A Life Cycle Environmental Impact Comparison of 1970s & R2000 House Designs

by Jamie Meil, Vice President, Athena Sustainable Materials Institute

In the winter of 2002, the Athena Sustainable Materials Institute undertook a benchmarking study for Natural Resources Canada (NRCan)[1] comparing the environmental performance of various single-family home designs as typically built in Canada from the 1970s through to the present. This article presents results that show the strides made from the typical practice of the 1970s to the modern home built to R2000 standards.

Results of this study make it clear that both vintages of homes embody significant environmental effects; R2000 homes, however, display greatly improved operating energy performance through their life cycle. Although achieving this improvement requires some additional materials (insulation, for example), and as a result incurs higher embodied effects, these increased effects are modest compared to the life cycle gains of R2000 homes.

Background

The work was part of a long-term NRCan research project to improve the sustainability of Canadian housing by a factor of "4" initially, and ultimately by a factor of "10". The first step was to benchmark typical Canadian housing to establish a reference from which improvement could be gauged.

The focus of the Athena Institute's work was on the embodied environmental life cycle effects associated with the framing and envelope materials of a custom, single-family home for the Ottawa market. The Institute's environmental assessment concentrated on the effects of manufacturing, transporting and installing the "as built" initial structure, partitions and envelope components, as well as the effects of maintenance and replacement over an assumed 30 year life span for the case study homes. The report results did not cover the "end-of-life" disposition of the houses due to the inability to adequately forecast the homes' actual life spans.

The reported results therefore provided a conservative estimate of the total life cycle environmental impacts of constructing and maintaining a home over its life. If all operating energy, interior finishes, furniture, landscaping and recurring renovations had been factored in over the useful life of the house designs, the full environmental impacts would have been greater than reported in the study. However, the results provided a valuable order of magnitude benchmark for assessing various scenarios for reducing the embodied environmental effects of future housing designs.

The analysis results were summarised in six key environmental measures: initial (embodied) energy use; weighted raw material use; greenhouse gas emissions (both fuel and process generated); measures of air and water pollution; and solid waste emissions.

Results were developed in terms of building totals as well as on a per square meter of gross floor area basis. The latter measures are more likely to be used as benchmarks for future design and material selections.

Methodology

Since the early 1990s, the Athena Institute has been developing an environmental life cycle assessment decision support tool, now commercially available as the *Environmental Impact Estimator*. The ultimate objective of developing this specialized software is to assist the building community in making more informed decisions regarding design and material options that will minimize a building's life cycle environmental impact.

The only North American software for the life cycle assessment of buildings, the *Estimator* is capable of modelling 95% of the building stock on the continent. It allows architects, engineers and researchers to assess the environmental implications of industrial, institutional, office, multi-unit residential, and single-family residential building designs. The software covers a building's life cycle stages from the "cradle" (natural resource extraction) through to its "grave" (end-of-life),

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[1] Buildings Group, CANMET Energy Technology Centre

including on-site construction and maintenance. It provides a full environmental life cycle inventory as well as the set of six summary measures mentioned above.

For Canada, the software and underlying databases represent average or typical manufacturing technologies and appropriate modes and distances for transportation. The *Estimator* offers six Canadian regions to choose from — Vancouver, Calgary, Winnipeg, Toronto, Montreal and Halifax — as well as two US regions and a US average. The Ottawa location of the benchmarking study was approximated using Toronto – the Ontario regional indicator.

Design Documents and Bill of Materials Data

The Institute received a set of "as built" drawings for the R2000 reference house located on the National Research Council's property. The project team then developed a design for a comparable house as it would have been built in the 1970s. NRCan subsequently provided various energy simulation results for the two designs.

The following table outlines the major material and design differences between the two house designs.

Material and Design Summary

Building Component	1970s Vintage Design	R2000 House Design
Gross Floor Area	207.4 m^2	207.4 m^2
Design (Mort.) Life	30 yrs	30 yrs
Primary Structure	Wood light frame construction w/ basement	Wood light frame construction, w/ basement
Envelope	2x4 wood studs (GRN), 89mm fibreglass insulation (R-12)	2x6 wood stud (KD), 140mm fibreglass insulation (R-20)
Exterior cladding/ fenestration	Brick / wood operable window, standard dble glazed	Brick / PVC operable window, Low "E" argon dble glazed.
Roofing system / insulation	Light frame wood truss, asphalt shingle, 150mm fg batt (R-20)	Light frame wood truss, asphalt shingle, 375mm fg batt (R-50)

Excluded from the assessment were the following: building site preparation and landscaping; interior finishes beyond initial gypsum board installation; and furnishings.

Maintenance and Replacement Scenarios

For both designs, NRCan stipulated a 30-year life span, which equates to the length of the typical mortgage, i.e., the house is fully depreciated at the end of 30 years. While somewhat arbitrary, the 30-year life provides an initial reference basis for the study. The Institute assumed that the roofing would be renewed every 20 years. Specifically, in year 20, a second layer of shingles would be added to the initial layer. At year 30, the roofing added at year 20 would still have another 10 years of life, so to confine the analysis to 30 years, only half of the materials and their consequent embodied environmental effects for re-roofing were attributed to each design.

Other scenario aspects specific to each design, made in discussion with NRCan, are described below.

1970s vintage design

For this design, the study team assumed the re-roofing schedule described above. In addition, they assumed that the ceiling insulation would be upgraded from 6" (R20) to 8.5" (R28) in year 20 (1990 standard), and that the original wood windows would be replaced at the end of 20 years with PVC windows having both a low "E" coating and argon between the two double panes. By year 30, the team assumed that 12% of the new thermal glazing units would have failed and been replaced (obviously, these failures would not have occurred all at once, but over the 10 year period — for modelling purposes, however, the team selected to model the failures at year 30).

R2000 vintage design
For this design, the study team again assumed the re-roofing schedule described above. They also assumed that at year 20, 25% of the thermal glazing units would have failed and been replaced, and that over the next 10 years (to year 30), 50% of the window units would be replaced. Clay brick should last the life of the building and may require re-pointing, but the team omitted re-pointing since it is likely to be of minor significance.

The table below provides a description of maintenance and replacement timing as well as quantities for both of the house designs.

Maintenance and Replacement Schedule

Description	Quantities
1970s vintage design	
Re-roofing at year 20 (add 2nd layer of shingles–16.6 sq/2 = 30 year impact)	8.3 squares
Replace wood windows at year 20 with PVC, low E argon	34.2 m^2 thermal glass unit 269 kg PVC frame
Between years 20 and 30 12% of thermal units fail and are replaced	4.25 m^2 thermal glass unit
At year 20 add 2.5" (62mm) of fiberglass insulation to roof (R20 to R28)	388.5m^2 1" thick equivalent
R2000 design	
Re-roofing at year 20 (add 2nd layer of shingles–16.6 sq/2 = 30 year impact)	8.3 squares
25% of glazing units fail and are replaced	8.54m^2 thermal glass unit
Replace 50% of original windows with PVC, low E argon	17.1 m^2 thermal glass unit 134.5 kg PVC frame

Detailed Results

Embodied Effects
1970s Design: The project team discovered that each square meter of 1970s vintage housing, built and maintained for 30 years, did the following:

- embodied 2.4 Gj of energy and required 0.6 tonnes of raw materials (weighted);
- produced greenhouse gases equivalent to 350 kg of CO2;
- required 44 cubic metres of air and 15 cubic metres of water to dilute these pollutants to acceptable levels; and
- resulted in 30 kg of solid waste.

From an embodied energy perspective, the structural systems and envelope each account for roughly 50% of the building's initial environmental burden. Together, they account for over 90% of the total embodied life cycle burden, with maintenance and replacement accounting for the remaining 10%. Within the initial structure, the below grade component is the single largest contributor to the environmental load for the structure. The use of both concrete and steel (used in the beams, lintels and columns supporting the wood floor) is the primary reason for the below grade component's greater environmental burden. This is equally true for the R2000 design.

By far, the largest contributing component to the overall energy and global warming results of the initial above grade envelope (as distinct from the initial structure) is the clay brick, followed by gypsum board and insulation materials.

While contrasting the effects of the structural, envelope materials and maintenance and replacement components is useful, the shear enormity of the total energy involved can easily go unnoticed. ***To help humanize the results, the Institute made a quick calculation, which revealed that the life cycle energy embodied in the 1970s home design is equivalent to driving a small car (consuming 8L/100km) a total of 191,000 km, or eight times around the earth.***

R2000 Design: Relative to the 1970s design, the R2000 design embodies about 15% more energy over its life. Both the structure and envelope are more energy intensive due to increasing the exterior wall stud size to 2"x6" from 2"x4", the use of kiln-dried wall studs (rather than green, unseasoned lumber in the 1970s design) and adding additional insulation to both the walls and roof. Generally, the maintenance and replacement embodied effects are lower due to not having to upgrade the roof insulation level or completely replace the window units over the 30 year time line.

Operating Energy

As the table below indicates, annual space heating costs for the R2000 home are only 27% of the costs of heating the 1970s home (a factor of 4 decrease); total R2000 annual operating costs are 42% of 1970s costs, and total 30 year life cycle energy of the R2000 house is 46% of the 1970s figure. The study team estimates that about 50% of the total improvement in operating efficiency can be ascribed to better envelope design, with the remainder being a function of improved HVAC equipment efficiency.

Total Embodied and Annual Operating Energy Comparison Summary

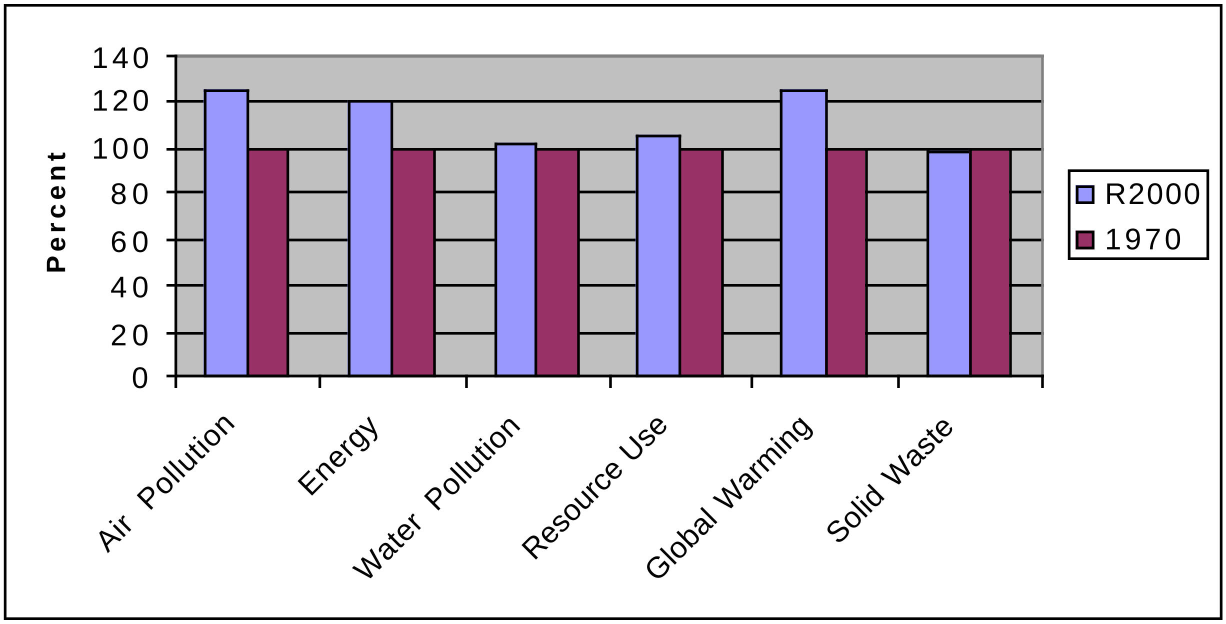
Component	1970s	R2000
Life cycle embodied energy	487 Gj	568 Gj
Annual space heat/AC	249 Gj	67 Gj
Hot water heating	29 Gj	27 Gj
Lights and appliances	32 Gj	32 Gj
Ventilation and fans	5 Gj	6 Gj
Total Annual Operating energy	315 Gj	132 Gj
Total 30 yr Life Cycle Energy (LCE)	9937 GJ	4528 GJ
Total LCE as % of 1970s design	100%	46%

Conclusions: 1970s Design versus R2000 Design

In summary , the results of this study show that the relatively small increases in embodied material effects incurred by building to R2000 standards in Ottawa are more than offset by significant reductions in related operating energy burdens (space heating/air conditioning) over the building's life.

The following chart provides detail on the higher embodied effects that result from building to R2000 standards — the environmental price for achieving impressive gains in operating costs. Note that for each of the summary measures, the 1970s design has been set at 100%, and the R2000 results have been normalized to that benchmark. The R2000 design embodies 20% more energy, emits 25% more air pollutants and 25% more global warming gases. However, when these embodied effects are combined with those of space heating, the Athena Institute's *Environmental Impact Estimator* indicates that the R2000 house design ends up using 60% less energy and emitting 61% fewer greenhouse gases over a 30 year time period.

ATHENA Environmental Impact Estimator Results Comparison of R2000 and 1970 House Designs Across Six Environmental Measures (Normalized to 1970 results)



Contact Information
For more information, please visit the Athena Sustainable Materials Institute website at www.athenaSMI.ca or the CANMET Energy Technology Centre, NRCan, at www.nrcan.gc.ca/es/etb.

Definitions

Embodied Effects: The full range of environmental effects associated with the manufacturing, transportation, use and disposal of building products or components.

Operating Energy: The energy used to heat and cool the space and meet lighting and plug load needs.

NB Operating energy itself has embodied effects associated with the production and transportation of the energy.