and water efficiency. REEP entered into an agreement with the Region of Waterloo to lease two houses owned by the Region and retrofit them to varying standards. Once completed, the 30/50 House was to be returned to rental housing, while REEP Green Solutions would retain management of REEP House.

REEP House is currently open to the public and serves as a forum for tours, presentations, education and continuing research into residential retrofits and sustainable living initiatives. As the primary local provider for the hugely popular ecoENERGY Retrofit-Homes program, REEP sought a way to educate and encourage area homeowners to go beyond the typical “easy” recommendations when retrofitting their homes. By demonstrating how a hundred year-old double brick home can be turned into a state-of-the-art low-energy house; REEP seeks to be a catalyst and inspiration for dramatically improved performance of our existing housing stock. Though the REEP House is presently used for public tours, it is modelled for performance when occupied by a family of 4, using NRCan's HOT2000 modelling software.

Integrated Design Process
From the outset, REEP sought to pursue a collaborative design process that incorporated the exceptional local resources in education and private sector innovation. A design committee was created drawing from University faculty, engineering consultants, contractors, environmental consultants, REEP staff and local stakeholders with expertise in energy and water efficiency to serve as a sounding board and guide for the design process.

Local sustainable design firm, Whiting Design, was retained as the project architect, based on their depth of experience with green building and residential retrofits as well as a desire to create a “Made in Waterloo Region” solution. Ball Construction, a local builder with extensive experience in LEED buildings, was hired as construction manager to oversee costing and guide the building process. Specific expertise in building science, solar/electrical load management and heritage preservation was sought for the design committee. An education committee was also formed to guide the outreach and community engagement programs and to integrate these considerations into the design.

Numerous design committee meetings, community forums and design charrettes established the parameters for the project. All stakeholders were present for design committee meetings, and broader stakeholder groups were engaged on a regular basis to brainstorm, gather input and
inform the design process.

**Guiding Principles**

Following the concept of sustainable living, the following guiding principles, were established:

- To demonstrate sustainable living behaviours and the difference they can make in a person’s impact on the environment.
- To identify ways to showcase lifestyle/behaviour choices dealing with:

  - Energy use
  - Water use
  - Waste reduction, recycling and composting
  - Indoor air quality
  - Landscaping alternatives and stormwater management
  - Local economy, materials and trades
  - Products that embody the least energy and production impact, as possible
  - Water conservation and water quality protection
  - Renewable Energy: To reduce the impact of the energy we use.
  - Minimizing construction waste
  - Using and promoting existing certification systems for products and buildings
  - Showcasing a variety of options suitable for different housing types and price ranges
Sustainable Site Measures

WALKABILITY/TRANSIT ORIENTED DESIGN

The house is in an established urban area within walking distance of the downtown core of Kitchener, Ontario. The house is also a close walk to the transit terminal, which places it in proximity to the current bus system, as well as the proposed Light Rapid Transit trains scheduled for operation in 2015. In addition, the spine of a cycling trail network passes within a half city block of the house, providing excellent connection to the local bike trail system. There are extensive local amenities available within walking and cycling distance, including bookstores, cafes, public library, and farmer’s market. A key element of promoting sustainable living is the use and enhancement of existing infrastructure and amenities, and increasing urban density.
WATER MANAGEMENT
On the house site itself, there are several unique features addressing water management and sustainable landscaping. The driveway and parking area feature permeable pavers, linked to a drainage and filtration system which addresses potentially harmful runoff with a biofiltration layer, thus protecting local groundwater and a nearby surface drainage creek. The entire remaining site is xeriscaped, with no municipally-supplied water used for watering or maintenance. In the backyard, a rain garden captures runoff from 25% of the roof area and slowly disperses it into the ground. The rear cistern is plumbed to use captured water to help flush a 3 litre toilet in the house. The front cistern is connected to a gravity fed drip irrigation system that serves the drought tolerant native habitat garden. The entire rainwater load on-site is either directly infiltrated back into ground water or re-used for house related functions.

Heritage Preservation (Cultural Sustainability)
It is worth noting the historic nature of the neighbourhood and the proximity of the house to the Victoria Park Heritage district in Kitchener. Great care was taken to not radically alter the outward appearance of the house and to preserve and celebrate its historic, durable, sustainable approach to design and construction, typical of the early 20th century. Double brick walls were left exposed, re-pointed and cleaned where required. Window styles and colours are in keeping with the original design. Many trims and outdoor features were either repaired or replaced versions of the original, with non-toxic finishes used and a regular maintenance schedule established. The idea of refreshing old housing stock with both performance and aesthetic concerns, addresses building durability and the question of how to maintain healthy urban cores in our cities. Great care was taken during construction to preserve a large mature maple in the
front yard and a mature white birch tree in the rear yard, with an arborist retained to prune for health and longevity.

**Demonstration and Education** - Engaging the public.

One of the early challenges in establishing the design principles for REEP House was how to show alternatives in the context of a single, optimized design solution. Since the primary goal of the project is education of the public about sustainable retrofit options, the unique example of this house is not applicable to many other situations (i.e. wartime housing, varied budgets, building orientations, construction types, etc.) REEP House is a departure from the “single ideal” engineered approach, because it demonstrates a variety of solutions for each retrofit challenge. One example of this approach is the two parallel heating systems, a wall hung boiler with hydronic distribution and a ground source heat pump with forced air distribution. Both systems are appropriate solutions and by installing both, the public is able to compare them side-by-side and make informed decisions based on their own needs. The dual heating options present an opportunity to run the house on different systems for the sake of experimentation to determine the true costs and benefits of one system over another, in a controlled manner.

The windows also demonstrate a variety of approaches, including tight fitting wooden storm windows, wood framed double-glazed styles, a retrofitted stained glass unit, and the standard use of fibreglass framed triple glazed units with optimized coatings for solar exposure.

REEP House is designed to host public workshops and to be a meeting place for industry participants to engage and educate homeowners about green retrofit options. The main floor was opened up to be a meeting room, with facilities in place to host groups, make presentations, and conduct tours.
**Energy Efficiency** – The core of the project

REEP House is designed to achieve a 90% energy reduction. This was an ambitious target and one that would allow the remaining 10% to be within the realm of affordability, in terms of alternative energy, enabling net zero if REEP were to pursue such a course in future years.

### Annual Energy Savings Breakdown

<table>
<thead>
<tr>
<th>Component</th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td><strong>Walls</strong></td>
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<tr>
<td>6” polyurethane spray foam (R-38)</td>
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<tr>
<td><strong>Basement</strong></td>
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<tr>
<td>6” polyurethane spray foam (R-38)</td>
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<tr>
<td><strong>Attic</strong></td>
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<tr>
<td>4.5” polyurethane foam, 4” polyiso board (R-50)</td>
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<td><strong>Air Leakage</strong></td>
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<tr>
<td>Overall air tightness of 1.8 ACH @ 50 Pa</td>
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<td><strong>Windows and Doors</strong></td>
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<td>Various high performance options</td>
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**Heat Loss Through Building Envelope**

- **Walls**: 6” polyurethane spray foam (R-38)
- **Basement**: 6” polyurethane spray foam (R-38)
- **Attic**: 4.5” polyurethane foam, 4” polyiso board (R-50)
- **Air Leakage**: Overall air tightness of 1.8 ACH @ 50 Pa
- **Windows and Doors**: Various high performance options

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**Heating System Option 1**
- 95% high efficiency boiler only

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**Heating System Option 2**
- Ground source heat pump only

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**Water Heating**
- Tankless water heater and drain water heat recovery

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*Gigajoules (GJ)*
It’s about the building envelope.

Three essential ingredients to any energy retrofit are:

1/ Insulate to a very high level (double building code).
2/ Seal the house tight.
3/ Utilize space efficiently to keep the house small.

If you achieve these three goals, you can turn nearly any modest home into a near net zero energy home.

More specifically, if you can achieve the following numbers:

1/ Insulate using the 5/10/20/40/60 targets (actual levels of house in brackets):
   - Windows   R5     (R3-R7)
   - Basement Slab R10   (R13)
   - Basement Walls R20   (R27)
   - Main Wall   R40   (R39)
   - Roof       R60   (R58)

2/ Seal it up to achieve an ACH of 1.5 or better at 50Pa (using the standard NRCan blower door test).
   REEP House achieved an ACH of 1.9. It is estimated that without the educational “truth windows” we could achieve 1.5 or less. *Truth windows are cutaways in the walls and roof which expose the layers behind the drywall, showing framing and insulation.*

3/ By small, we mean below North American average. Average is 2400 square feet (223m2), which is double the 1950 average. REEP House is 1540 sf which was a large house in its era. Several strategies are employed to increase usable, livable space within the existing building envelope, and to use the existing space very efficiently.

REEP House achieved an 87 on the EnerGuide scale, outperforming most modern homes. With the addition of on-site renewable energy sources (solar PV and solar thermal), the end target is a 92. Prior to the retrofits, the house was rated at a 49, which is typical of unimproved houses of this type and age.
Insulation
Insulation can be done either by external wrapping, cavity retrofitting (as in the example of the 30/50 House next door) or by gut retrofitting. Exterior insulation was ruled out due to the desirability and durability of the existing historic brick exterior, as well as complications with extending windows, door jambs and overhangs. Cavity retrofitting could not achieve the performance numbers of the deep retrofit goals, with only 1-2” of space behind the plaster and lathe. REEP House is insulated as a gut retrofit from the inside in the following manner:

Basement Slab:
The existing 3” concrete slab was removed. The basement was excavated 8” deep over the floor area, with a 12” x 12” deep drainage trench added at the perimeter. Two inches of rigid polystyrene with taped joints was added to the floor area, with care taken to ensure continuity around the edge of the new slab to tie into the wall insulation. A new four inch high fly ash content concrete slab was added, with embedded radiant heat PEX tubing.
Next door to REEP House, a simpler predecessor project was undertaken to demonstrate the benefits of retrofitting without gutting the interior of the house. The goal was to achieve a 50% energy use reduction, for a budget of $30,000 or less. With this limited budget, a gut retrofit is not feasible.

The house is a double brick century home, with plaster and lathe on the interior, nearly identical to REEP House, and typical of homes this age. The exterior brick was in excellent condition and there was no desire to cover it. The interior of the house was repaired and maintained as is, with the original plaster and trims. The only available opportunity for improving insulation is a small gap, varying from 3/4” to 1.5” wide, between the back side of the lathe and the inside face of the brick. (see illustration)

The primary challenge of retrofitting this space is that it is small, quite irregular, and often blocked by strapping, solid wood blocking for cabinets and trims, excess mortar on the backs of bricks or fallen to the bottom of the cavity, and plaster “keys” with similar fates. The space is too small for cellulose or other loose type insulations, which need to circulate freely to achieve even distribution and are better suited to cavities 3” and larger. Conventional expanding spray foams cure quickly and thus block cavities before they are completely filled. The only available option was a pour fill type expanding spray foam which flows freely prior to curing, and is better at filling all the nooks and crannies. The foam was injected through 1/2” holes drilled from the interior through the plaster on roughly 16” centres. Additional fill holes were drilled in areas known to have obstructions (i.e. behind kitchen cabinetry).

The R-value of the added spray foam is 4.5 per inch. With the foam averaging 1” in thickness, this is a relatively small increment in thermal resistance. However, the primary benefit was in improving air tightness significantly: air changes per hour (ACH50) were reduced by 34% (from 11.7 to 7.7) and the reduction of equivalent leakage area (ELA) was reduced by 30% (from 281 in2 to 197 in2). Many visitors to the house noted its significantly increased thermal comfort due to reduced drafts. Wall insulation was the single greatest factor in the reduction of energy use, with increased attic insulation (from R24 to R60), basement wall insulation (to R24) and a new furnace (96.5 % efficient natural gas forced air) accounting for the majority of the remainder. The house energy use was ultimately reduced by 60%, for a budget of $28,500.
**Main Walls:** All existing plaster, lathe and wood strapping was removed to expose the back of the double brick. New 2 X 4 inch FSC certified wood studding was set one inch off the back of the brick, on 24” centres using advanced framing practice to reduce wood use. Perimeter floor boards and ceilings were removed to allow full access to headers and reduce thermal bridging. Wood was used to take advantage of its reduced thermal bridging relative to steel, as well as to provide a reliable attachment point for future installations of cabinetry, shelving, etc.

Continuous closed cell spray foam was applied to the entire wall area and tied in with window boxes, headers, and service penetrations. A high recycled content drywall and zero VOC paint were used as finishes.

**Rafters / Roof assembly:** The spaces between rafters were insulated with a closed cell spray foam (5” rafters x R6 / inch = R30). The existing planking and shingles were left in place. The shingles, being a free layer of waterproofing “insurance,” would otherwise have gone to landfill. A layer of 4” one-side sheathed structural insulated panels (SIP) with polyiso insulation (+R28) was added on top of the existing roof using SIP screws, fully sealed with ice and water shield, and then Enviroshake recycled composite shingles were applied. It is worth noting that due to the added thickness of the roof profile, fascia boards needed to be rebuilt to the new depth.

**Windows and Doors:** Twelve of the 15 windows were replaced with double and triple glazed, fibreglass framed units from Inline Fibreglass, all with advanced coatings from Cardinal Glass, which are optimized to their new location and solar orientation. The average R value for these windows is R6. Three windows were used to demonstrate different options: an original condition, single-glazed wood frame, double-hung with an aluminum storm frame; a custom-manufactured, double-glazed, wood framed arch top with an integrated stained glass pane; and an existing stained glass picture window, retrofitting with a double-pane glazing, using the original frame. The two exterior doors are a solid wood front door with double-paned stained glass inset window (approx. R4), and an insulated fibreglass shell and frame back door.
The improved air tightness reduces energy demands of the house so dramatically, that the need for a heating system is considerably less than that of a typical home. One of the greatest challenges was to find a system that was scalable to the heat loss characteristics. Another challenge was to demonstrate systems which are more advanced and have more potential than conventional forced air natural gas furnaces.

Mechanical cooling was considered and determined to be unnecessary given the high insulation values, the tightness of the building envelope, the advanced window coatings, the thermal mass of the double brick structure and the shading from mature deciduous trees. Heat recovery ventilation and moderate humidity control is provided by an energy-recovery ventilator. Ceiling fans in all rooms provide air movement and increase occupant comfort on warm days.

The primary heating system is a Viessman Vitodens 100 wall-hung boiler, which has a heating capacity much greater than required for the house. It is the smallest unit available and has an advantage in the ability to modulate down to 24,000 Btus, which is 20% greater than the design heat loss of the house. The heat from this boiler is distributed through radiant PEX piping in the floors of the basement and ground floor area, and through wall radiators on the second floor.

Water distribution with a pump uses one sixth of the energy consumed by the fan in typical forced air systems and can be zoned easily. Radiant heat has the advantage of increasing occupant comfort and the perception of heat, enabling lower thermostat settings. Homeowners will often feel cooler in homes heated with forced air because the blowing air is perceived as being cooler. Radiant heat conducts directly into the body and is perceived as feeling warmer. It also has the potential to be tied in to a solar hot water system in future, with
rough-ins provided to ease such integration. The primary disadvantage of this system is its cost, which is approximately double that of a conventional forced air gas furnace.

An entirely separate secondary system is also installed. Late in the design phase of the project, a local company stepped forward to donate the majority of a ground source heat pump system. It was decided that this presented an opportunity to showcase and explain this popular and promising technology to homeowners. While the smallest available system is oversized for the REEP House energy demands, it effectively demonstrates the most efficient heating technology available on the common market today. It also shows the challenges and advantages to retrofitting a forced air duct system to a century home in comparison to the hydronics associated with the boiler. REEP has taken this opportunity a step further and plans to run each system independently for a year to compare energy usage and performance.

**Water Efficiency**

Water efficiency is split into two primary categories; site water and domestic water. Site water is managed in a way to minimize, if not entirely eliminate site runoff and to use it productively where possible. Two large rain barrels collect roof drainage with a total capacity of 1,900 litres. This will effectively contain all but the largest stormwater events (approx. 2% of all such events), if the tanks are emptied on a regular basis. The remainder of the site is designed as a naturally infiltrating surface utilizing rain gardens or permeable paving with deep layers of aggregates to manage stormwater run-off. Stored rainwater will be used in outdoor irrigation for landscaping and gardens, and directed inside the house for greywater system re-charging and toilet flushing.

Domestic water use is reduced significantly through a number of measures. All sinks and shower heads are fitted with low-flow faucets and shower heads. Both hot and cold plumbing runs are minimized by stacking the water service in the basement, the kitchen and the washroom directly above one another. This reduces the “let the water run” factor with occupants waiting for either hot or cold water from their taps.

A greywater system provides drain water capture, filtering, treatment and re-use from sinks and shower. This water is then recycled for toilet flushing. During the warmer season, rain water is used to recharge the greywater system, ensuring that all toilet flushing can be from renewable sources for at least eight months of the year. All fixtures benefit from home run plumbing systems to allow for future rain and greywater use, as permitted by the municipality. Home
running the plumbing allows any fixture in the house to be connected to alternate water supplies, by isolating the supply to each fixture and terminating it in proximity to municipal, rainwater, and greywater supplies in the house.

Living Small

As a principle, the simplest way to make a reduction in energy and other resources is to live in less space. A smaller area of conditioned space means less air to heat and cool, fewer building materials are consumed in its construction, less land is utilized and fewer infrastructures are required to support it. This is also one of the most difficult reductions to achieve, as it asks for dramatic lifestyle adjustments for most homeowners.

Forgoing luxuries like walk-in closets, four-piece and en-suite bathrooms and sitting areas in bedrooms, are merely a starting point. Getting creative about multi-functional use of space, smart storage, efficient layouts, and maximizing overlooked opportunities is essential.

It is worth noting that in super insulating the walls of REEP house from the interior, some usable floor space was lost. The existing 1.5” air space and 1.5” of framing, plaster, and lathe was replaced with a total of 6” of new framing, insulation and drywall. This effectively reduced each room by 3” in two directions, resulting in a net loss of 47 square feet of usable floor area. It is also worth noting that by removing several partition walls and optimizing layout towards a more open plan and efficient bedrooms and closets, we were able to gain a total of 24 square feet back, for a total net loss of 23 sf.
REEP House takes full advantage of two typically under-utilized spaces, the basement and the attic.

The basements of older homes are typically relegated to house the furnace and water heater, and serve storage that is less than ideal (i.e. damp). With a properly drained, insulated, conditioned and finished basement, we effectively add an entire new floor to the house. Bedrooms, home offices, proper storage and play areas are now all enjoyable and healthy uses for this once forgotten area.

In REEP House, the basement slab was removed, then perimeter drainage and a sump pit were installed on the interior of the stone walls, and a new insulated slab was poured, with integrated hydronic heat tubing.

Walls were clad in a drainage layer (using dimple board), insulated to R24 with closed cell spray foam and clad with paperless drywall to discourage mold growth. Two south facing windows were enlarged to increase natural lighting, passive solar gain and to allow a legal egress for bedroom use.

Attics are often under-utilized and poorly-designed spaces. The Ontario Building Code (OBC) requires a vented roof assembly, so insulation is typically placed at the level of the second floor ceiling with venting often improperly installed at the soffits, ridge and along the lower rafters where they intersect the insulated building envelope. This ceiling insulation is then penetrated by an attic hatch and can be compressed by the installation of plywood or planking on the attic floor to allow accessand storage. Unconditioned attics represent a massive source of heat loss and heat gain, causing freezing in the winter and heating in the summer.

REEP House used an unvented roof assembly, which is permitted under a recent OBC ruling and considered by building scientists to be a superior assembly. This pushes all variables of temperature and moisture to the building perimeter, which is its proper position in the building envelope. With the building envelope now pushed up to the level of the rafters, a finished, conditioned attic becomes part of the usable space. In one half of the upstairs the attic was
exposed to create a cathedral ceiling, allowing for exposed collar ties and a high ceiling fan, which creates a spacious feel from two small rooms. The other attic area is finished with drywall and a plywood floor which can be accessed by a comfortably sized hatch with a drop-down ladder stair. This substantial volume of area is now available as conditioned, dry storage.

On the **main floor**, all walls were removed to create one large, open space which can serve a variety of functions. In the case of REEP House, this room is available to host groups of up to 20 people for educational seminars and tours.

As a home design this type of space permits an expandable dining area, open lines of sight from kitchen to living space and additional light, which makes living in a smaller space more pleasant.

The kitchen layout is small and efficient. The traffic pattern from front to back of house and basement access is minimized, allowing more space to be used for furnishings and living areas. A new large window is installed facing the back yard, creating a sense of openness, light, and connection with the outdoors.

Since the retrofit has been completed, the annual performance numbers are modelled to be:

- **an 86% reduction in energy use**
- **an 85% reduction in annual energy costs** (annual utility bill of $336.00)
- **a 54% reduction in carbon emissions**
Comparison to Passive House Standard

The post retrofit annual energy use is 27,011 MJ / year (7503 kWh), including heating, cooling, electrical load, and hot water. Since the house is 161 m², including the basement, this represents a value of 46.6 kWh/m² annually, which far exceeds the Passive House standard of 120 kWh/m². The air tightness of 1.9 ACH@50Pa falls short of the Passive House requirement of 0.6.

Energy Savings 86% 153,062 MJ/yr

Cost Savings 85% $1,894/yr

Carbon Savings 54% 7.6 tonnes/yr

Space and water heating energy and emissions savings modeled using Canada’s EnerGuide Rating System. Savings based on combined use of ground source heat pump and high efficiency boiler unless noted otherwise.
Conclusion

REEP House is a demonstration that deep energy retrofits to brick century homes are possible without compromising the historic nature and appearance of the house. By concentrating on a detailed, comprehensive approach to the building envelope from the inside, all of the original, durable qualities of the house were preserved while dramatically reducing energy usage. The retrofit was achieved using local trades and primarily locally-sourced materials, including many re-used finishes. This is key to the replicability of the project in that most, if not all, of these resources are available in most Canadian municipalities. The ongoing use of REEP House as a public meeting space helps to demonstrate the concept and educate the public in a real, hands-on manner, which is important because thousands of similar deep retrofits will be necessary to achieve significant energy reductions on the national level. An unexpected success of the project is the management of 100% on-site stormwater through the use of permeable paving, cisterns and rain gardens. This serves as a great example to solve a pervasive problem, which represents a huge cost to many municipalities. Elements such as the retrofitted radiant heat system in the basement and upper floors prove that a century home can become a very high performing residence not only in terms of energy usage, but also human comfort and value. The principle of living small is followed throughout the project, showing that the homes of 100 years ago can be bright, airy and efficient while still retaining their charm and usability within the original footprint. And finally, the house is now prepared for the next 100 years, carrying forward the durability inherent in its original quality construction.