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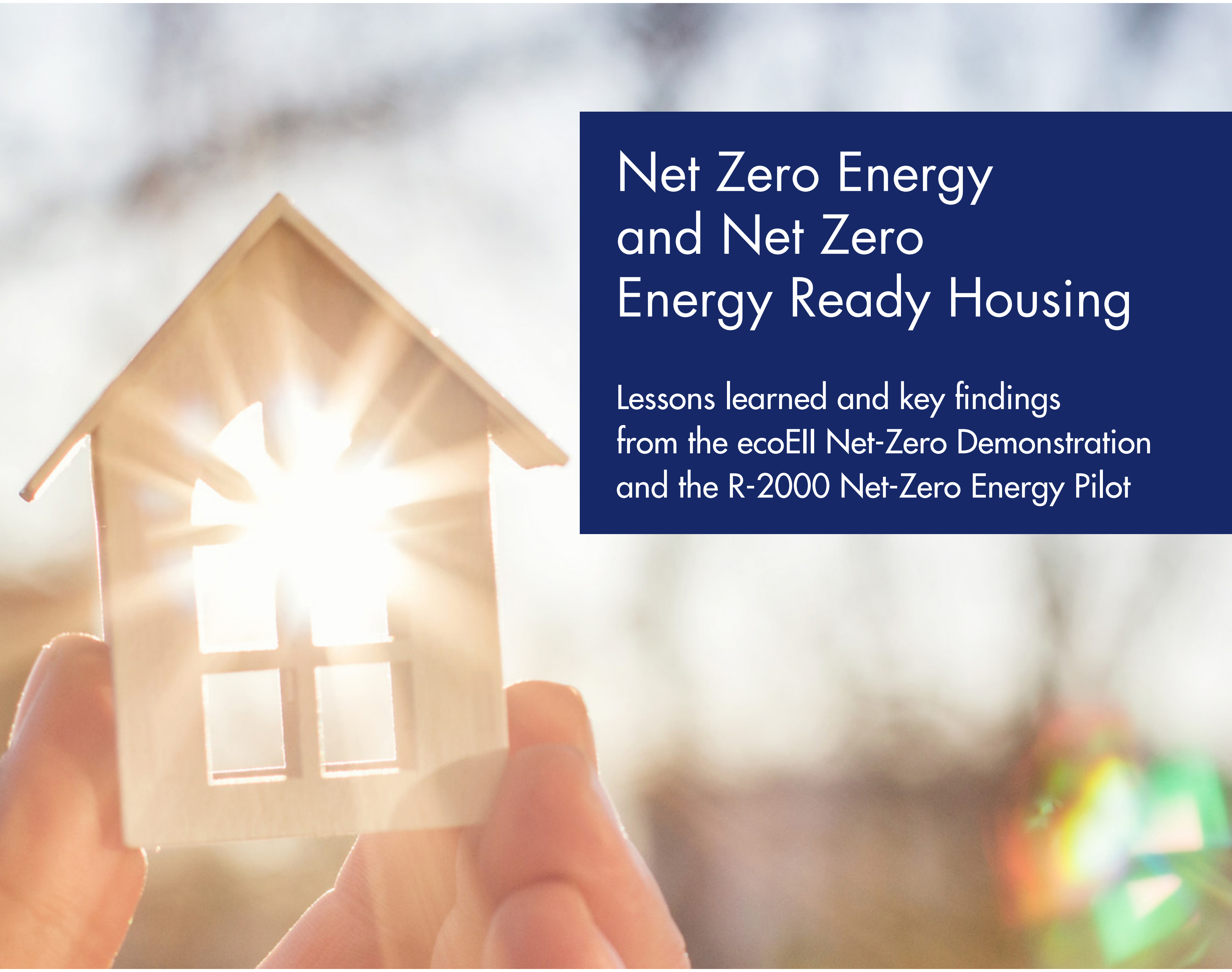

Net Zero Energy and Net Zero Energy Ready Housing

Lessons learned and key findings from the ecoEII Net-Zero Demonstration and the R-2000 Net-Zero Energy Pilot

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1. Introduction

In 2013, Natural Resources Canada (NRCan) launched two initiatives: the R-2000 Net-Zero Energy Pilot (R-2000 NZE) and the ecoEII Net-Zero Energy Housing Demonstration Project (ecoEII).

The **R-2000 NZE** was a pilot program to label Net-Zero Energy (NZE) houses. This initiative drew upon NRCan's "next generation" draft 2014 R-2000 Standard, the EnerGuide Rating System (ERS) and the HOT2000 modelling software, with new procedures that allowed builders to demonstrate that their houses would generate as much renewable energy as they would consume annually. NRCan issued a call for applications for the R-2000 NZE, whereby participating builders constructing high-performance houses received technical support for modelling the energy performance of their houses. Although fifteen builders applied to the R-2000 NZE initiative, only two went on to construct and label one NZE house each as part of the Pilot (Annex A). The remaining builders did not complete the NZE labelling initiative for a variety of reasons, including:

- They opted to withdraw from the Pilot rather than adapt their house designs to meet the Pilot requirements;
- They were unable to meet the final labelling deadline;
- They made use of ineligible technologies; or,
- They did not install the photovoltaic (PV) system required to achieve the NZE performance level.

NRCan's **ecoEII** was led by Owens Corning, with funding support from NRCan's ecoEnergy Innovation Initiative. Five production home builders (Annex A) from across Canada (Nova Scotia, Quebec, Ontario and Alberta) were selected to build net-zero energy market-ready houses. This project saw the builders construct 11 NZE single-family dwellings, one four-unit NZE row house, one NZE MURB (comprised of 6 units) and five NZER houses (this builder applied the initiative's design and modelling procedures but elected not to install the renewable energy systems required to achieve net-zero energy performance). The ecoEII builders, having constructed the NZE houses and MURB units using the same standards, methodologies and tools as those participating under the R-2000 NZE, were also included in the R-2000 NZE Labelling Pilot (outlined above).

Between the two initiatives, a total of 13 NZE single-family dwellings, one four-unit NZE row-house, one six-unit NZE multi-family building and five NZER houses were constructed. For the purposes of this paper, the term 'Pilot' shall refer to all the participating builders of net-zero energy housing, as outlined above; otherwise, each initiative will be referred to separately.

To demonstrate that their houses achieved NZE or NZER performance, Pilot builders had to comply with specific eligibility, modelling, testing and certification/labelling requirements.

The Pilot houses are among the most advanced houses ever constructed in Canada in terms of energy performance. They draw upon 40 years of research and innovation in energy-efficient housing (see Table 1) and benefit from the contributions of Canadian home builders, manufacturers, universities, federal and provincial governments, and the homeowners and early adopters that invested in those houses.

The Pilot houses represent an important step towards the broad adoption of net-zero and low-carbon home design and construction. They incorporate technologies, practices and learnings from the Canada Mortgage and Housing Corporation's EQuilibrium Sustainable Housing Demonstration Initiative (EQuilibrium), Canada's first effort to work with leading builders to plan, design, build, demonstrate and monitor net-zero houses, which were adapted for application in production homebuilding. As such, the Pilot marks a key milestone in moving towards some of the goals of the Pan-Canadian Framework on Clean Growth and Climate Change (e.g. Net-Zero Energy Ready building codes by 2030).

Table 1: Chronology of Canadian Advanced Housing Programs and Initiatives

Year/Time Frame	Initiative/Program
1977	Saskatchewan Conservation House
1980	Super Energy Efficient Homes (SEEH) Program
1982 – Present	R-2000 Program
1991 – 1993	Advanced Housing
1998 – Present	Canadian Centre for Housing Technologies (CCHT)
2005 – 2009	EQuilibrium Sustainable Housing Demonstration Initiative
2007	Factor 9 House
2013 – 2016	R-2000 Net-Zero Energy Pilot
2013 – 2016	ecoEII Net-Zero Energy Demonstration Project
2017	CHBA Net-Zero Home Labelling Program (v1)

This document summarizes key findings related to the design and construction of the Pilot houses, including the experiences of the builders participating in the program, and highlights how the Pilot programs built upon the knowledge gained under EQuilibrium.

2. Definition of a Net-Zero Energy House

For the purposes of this paper, Net-Zero Energy and Net-Zero Energy Ready are defined below:

A **Net-Zero Energy (NZE)** house is a house that produces as much energy from on-site renewable energy sources as it consumes each year. NZE houses are designed, modelled and constructed in accordance with NRCan's R-2000 Net-Zero Energy Pilot technical requirements.

A **Net-Zero Energy Ready (NZER)** house is a variant of the NZE house in which the builders have not installed the renewable energy generation system. NZER homes are also designed, modelled and constructed in compliance with NRCan's R-2000 Net-Zero Energy Pilot technical requirements, but instead of installing the renewable generation systems, builders provide home buyers with a design of a suitable system that would enable the home to reach net zero, and provisions within the home for installing such a system in the future.

The Pilot houses contain a range of proven and commercially available technologies and building practices designed to reduce the amount of energy a house requires to keep occupants comfortable. These houses share three common characteristics:

- **Building envelope measures:** NZE and NZER houses incorporate levels of insulation that generally well exceed current building and energy code requirements, achieve exceptional levels of airtightness and have fewer thermal bridges than code-built houses. With improved windows and insulation and fewer air leakage pathways, these houses reduce the amount of heat lost in the winter and heat gained in the summer, making them much more energy efficient while also keeping occupants more comfortable. The houses are also quieter since outside noise penetration is significantly reduced by the improved envelope.

- **High-efficiency equipment:** NZE and NZER houses use very efficient technologies for space conditioning (heating and cooling), water heating, equipment control systems, ventilation equipment, lighting and appliances (such as ENERGY STAR®), thereby reducing the house's energy needs even further and helping to improve occupant comfort. NZE and NZER houses also incorporate energy or heat recovery ventilators (E/HRVs) to ensure a healthy environment by exhausting contaminates and providing occupants with fresh air to improve the indoor air quality while minimizing energy use.
- **Load reduction measures:** NZE and NZER homes use highly efficient lighting to reduce electricity use and low-flow fixtures to reduce water consumption. Some builders may opt to include high-efficiency appliances as well.

To offset their annual energy consumption demands, NZE houses also incorporate on-site renewable energy technologies such as solar photovoltaics. NZER houses, on the other hand, include provisions to allow homeowners to more easily install renewable energy systems at a later date should they decide to do so.

3. Improvements/Progress/Changes from Prior NZE Initiatives

From a modelling and certification perspective, the lessons and experiences from EQuilibrium led NRCan to introduce two significant changes in the development of the Pilot's requirements:

1. **Equipment performance ratings:** While prior NZE and low-energy demonstrations placed few limits on the technologies that could be used, NRCan introduced a new requirement that all mechanical and renewable systems be modelled in HOT2000, using data from an accepted performance test standard. This requirement meant that an emerging technology that had not been previously tested for use in Canada would be ineligible in the Pilot. The purpose of this requirement was to demonstrate that builders across Canada could utilize readily available technology to build NZE/NZER homes.
2. **Appliance and lighting baseloads:** Previous NZE and low-energy housing demonstration initiatives allowed participating builders to claim significant appliance and lighting load reductions and provided no guidance on how those reductions should be estimated. Post-construction monitoring from the EQuilibrium homes indicated that these homes consistently used more electricity for appliances and lighting than assumed during the design stage. To increase the probability that Pilot homes achieve NZE performance, NRCan provided a prescriptive procedure for estimating appliance and lighting loads. This procedure reduced the eligible load reduction that Pilot builders could claim.

4. Pilot Builder Experiences

Following the completion of the Pilot, NRCan interviewed the participating builders to solicit their observations and feedback on a variety of issues, including costs and affordability, construction practices, regulatory approval and homeowner awareness of NZE/NZER technologies. The following reflects the builders' perspective and experiences while participating in the Pilot initiatives:

Benefits of NZE/NZER housing

The builders participating in the Pilot cited several benefits of building a NZE house, including thermal comfort and a quiet indoor environment for the occupants, and lower annual energy bills that protect the homeowners from future increases in energy prices.

Costs and affordability

Pilot builders offered the following observations about construction costs and pricing of NZE houses:

- **Costs are hard to estimate:** Builders found that construction costs are difficult to determine especially during design, in part because problems and delays arising from the use of advanced technologies and construction methods cannot easily be priced out. One builder noted that the biggest costing challenge they incurred was related to the country of origin of mechanical and solar renewable systems. For example, contractors/sub-trades could only lock pricing offered to the builder for a three-month period because the systems were tied to fluctuating currency exchange rates (between United States and Canadian dollars). Builders may have to charge higher premiums and carry larger contingency funds to manage this risk and some said that they have been able to rapidly refine costing over the first four or five houses.
- **Costs and benefits may not be obvious to buyers:** Builders noted that the higher upfront capital costs associated with NZE/NZER houses may deter potential buyers or steer them towards resale markets. Home buyers traditionally value other more tangible upgrades such as interior finishes and other amenities over energy efficiency. One builder noted that, given the cost of natural gas and electricity (in most markets), home buyers may not be prepared for a long-term return on investment.
- **Resale value uncertainty:** Home buyers, real estate agents and lending institutions are uncertain about the resale value of NZE houses, raising concerns that a NZE/NZER home will retain no more value than a conventional home in future years. The financial and real estate sectors, including house appraisers, realtors and lenders, must quantify and communicate the value proposition in these products to alleviate concerns and enable home buyers to make an informed decision to purchase NZE/NZER houses.

Construction practices

NZE and NZER houses can represent a significant departure from current practices and code requirements. Pilot builders noted that the challenges of moving quickly to NZE housing are particularly acute because builders must address many issues all at once. One builder suggested that a stepped approach towards Net-Zero Energy or Net-Zero Energy Ready might ease the transition.

Costs associated with additional design work, changing practices, obtaining approval and remedying mistakes can quickly erode profit margins. Pilot builders reported the following challenges:

- **Training:** NZE/NZER houses use building envelope systems whose components and assembly steps differ from typical practice. Even though most Pilot builders used off-the-shelf components from a major insulation supplier, builders reported that trades training remained a challenge. Subcontractor training on the installation/construction details of building high-performance houses can represent a significant investment for builders. Participants are also concerned about retaining trades—builders may have to provide continuous training as subcontractors move from job to job. If NZE/NZER houses are to become widespread, builders need skilled labourers trained in building high-performance envelopes correctly and at fair prices. Despite these challenges, one ecoEII builder reported that trades and training costs dropped between each of the net-zero homes they built. After five net-zero homes had been built, they found that building a net-zero home required no more construction time than their standard product.
- **Quality control:** Quality control is critical in achieving high-performance and NZE/NZER housing. For example, poor attention to detail can create air-leakage pathways, which can make it difficult or impossible to achieve airtightness targets and increase the future risks of condensation in wall assemblies. Mistakes can be difficult and expensive to remedy. Pilot participants spoke about the importance of trained site supervisors with experience in the construction of low-energy and NZE/NZER housing. In particular, supervisors require skills in integrating the various NZE/NZER technologies and assemblies (e.g. house as a system), and scheduling and coordinating the various trades to avoid unintended consequences.
- **Scheduling:** Aside from the obvious increase in construction timeframes due to the installation of additional insulation levels throughout the building enclosure and achieving quality control measures such as airtightness testing, NZE/NZER construction introduces new scheduling challenges that builders must accommodate. For instance, trades that do not normally interact in conventional construction practices may be on site at the same time and may be unsure about how to complete interdependent tasks. If not coordinated in a timely manner, additional inspection of the PV system installation and grid connection by the Electrical Safety Authority (ESA) could impact and delay the scheduling of downstream activities, including inspections by municipal code authorities and blower door testing.

Code authority and Local Electrical Distribution Company (LDC) approvals

Building inspector education: NZE and NZER technologies differ from standard practices. Code authorities and building inspectors may be unfamiliar with NZE approaches and require additional building science training to understand and mitigate unintended consequences. For instance, Pilot builders reported that municipal inspectors expected to see polyethylene vapour retarders in place during framing inspections, even though those details are not recommended for advanced wall assemblies with low and impermeable external sheathing and integrated air barriers.

In addition to these challenges, some municipal architectural planning committees and bylaws prescribe limits on how and where photovoltaics (PV) can be installed. For example, municipal code authorities instructed one Pilot builder not to install PV on facades facing the street. This could be a major impediment to NZE if, for instance, the street side is the optimal orientation for PVs.

A NZE home's most visible characteristic—photovoltaics—also poses particular approval challenges:

- According to some builders, the Local Distribution Companies (LDCs), that is, companies responsible for distributing power from transmission lines to people's homes, were slow to approve grid-connected PV installations; some builders reported waiting months for permits to arrive.
- Builders observed that some LDCs may be unfamiliar with the bi-directional, net-metres used in NZE houses even though these metres may have been mandated in provincial legislation for their province.
- Electrical trades may be unfamiliar with ESA inspection procedures and timelines for grid connections.
- In some service areas, LDCs may be unable to connect photovoltaics to their current grid infrastructure. One Pilot participant reported that the LDC was unable to accommodate grid-connected PV, preventing the builder from meeting the Pilot requirements.

Homeowner awareness of NZE technologies and their benefits

Pilot builders generally agreed that homeowner awareness of NZE technologies, practices and benefits has not kept pace with industry. Home buyers generally have not equated the benefits of NZE/NZER houses, such as improved long-term thermal and occupant comfort, improved air quality and significantly reduced operating costs, with the higher initial capital investment costs. Based on their home buyer preference survey, one builder noted that home buyers expressed concerns around equipment maintenance requirements, lifespans (especially for solar panels) and replacement costs, and whether the home needed to be operated differently from conventional houses. In addition, the rules and regulations surrounding net-metering and grid connection are not clear to homeowners. This is an important issue for home buyers who want to understand their utility bills before they buy a new home.

House design – Improvements through iteration

One of the ecoEII builders, together with their energy consultant, continued to streamline and evolve the design of each successive house in the initiative, thereby driving down construction costs and cycle time. For example:

- By reducing XPS exterior wall insulation from three inches (75 mm) to two inches (50 mm), a builder was able to greatly simplify their wall design. The thinner wall profile enabled the builder to use standard fasteners, brick anchors and foundation ties instead of more expensive speciality hardware. The foundation could also be constructed one inch (25 mm) thinner while still supporting the brick veneer. Savings on hardware, labour and concrete amounted to a \$3,000 to \$5,000 cost reduction.
- The mechanical system was optimized by switching the all-electric premium heat pump (in the initial house design), which can operate at temperatures below -20°C, to subsequent house designs that incorporate a small-capacity hybrid gas furnace with an integrated electric heat pump, providing cost savings of up to \$6,000. In this hybrid system, the heat pump delivers heat efficiently at milder temperatures (above -15°C), and switches to the gas furnace in colder weather.

- Targeting the house airtightness levels to between 1.0 and 1.5 air changes per hour (at 50 Pa) resulted in a time and labour reduction of approximately 40 hours of work and a cost savings of approximately $2,000.
- The original HWHP, which was very costly to install and operate, was replaced with a natural gas condensing unit with a 60% DWHR, saving approximately $2,000.

The final two (out of five) NZE homes reached their "sweet" spot, balancing between the insulation levels, airtightness and amount of PV in order to significantly reduce costs from the first house built and maintain relatively equivalent modelled performance. NRCan's R-2000 NZE technical protocols prevented the trade-off of building envelope performance for renewable energy systems (such as PV) and ensured that the envelope performance alone provided at least a 33% improvement in the home's energy efficiency compared with the building code.

Having embarked on building NZER houses in nearly all of their new developments, the builder recommended incorporating dual-fuel (electricity and natural gas) heating systems in NZER houses as the cost to operate the electric air-source heat pumps can be prohibitive.

5. Observations from the Pilot

Based on examination of the Pilot home designs and feedback from builders, several observations about the current state of NZE home design are highlighted below.

Principles of NZE/NZER house design

The Pilot builders used the same design principles as other NZE and low-energy housing demonstration projects:

1. Design and construct a well-insulated and well-air-sealed envelope.
2. Use highly efficient equipment and appliances such as LED lighting and ENERGY STAR equipment, and conservation measures such as low-flow fixtures and smart thermostats to reduce the consumption of energy within the home.
3. Ensure the correct sizing of heating, hot water and ventilation equipment for a very efficient home (i.e. small loads).
4. Install on-site renewable energy (for NZE houses) or prepare the house for future renewable installation (NZER).

A key achievement in the Pilot was to demonstrate that these principles are relevant to the design of production-oriented housing and that they provide a pathway to cost-effective NZE performance using off-the-shelf technologies.

Attributes of the Pilot houses

Table 2, below, highlights some of the key building envelope and mechanical system attributes common to the Pilot houses and provides a range of performance levels that the various Pilot builders adopted in attaining their respective net-zero energy design. The minimum requirements (where applicable), as outlined in the 2015 National Building Code of Canada, are provided for reference purposes only. The design characteristics and specifications incorporated into a sampling of the Pilot houses are provided in Annex B.

In most instances, the minimum performance levels in the NZE houses exceeded the minimum National Building Code (NBC) requirements. All of the attributes of the NZE houses, taking into consideration their respective climate zones, significantly exceeded those outlined in the NBC.

Table 2: Range in Performance Levels for Various Attributes in NZE Pilot Houses

Attributes	**NZE Pilot Ranges**	**2015 National Building Code[1]**
Airtightness (ACH @ 50 Pa) – 1.5 ACH_{50} maximum prescribed	0.43 – 1.5	2.5 ACH_{50}[2]
Roof/Attic RSI (R-value)	9.3 – 15.12 (R-53 – R-86)	6.9 – 10.43[3] (R-39 – R-59)
Main exterior wall[4] RSI (R-value)	4.57 – 7.47 (R-26 – R-42)	2.78 – 3.08[3] (R-16 – R-17)
Foundation walls RSI (R-value)	4.32 – 6.37 (R-25 – R-36)	1.99 – 2.98[3] (R-11 – R-17)
Underslab – Above frost line RSI (R-value)	2.64 (R-15)	Unheated floors[3] 1.96 (R-11)
Underslab – Below frost line RSI (R-value)	1.76 – 3.52 (R-10 – R-20)	Unheated floors[3] Uninsulated
Window U-value (W/m²K)	1.15 – 0.94	1.8 – 1.4
Window ER	25.92 – 44.16	21 – 29
Space heating (air source heat pump)	HSPF 7.83 – 9.74	HSPF ≥ 7.0
Water heating (heat pump water heaters)[5]	EF 2.73 – 3.27	Heat pump[1] EF ≥ 2.0
Heat recovery ventilator (HRV) efficiency (@ 0°C/@ -25°C)	67%/60% to 84%/72%	60% @ 0°C 55% @ -25°C
Drain water heat recovery (DWHR) efficiency	42.0% – 58.9%	NA
Solar PV capacity – NZE houses only (kW)	6.2 – 11.2	NA

[1] Values based on climate Zone 4 to Zone 8, respectively, and for houses with heat pumps for space heating.
[2] Air leakage rate assumed in NBC 9.36 performance path; not a mandatory requirement.
[3] Effective thermal resistance values; houses with a heat recovery ventilator (HRV).
[4] All five builders (see Annex A) in the ecoEII initiative exclusively used an exterior insulation system with an integrated air barrier in the building envelope design, a system supplied, manufactured and distributed by Owens Corning, the lead partner in the ecoEII Demonstration. The two builders under the R-2000 NZE Pilot used an insulated double-stud exterior wall assembly and exterior insulated wall assembly, respectively.
[5] One of the builders incorporated a natural gas tankless water heater (having an EF of 0.98) in the design of their NZE house.

How the Pilot houses built differ from previous NZE designs

NRCan examined the home designs submitted under the Pilot and compared them to houses constructed in previous low-energy and NZE demonstration programs in Canada, including the 11 net-zero houses constructed under EQuilibrium. Although the Pilot program dictated some specific requirements, the following comparisons provide insight into how the Pilot builders incorporated technologies and approaches.

- **Simpler mechanical systems:** Analysis of the NZE Pilot designs shows that participating builders relied on using simpler approaches based on commercially available and proven technologies. Whereas prior NZE houses made extensive use of custom and experimental solar thermal systems for space heating and hot water, Pilot builders relied exclusively on readily available technology (e.g. cold-climate air-source heat pumps) and all but one used heat pump water heaters.
- **Cost-effective envelope design:** All of the NZE houses constructed in the Pilot significantly exceed insulation levels required by current building codes and demonstrate enhanced air tightness levels compared with conventional construction. However, the amount of insulation used in walls, attics and below grade was lower than previous NZE housing initiatives. This is likely because a higher efficiency air-source heat pump allowed the thermal properties of the building envelope to be offset while still achieving overall net-zero energy modelling performance. Because the lead partner in the ecoEII project was the project sponsor and insulation supplier, all of the ecoEII builders used the same exterior insulated sheathing and air barrier system.
- **Less reliance on passive solar:** Most of the NZE Pilot participants were production builders of houses in tract-built subdivisions. Limited lot orientations with appropriate south-facing exposures often restricted the ability to optimize passive solar design. Nevertheless, Pilot builders reported that the houses were designed to limit solar heat gains, reducing the risk of overheating and thereby decreasing the energy demand for the cooling of these highly insulated houses. Consequently, the Pilot houses featured smaller south-facing window areas than low-energy and NZE houses constructed in previous initiatives.
- **Greater use of solar PV:** Pilot builders made greater use of solar PV systems, which generate electricity from sunlight. Pilot builders included nearly twice as much PV in their house designs compared to previous demonstration initiatives (e.g. EQuilibrium) on a per square metre (m^2) of floor area basis. One of the key drivers reported in influencing the greater use of PV is the reduction in PV prices; PV costs were more than 50% less during the Pilot than they were ten years before. Increased use of PV is also displacing other solar energy technology. For example, none of the Pilot builders installed solar thermal space heating or solar thermal water heating systems.

Finally, data from the Pilot builders suggest the costs to construct NZE houses are falling. While the costs vary from builder to builder, the median costs to upgrade a code-compliant home to NZE (including the renewable energy systems) under the Pilot were \$340/m^2 (\$31/ft^2). If these houses had been constructed to NZER requirements, their estimated upgrade costs would have been approximately \$164/m^2 (\$16/ft^2).

The observed NZE costs are lower than prior NZE cost benchmarks, including those reported in the EQuilibrium initiative. The biggest factor in this cost reduction is the falling price of PV. At the time of EQuilibrium, PV costs were approximately $10/W installed, while Pilot builders reported average installed costs of $3.50/W.

Analyses undertaken on the NZE Pilot project show that estimated utility bills in NZE and NZER houses are less than similar houses constructed to the 2015 National Building Code. Utility bill savings depend on local energy rates and what kind of house the NZE house is compared to.

- Savings in NZE and NZER are highest when compared to code-built houses with electric resistance heating. In Calgary, Ottawa and Toronto, median utility savings compared to these houses was approximately $2,000/yr when constructed to NZER specifications, and approximately $3,600/yr when constructed to NZE (including PV).
- Savings are lower when compared to gas-heated, code-built houses. Median NZER savings are estimated to be approximately $400/yr, and NZE savings are estimated to be approximately $2,000/yr.

While NZE/NZER houses do save energy and reduce utility bills, there are several reasons why NZE/NZER houses are unlikely to have a $0 utility bill:

- Utility fuel consumption is driven by weather conditions and occupant behaviours and lifestyles that may be outside the envisaged design and modelling parameters.
- Make-up of provincial/territorial utility grids and their associated fuel costs.
- Availability of and rates for ‘net-metering’ and ‘Feed-In Tariffs.’
- Unless the home is completely independent from the grid, homeowners are still obligated to pay fixed charges related to the utility’s infrastructure and administration costs. In a NZE/NZER home, these charges will likely form the largest portion of the utility bill.

Replicability

In Section 4, the participating Pilot production builders identified some very real concerns (such as cost, affordability and construction practices) that appear to increase risks borne by the builder and may slow down the broader adoption of NZE/NZER housing by production builders. Despite the improvements in the Pilot program framework over previous initiatives, the scale of NZE (or NZER) house production is still very much at the “one-off” stage.

To date, the broad-scale adoption of NZE/NZER housing has been inhibited by a number of issues such as selection of appropriately sized heating, cooling and ventilation systems and equipment, a trained and qualified labour force, and an efficient approvals process by the authorities having jurisdiction. Furthermore, current production levels of NZE/NZER housing fall short of the production volumes necessary to benefit from “economies of scale.”

There is a strong likelihood that some of the concerns and issues previously identified by the Pilot builders will be addressed only by stimulating and encouraging increased NZE/NZER house production levels and the continued development of cost-effective and reliable technologies and practices. Despite these concerns, Pilot builders continue to streamline their house designs and construction processes, and one builder has embarked on building nearly all of their new housing developments as NZER.

6. Future Work

While the Pilot demonstrated that NZE/NZER housing could be constructed affordably by production builders using off-the-shelf, commercially available products and technologies, some obstacles remain that hamper the broader adoption of NZE/NZER housing.

Monitoring of NZE and NZER houses

The biggest knowledge gap surrounding NZE/NZER houses is the lack of in-situ monitored performance data. While the EQuilibrium initiative included a year of comprehensive post-occupancy monitoring, the availability of independent, monitored data from the Pilot houses is sparser. While some Pilot participants installed monitoring equipment on specific components, the builders followed no consistent instrumentation strategy and data from these homes has not been compiled. The number of homes that approached or surpassed NZE performance is therefore unknown.

Despite the limited monitoring results, the Pilot houses are expected to use much less energy than conventional houses built to meet current energy efficiency requirements. Building envelope measures (including added insulation, upgraded windows, and improved air sealing techniques and procedures) provide consistent and predictable reductions in space heating demand.

There are many factors beyond the builders’ control that affect energy use; however, two factors have a significant impact and effect on a houses’ performance: weather and occupants (including the number of occupants and their behaviours and lifestyle). Both of these factors take on assumed values in the predictive energy modelling software, making it difficult to compare against actual performance. Nevertheless, previous monitoring studies confidently demonstrate that NZE houses use much less energy than a similar house built to code and the best knowledge suggests that the energy use should be close to net-zero energy on an average year.

Long-term envelope performance

NZE homes introduce new technologies that change the way the building envelope behaves—particularly the walls:

- Higher amounts of insulation reduce the amount of heat that flows through walls, affecting the temperatures inside the walls.
- Use of low-permeance insulation materials affects the way moisture moves into and out of wall systems.

In light of these new approaches, some observers in the construction industry have asked, “How will NZE wall systems perform over the life of the home?” Significant evidence suggests that these wall systems are sufficiently durable and resilient for use in Canadian housing:

- All of the envelope materials used in the Pilot are approved by the Canadian Construction Materials Centre (CCMC) and are accepted for use in Canadian construction under CCMC’s guidance.
- Most of the Pilot homes used insulated sheathing wall systems; federal and university researchers have evaluated these systems over the last 20 years.

- Academic researchers and private consultants have used thermal and moisture simulation methods to examine the performance of these systems under a range of climate conditions.
- Variants of these systems have been used as part of low-energy demonstration and labelling programs over the last 30 years (refer to Table 1) and are increasingly used to comply with provincial building code requirements such as the Ontario Building Code, Supplemental Standard SB-12.
- Complementary work by third parties explores variants of these systems, with different combinations of air barrier, sheathing, framing, insulation, and vapour control systems. These systems and recommendations for their use are publically available.[1]

All available evidence indicates that these wall systems are suitable for Canadian homes.

Nevertheless, follow-up on research is warranted. In prior energy efficiency demonstrations (including the R-2000 program), federal researchers have conducted long-term follow-ups on the constructed homes to ensure they continue to meet durability, comfort and performance expectations. Due diligence requires similar follow-up for homes built as part of the Pilot. In addition, emerging insulation materials may offer builders easier and more cost-effective ways to construct NZE homes; these materials and approaches will require monitoring and modelling to verify durability.

7. Concluding Remarks

In the R-2000 NZE Pilot and the ecoEII NZE Demonstration initiatives, a total of 13 single-family dwellings, one four-unit row house and one six-unit residential building were all constructed to NZE performance levels, in addition to five houses constructed to NZER. These houses are among the most energy-efficient houses constructed in Canada and they mark an important milestone towards the broader deployment of NZE and NZER houses.

The houses constructed under the Pilot generally used off-the-shelf technology compared with previous NZE and low-energy housing programs. They incorporate commercially available products in place of customized or experimental energy systems and, while constructing NZE/NZER houses still requires a cost premium above minimum code construction, this incremental cost was significantly lower in the Pilot than in previous low-energy demonstration programs and initiatives.

While Canada knows more about NZE/NZER houses than ever before, additional research is required to support their commercialization:

- The performance of the current generation of NZE/NZER houses has not been verified through monitoring or utility bill verification, leaving some uncertainty about their stated energy savings.
- Emerging materials and approaches that have not yet been tested in Canadian environments may impact envelope durability and should be investigated.
- Additional work is required to better understand and optimize the costs associated with building NZE/NZER housing and improving affordability of these advanced houses for Canadians.
- As these buildings age, researchers should conduct follow-ups to ensure that they continue to meet performance, comfort and durability expectations.

[1] See the Canadian Wood Council's Effective R Calculator (http://cwc.ca/resources/effective-r/)

These gaps can be addressed through ongoing follow-ups. Efforts to monitor energy use, wall moisture, indoor air quality, thermal comfort and occupant perceptions of the living environment, and to reconcile utility bills with the predictive models and tools, will build consumer and industry confidence in NZE/NZER design and technology.

Builders participating in the Pilot commented on the changes that NZE brings to production home building. Their feedback indicates that NZE construction may pose challenges not just to the builder, but also to the sub-trades, building inspectors, municipal code and utility approval departments, real-estate agents, and even home buyers. These groups are unfamiliar with the components within a NZE home, construction schedules and costs, and the benefits NZE housing has to offer. Builders suggested that improved training resources for sub-trades and building approval staff could help reduce costs and delays associated with NZE houses. Efforts to improve awareness among home buyers, the real estate industry and lending institutions would help ensure the market understands the value and benefits of these houses and is prepared to bear the initial upfront investment at this early adopter stage.

While improved awareness and training will provide a foundation for broader NZE/NZER deployment, industry capacity will grow as more builders incorporate NZE houses into their product lines. Increasing participation in voluntary programs and demonstration projects such as R-2000, the CHBA Net-Zero Labelling Program and Passive House will therefore be an essential strategy in meeting the objectives of the Pan-Canadian Framework (PCF). The PCF improves the energy efficiency of new constructions through the development and adoption of increasingly stringent model building codes, starting in 2020, with the goal that provinces and territories adopt a ‘net-zero energy ready’ building code by 2030.

ANNEX A:

PARTICIPATING BUILDERS IN THE R-2000 NET-ZERO ENERGY PILOT

Habitat Studio – Edmonton, Alberta

Sloot Construction Ltd. – Guelph, Ontario

PARTICIPATING BUILDERS IN THE ecoEII NET ZERO ENERGY DEMONSTRATION PROJECT

Reid's Heritage Houses – Guelph, Ontario

Minto Communities – Ottawa, Ontario
Detached House

Minto Communities— Ottawa, Ontario (four units, attached houses)

Construction Voyer – Laval, Quebec

Mattamy Houses – Calgary, Alberta

Note:

Provident Developments Inc. (from Halifax, Nova Scotia) was also a participating builder in the ecoEII project, building five Net-Zero Energy Ready (NZER) houses.

ANNEX B:

Design Characteristics Incorporated in Representative NZE Pilot Houses for Each Participating Builder

Builder	**Habitat Studio (Edmonton, AB)**	**Mattamy (Calgary, AB)**	**Minto – Detached (Ottawa, ON)**	**Minto – Attached (Ottawa, ON)**	**Reid's Heritage Homes (Guelph, ON)**	**Sloot Construction (Guelph, ON)**	**Construction Voyer (Duvernay, QC)**
Heating Degree Day (HDD)	5,120	5,000	4,500	4,500	3,890	3,890	4,200
Roof	R-80 blown/ R-40 flat	R-60 blown	R-60 blown	R-60 blown	R-60 blown	R-60 blown	R-52 to R-60 blown/ R-40 flat
Main walls	R-24 + R-17 (continuous insulation, double-stud)	R-24 + R-22.5 XPS (4.5")	R-24 + R-10 XPS (2")	R-24 + R-10 XPS (2")	R-22 batt + R-15 XPS (3")	R-24 + R-10 XPS (2")	R-24 + R-10 XPS (2")
Basement walls	2" Type 1 EPS	R-14 + R-20 XPS (4")	R-12 + R-15 XPS (3")	R-20 batt + R-15 XPS (3")	R-22 batt + R-10 XPS (2")	R-20 + R-5 XPS (1")	N/A
Underslab	R-15 XPS (3")	R-20 XPS (4")	R-10 XPS (2")	R-10 XPS (2")	R-10 XPS (2")	R-10 XPS (2")	R-15 XPS (3")
Windows	low-E triple-pane	low-E triple-pane	low-E triple-pane	low-E triple-pane	low-E triple-pane	low-E triple-pane	low-E triple-pane
HRV/ERV* 0 °C/-25 °C	84%/72%	84%/72%	75%/70%	75%/64%	67%/60%*	67%/60%	74%/64%
Space heating	ASHP 7.83 HSPF + Elec backup (in ductwork)	ASHP 9.57 HSPF + Elec furnace	ASHP 9.57 HSPF + Elec furnace	ASHP 8.26 – 8.43 HSPF + Elec furnace	ASHP 8.09 HSPF + Elec furnace	ASHP 8.7 HSPF + 97.5% AFUE NG furnace	ASHP 8.87 – 9.74 HSPF + Elec baseboard
Water heating	HPWH 3.27 EF	HPWH 2.78 EF	HPWH 2.78 EF	HPWH 2.78 EF	HPWH 2.78 EF	NG 0.98 EF tankless	HPWH 2.73 EF
DWHR	42%	43.5%	42.8%	46%	53.3%	58.9%	57.3%
Airtightness	0.43 ACH_{50}	0.82 ACH_{50}	1.24 ACH_{50}	1.47 ACH_{50} average	1.13 ACH_{50}	0.93 ACH_{50}	0.75 ACH_{50}
Solar PV	39 x 275 W	40 x 280 W	36 x 265 W	30-34 x 250 W per unit	33 x 265 W	41 x 235 W	150 x 255 W