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Confidential

Considerations for Environmental Footprinting of Wood Doors

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Abstract

This is a discussion paper addressing the factors involved when considering the total environmental footprint of wood doors. The discussion is within the context of a new amendment to BC energy regulations affecting doors and the subsequent market shifts that will occur as a direct result. The energy regulation applies a U-value threshold to doors. U-value is a physical (thermal) property of an assembly indicating the rate of conductive heat flow through the assembly. A maximum U-value for doors is being specified in BC that cannot be met by the current commonly-manufactured configuration for solid wood doors. In this paper, a life cycle assessment (LCA) approach is used to discuss the broader environmental picture beyond the single criterion of U-value, specifically focusing on the trade-off between embodied energy in a product and the impact of that product on the operating energy of the building in which it is installed. Any change to the current manufacturing process for wood doors for the purpose of improving thermal characteristics should be done within an LCA perspective so that the changes don't inadvertently lead to a net increase in total lifetime energy consumption. Similarly, any market shift to non-wood alternatives for doors should also be done within an LCA perspective for the same reason. A detailed and precise analysis of door footprints requires LCA data and energy simulation results, both of which are beyond the scope of this study. In place of full LCA data, we accessed existing literature and existing partial LCA data (from the Athena Institute) to roughly estimate the embodied energy differences between door types, and to discuss the other environmental impacts of a substitution from today's common wood doors to non-wood alternates. Three generic door types were compared: wood, steel and fibreglass. In all the environmental metrics examined, including embodied energy, the wood doors have the lowest impact. Although insulated steel and fibreglass doors typically have a lower U-value than wood doors, they involve more energy consumption in their manufacturing. This means that the added energy investment in steel and fibreglass doors will require some time to be paid back through reductions in a home's heating and cooling costs. Similarly, an improvement to wood doors to reduce U-value may increase the embodied energy, requiring a payback period that may or may not be reached within the lifetime of the door.

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1 Objective

Provide the BC wood door industry with information on the environmental attributes of wood doors compared to alternative doors, in the context of BC energy code prescriptive requirements for doors.

2 Method

As a precursor to a possible full life cycle assessment (LCA) study of BC wood doors, this work accessed existing global LCA literature on doors and accessed existing data for the materials involved in wood doors and competing steel doors and fibreglass doors as a proxy for a true LCA study of these products. Interpretation and analysis were applied to approximate an LCA conclusion about BC-made wood doors. Environmental metrics addressed included global warming impacts, resource and energy consumption, emissions to air and water, and waste generation. Full life cycle issues were covered, from extraction of the initial raw resources, to transportation, manufacturing, use and disposal at end-of-life. This existing data was drawn from the databases of the Athena Institute for Sustainable Materials. The Athena Institute was engaged to examine its data and adjust it to suit the purposes of this study.

3 Scope and Limitations

Limitations on the data and its applicability are addressed here. This discussion paper is based on LCA, but this is not a full LCA study of the door industry. LCAs require considerable effort and time and therefore are costly to perform. In this study, partial LCA data is used as a reasonable proxy for full LCA data, however several key components of environmental footprint are not represented in this partial data and therefore the comparative results should be viewed with caution. While the relative performance of each door to the others is probably approximately correct, there may be minor adjustments in those relationships were the data more complete, and – in particular – the absolute values would likely be different. The data should be viewed here as a discussion tool only. Note as well that a comparison of embodied energy to operating energy requires a detailed energy study, which was not part of the work reported here. Such a study would be a recommended next step.

4 Background

The British Columbia Ministry of Energy, Mines and Petroleum Resources (MEMPR) recently made amendments to its Energy Efficiency Standards Regulation (part of the Energy Efficiency Act). These amendments, which came into effect on January 1, 2009, are relevant to exterior doors. MEMPR is applying prescriptive requirements to such doors with an intention of reducing the conductive heat loss through doors. Door manufacturers can meet the requirements of the regulation through one of the following paths:

- The total U-value[1] of the door cannot exceed 2.0 W/m^2-K (0.35 BTU/hr-ft^2-°F or R 2.9), or

[1] U-value (also known as U, U-factor, or – more technically - overall heat transfer coefficient) indicates the rate of heat transfer through an element. In metric units, it is expressed in Watts per square meter -Kelvin. For U-values, a low number indicates a good thermal performer. R-value is the inverse of U-value and expresses resistance to heat flow. For R-values, higher is better.

- If the door has glass lites, the lites must be multiple-glazed with at least one low-E coating, include an argon gas fill, and have high-performance spacer bars, and/or
- If the door has hollow panels, they shall be insulated to a total R-value of 0.875 m^2-K/W (5.0 ft^2-°F-h/BTU)

Currently, solid wood doors (no glazing) are exempt from the regulation until January 1, 2011. In the interim, the Window and Door Manufacturers Association of BC (WMDA-BC) has formed a Wood Door Working Group to collaborate with MEMPR in developing an appropriate energy efficiency standard for solid wood doors.

For the January 2009 implementation of the regulation amendment described above, MEMPR originally proposed only a single prescriptive path: all windows, skylights and doors shall not exceed a maximum total U-vale of 2.0 W/m^2-K. The vast majority of solid wood and partly-glazed exterior doors produced by BC manufacturers do not meet this threshold and hence would see a complete loss of their provincial business in exterior doors. This would likely lead to business closures in BC. In response to this threat, four of the largest solid wood door manufacturers in BC formed a working group and negotiated a temporary exemption from the regulation. A two-year exemption was granted, to allow the door industry time to consider options for improving the U-value of wood doors and to work with MEMPR in crafting an appropriate standard.

FPInnovations-Forintek was engaged by WMDA-BC to provide assistance in meeting some of its obligations to MEMPR during the two-year exemption period. This paper forms part of an initial research phase that will lead to a development phase during which thermal improvements to wood doors will be explored.

Wood doors have a low and dropping share of the exterior door market, expected to be just 8% by 2010 with 58% going to steel doors and 34% going to fibreglass[2] (FPInnovations-Forintek 2008). Wood doors once dominated the entry door market, but have steadily lost ground to steel for cost, durability and security reasons. In the last decade, fibreglass entry doors have been introduced to the market. These doors have many of the characteristics of a steel door, but are lighter and can be manufactured to look like wood doors.

Consumers that are interested in the environmental footprint of these various door options would be hard-pressed to find data. North America has yet to adopt environmental labelling or any sort of standards guiding the marketing use of environmental language. Relatively few segments of manufacturing have even begun to address the environmental profile of products. Of those that have, the most advanced are using LCA to characterize and understand their environmental footprints.

LCA is called a “cradle-to-grave” approach as it tracks the environmental impacts of a product from raw material extraction up to the ultimate disposal of the product. It examines energy and raw material use, and all environmental outputs such as pollution and greenhouse gas emissions. LCA is considered to be one of the most important tools in the field of environmental management for the assessment and improvement of environmental performance of products or services (UNEP 1996). LCAs are useful for manufacturers, architects, builders, and government agencies for answering environmental impact questions and for identifying areas for improvement (NREL 2008).

[2] This data is for the US and originates from the Window and Door Manufacturers Association.

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LCA information addresses four product life stages: raw material acquisition, manufacturing, use, and ultimate disposal (ISO 2006). Looking specifically at the life cycle energy consumption of a door, we would find energy use in all four stages. For example, energy is required to collect the raw materials used in the door – for example, wood harvesting. Energy is required in manufacturing the door – for example, sawmilling. Energy is consumed during the use of the door – for example, the manufacturing and transportation of paint, hardware and weather-stripping that will be initially applied and periodically replaced during the life of the door. And finally, energy is used at end-of-life – for example, transporting the door to landfill.

These energy flows are quite independent of the energy consumption related to operating the house (heating, cooling, etc.) in which the door is installed. The door itself is not a direct consumer of energy, however, it may affect the energy consumption of a furnace (for example) based on the door's inherent thermal properties, the effectiveness of its weatherstripping, the frequency it is opened, etc.

In this discussion, we are comparing the *embodied energy* involved with doors to the *operating energy* of the buildings in which they are installed. In discussions of energy efficiency, many people are inclined to essentially ignore embodied energy, given that it is typically dwarfed by lifetime operating energy figures. However, this may soon be an outdated notion, as buildings become more energy efficient and perhaps even approach zero-energy.

5 Results

In this section, three aspects of the discussion topic are explored: the embodied energy consumption in materials in general, the embodied energy in doors specifically, and the relationship between doors and building operating energy.

5.1 LCA of materials – previous work

There are numerous published works addressing the environmental footprint of construction-related materials. A comprehensive summary of worldwide studies is contained in Werner and Richter (2007). In this literature review of previous life cycle assessments of wood products compared to non-wood products, the wood products generally had better performance in all environmental impact categories. This study provides credibility to a wide-held belief that wood products typically have a light environmental footprint compared to substitutes. Similarly, Sathre and O'Connor (2008) performed a literature review of 48 world studies, specifically examining the range of results regarding the net impact on greenhouse gases of wood use, and found a strong consensus that increasing the use of wood products over non-wood substitutes has a net benefit for climate change mitigation.

Werner and Richter looked at LCA studies over the past 20 years; these studies covered a range of products such as door and window frames, insulation, flooring, wall framing, railway sleepers, utility polls, and complete buildings. Wood products performed particularly well versus competing products in terms of energy use, fossil fuel consumption and solid waste generation. The strong environmental performance of wood products versus functionally-equivalent products made of alternate materials is widely-enough accepted that it will not be further discussed in this paper.

5.2 LCA of doors – previous work

In our literature search, we were able to find only one paper specifically addressing LCA of doors. In this collaborative work between a highly-respected LCA consultancy (Franklin Associates) and the US Forest Products lab, a comparison was made between wood and steel doors (Knight et al. 2005). This study was a partial LCA, including only the resource and manufacturing phases (a cradle-to-gate study). If the two door types are associated with different maintenance, re-painting and end-of-life scenarios, then the results might be somewhat different. However, the magnitude of the differences between the two doors in this cradle-to-gate study is so large that the performance edge to wood doors may not change no matter what transpires in the gate-to-grave portion of the life cycle.

In the Knight et al. study, a typical galvanized steel door with polystyrene insulation is considered, along with a typical solid wood door (the study actually addressed wood doors with fibreglass reinforcement at joints, however the fibreglass is omitted from the LCA because of its very small contribution to the LCA results). A summary of the results is given in Table 1.

Table 1 Cradle-to-gate LCA summary results from Knight et al, wood vs steel doors

Environmental Factor	Steel door result	Wood door result
44 air emissions were examined[3]	31 were significantly higher for steel	7 were significantly higher for wood
32 water emissions were examined[4]	28 were significantly higher for steel	0 were significantly higher for wood
Energy use per door[5]	2.17 Gj	0.10 Gj
Solid waste per door	22.3 kg	0.51 kg
Greenhouse gas emissions	141 kg CO_2e	5.25 kg CO_2e

According to this study, steel doors create 40 times more waste, cause 27 times more greenhouse gas emission, and consume 22 times more energy. These results also show substantially more air and water pollution with steel doors versus wood.

[3] Of the 44 air emissions, some are not included in this table because there was either no significant difference between the two doors, or because they were reported for only one door and not the other.

[4] Of the 32 water emissions, 4 were only reported for steel doors and so are not included in the table.

[5] Includes fossil and non-fossil fuels. Wood manufacturing often involves the use of non-fossil fuel (wood waste), which is included in this total in spite of being a renewable energy source.

5.3 LCA of doors – Athena data

We engaged the Athena Sustainable Materials Institute to examine their databases regarding doors. The Athena Institute is North America's leading organization addressing LCA as it relates to buildings. Over the past decade, the Institute has developed groundbreaking software, world-class databases and customized consulting services, as well as an international reputation in the field of sustainable building and LCA. Athena also offers the only tools in North America for the life cycle assessment of whole buildings and assemblies. Athena is based in Ottawa, with an affiliate office in the US.

The basis of LCA for buildings or assemblies is the underlying environmental data on materials. Athena develops and maintains comprehensive, comparable life cycle inventory databases of various building materials and products. We asked Athena to help us characterize the embodied energy differences between wood, steel and fibreglass doors based on data already in hand.

Athena has only partial information on doors. Ideally, a life cycle inventory database for a generic product group (for example, wood doors) is developed by surveying a sample of actual manufacturing facilities. Detailed input/output data is gathered and then analyzed using a sophisticated life cycle assessment software package such as SimaPro to develop a comprehensive quantification of environmental impact following the ISO 14040 series of LCA standards. This full LCA effort is a lengthy and costly endeavour. To our knowledge, this has never been done for the door industry in Canada and would be outside the scope of this paper.

In place of full LCA data, the discussion that follows is based on Athena's partial LCA data. The Athena databases contain information on almost all of the basic materials involved in the door types in question. Where materials or other aspects of data were missing, Athena staff accessed secondary data, used proxies based on their judgement, and used SimaPro to fill in the gaps as needed.

Regarding data on raw materials, the only major gap in Athena's databases relevant to this study is fibreglass. Athena staff explored two strategies for crafting a proxy. First, they used batt fibreglass (a material that is available in their databases) and modified it to approximate an equivalent volume of fibreglass in a door. For a second approach, they accessed European data on glass fibre via SimaPro, using past work from a window comparison study (Salazar 2007). This data was normalized to North American energy grid data, transportation data, and impact assessment methods. Note that the modeled fibreglass door did not include binding materials such as epoxy that would typically be used in the manufacturing of a wood core fiberglass exterior door. In the Knight et al. (2005) study, epoxy was also excluded due to its minimal contribution to the total mass of the door.

The Athena data on doors is also incomplete regarding manufacturing effects. This data was not gathered through a true life cycle inventory process (as described earlier), but is approximated based on the raw materials involved. For example, a door in the Athena suite is modeled as if all the raw materials (for example, kiln-dried softwood lumber, nails, paint, etc.) arrive on site, where they are assembled into a door. While this is a reasonable rough approximation of LCA data for the door assemblies, it nonetheless is missing some environmental effects such as waste during the manufacturing process, transportation to and from the manufacturing facility, etc.

Athena data was explored for wood, steel and fibreglass exterior doors, without glazing and with 50% glazing. Door specifications were initially provided to Athena by the engineering firm Morrison Hershfield and are based on commercially-available commonly-used doors, with a dimension of 32 inches by 84 inches. The glass is standard double-pane insulating units with no gas fill and no coatings. As mentioned, the fibreglass door was modeled using two different approaches to approximate the fibreglass component, which is a material missing from the Athena databases. Each of the three material types, each with 50% glazing, is compared to the others across various environmental impact measures in Figure 1 to Figure 8. These LCA results do not include periodic re-painting of the doors or replacement of the glazing, which the Athena data indicate would be approximately the same for all three door types. Details and assumptions are in Table 2 to Table 6 following the graphs.

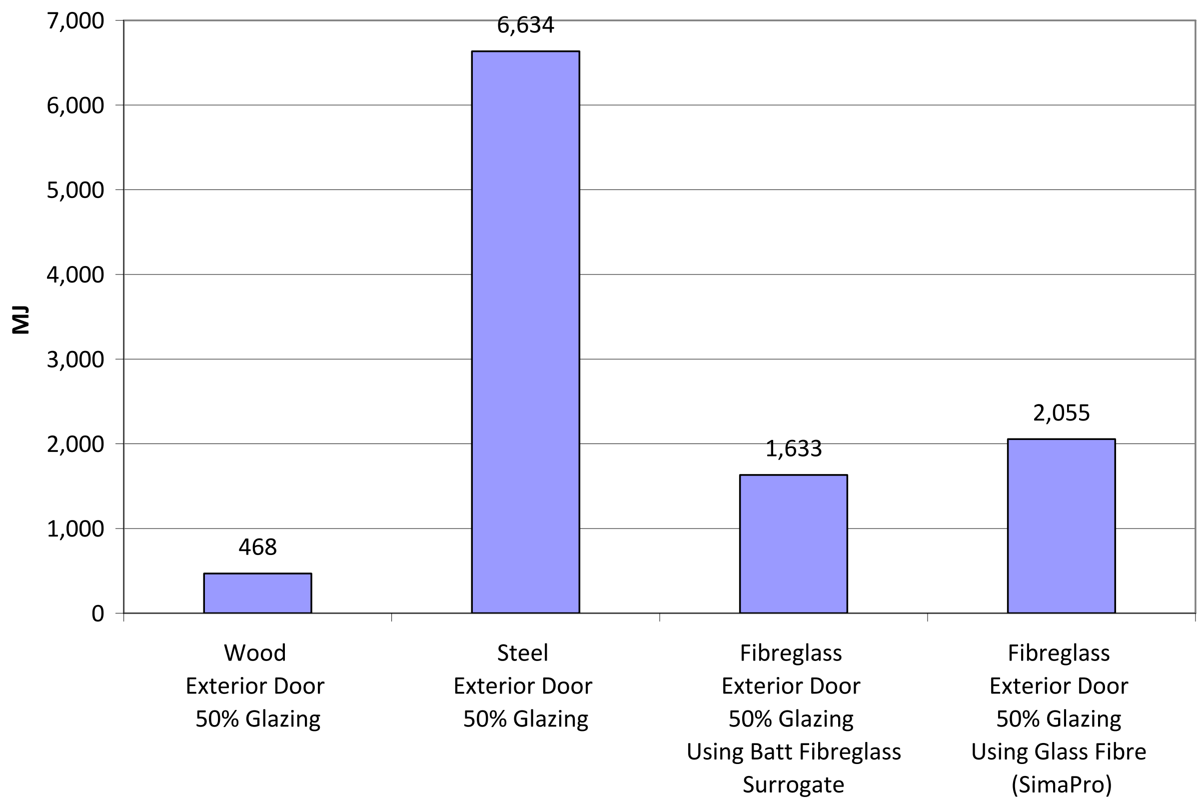

Figure 1 Primary energy consumption[6] by door type

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

[6] Also known as embodied energy, this is the total energy consumed by extraction of raw resources, manufacturing, maintenance (excluded in this case) and transportation of the door over its lifetime. This is non-renewable energy, which includes fossil fuels and nuclear, but does not include hydroelectric and other renewable energy sources.

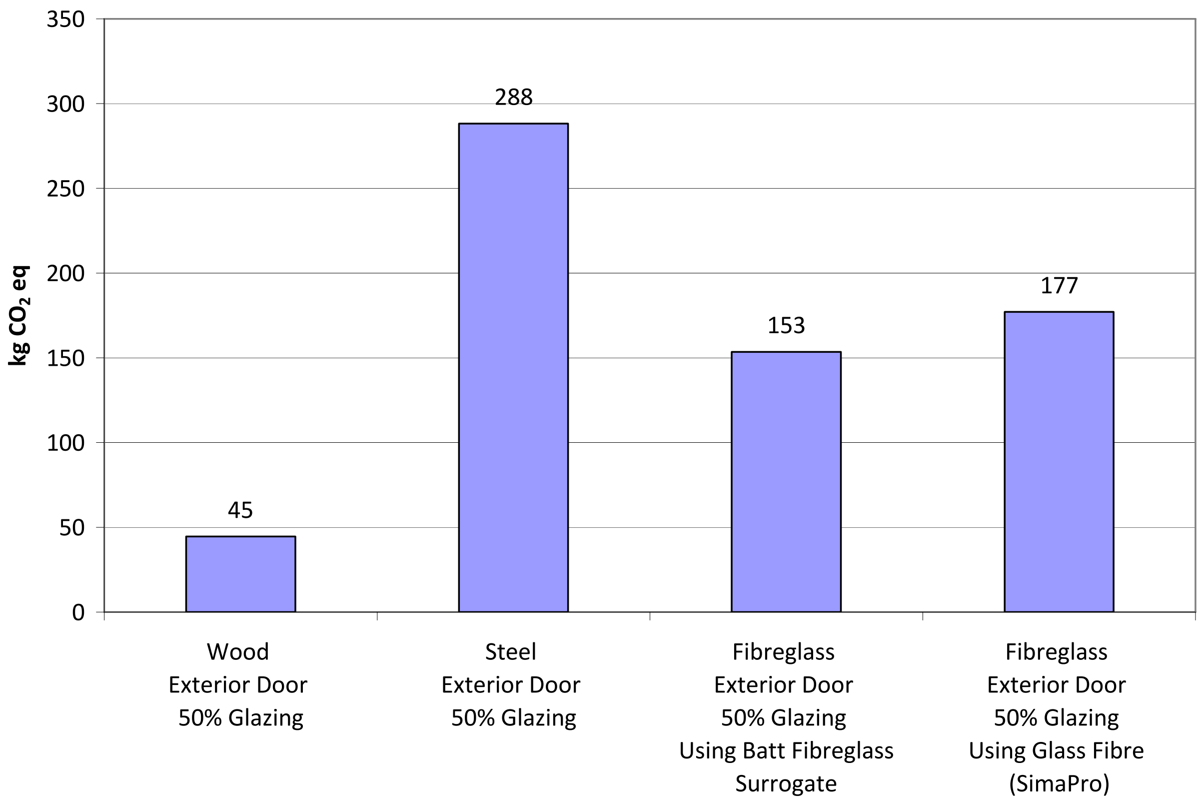

Figure 2 Global warming potential[7] by door type

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

[7] This is the total greenhouse gas emissions due to extraction of raw resources, manufacturing, maintenance (excluded in this case) and transportation of the door over its lifetime, converted to a carbon dioxide equivalency.

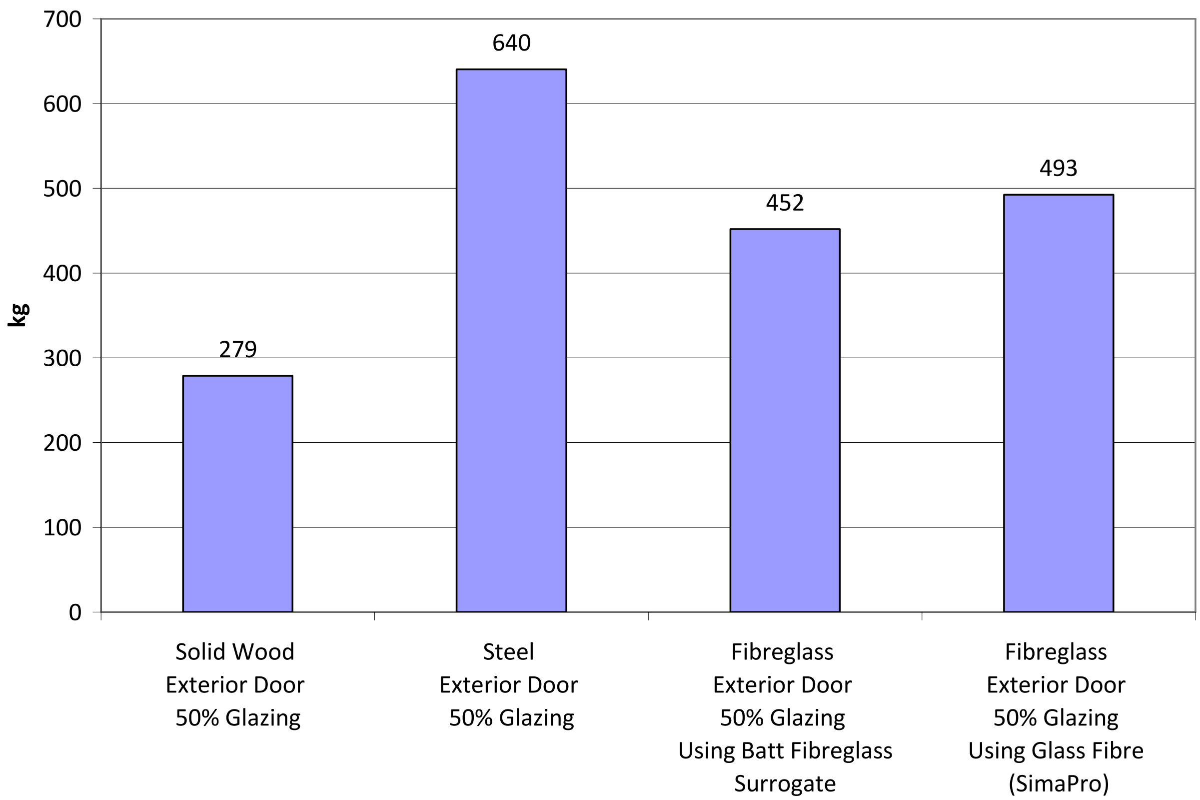

Figure 3 Weighted resource use[8] by door type

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

[8] This is a measure of amount of materials used in a product, weighted to reflect the varying levels of environmental impact from resource extraction of different materials and thus what is reported here are "ecologically weighted kilograms." Weighting is subjective and was developed by the Athena Institute under the guidance of experts. This weighting does not include any social or economic effects of resource extraction.

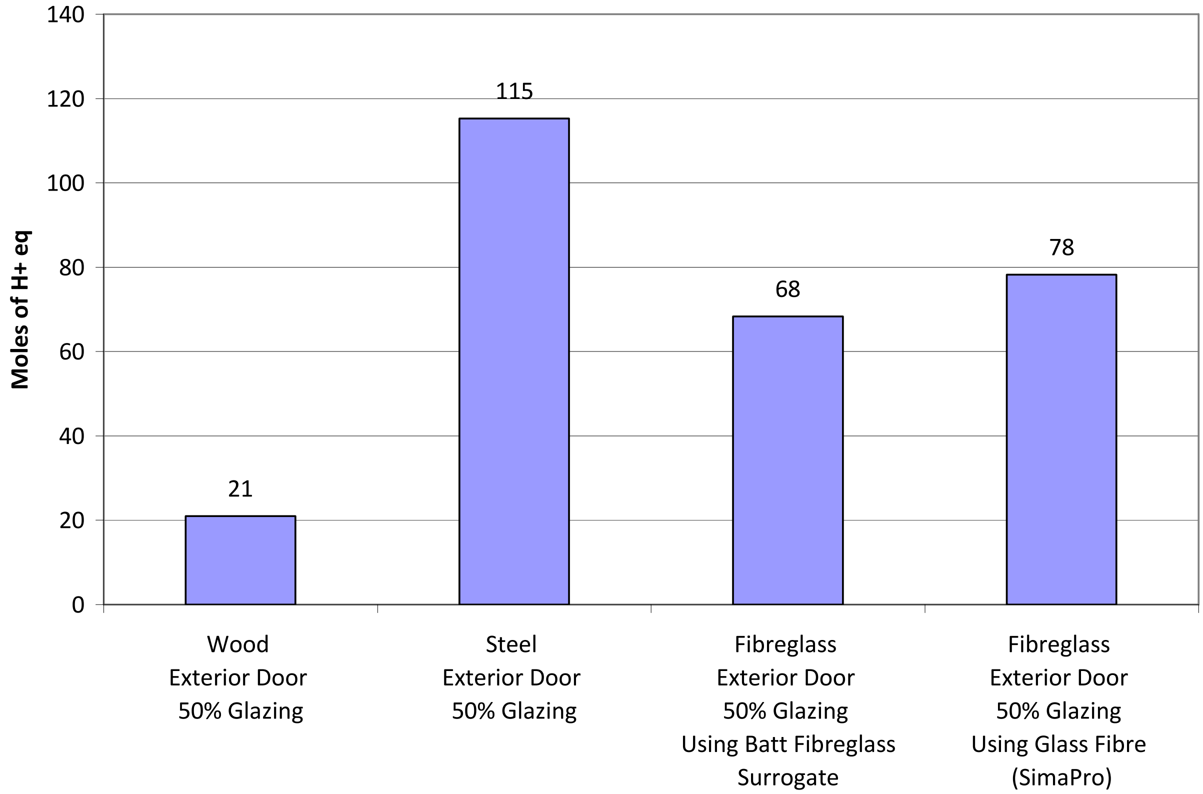

Figure 4 Acidification potential[9] by door type

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

[9] This is a measure of the amount of acidifying compounds reaching ecosystems as a result of the product, reported in hydrogen ion equivalents.

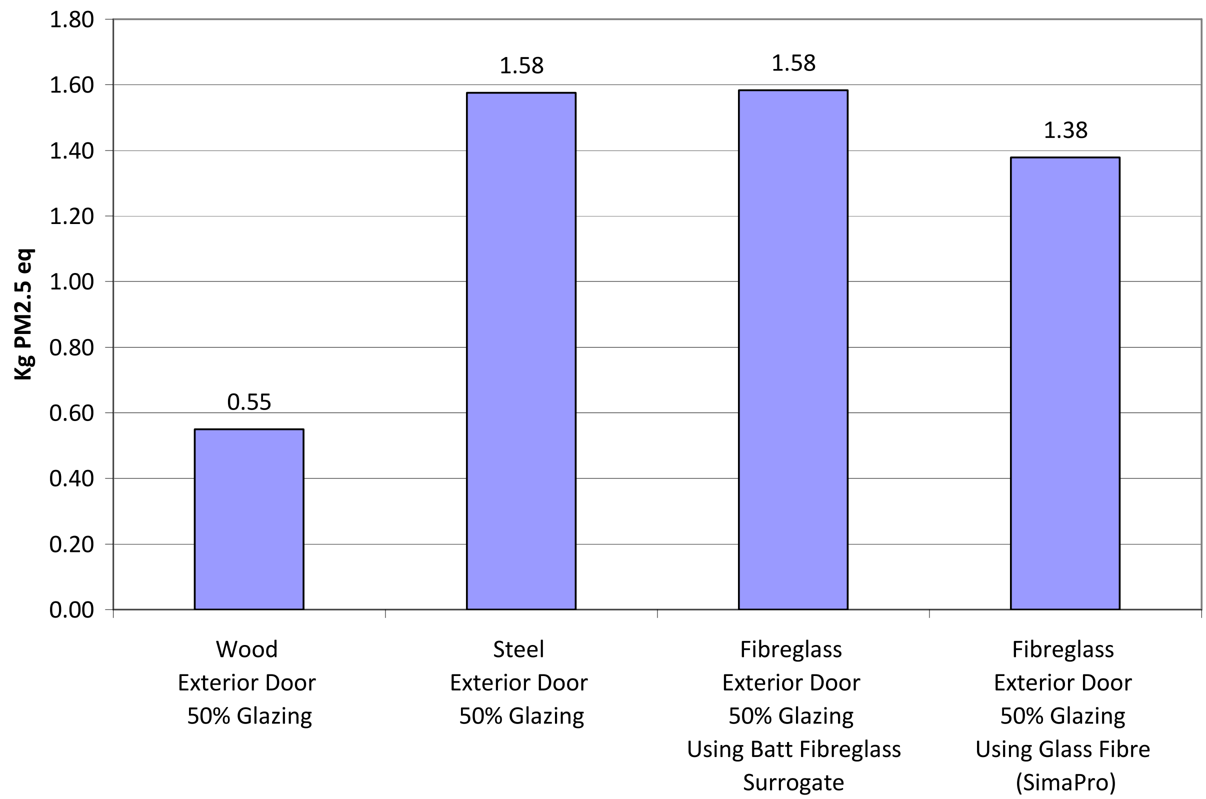

Figure 5 Human health respiratory effects[10] potential by door type

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

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[10] This is a measure of airborne particulate matter due to the product, reported in equivalent units of PM2.5, which is particulate matter of a diameter 2.5 micrometers or less (small enough to penetrate the narrowest human airways).

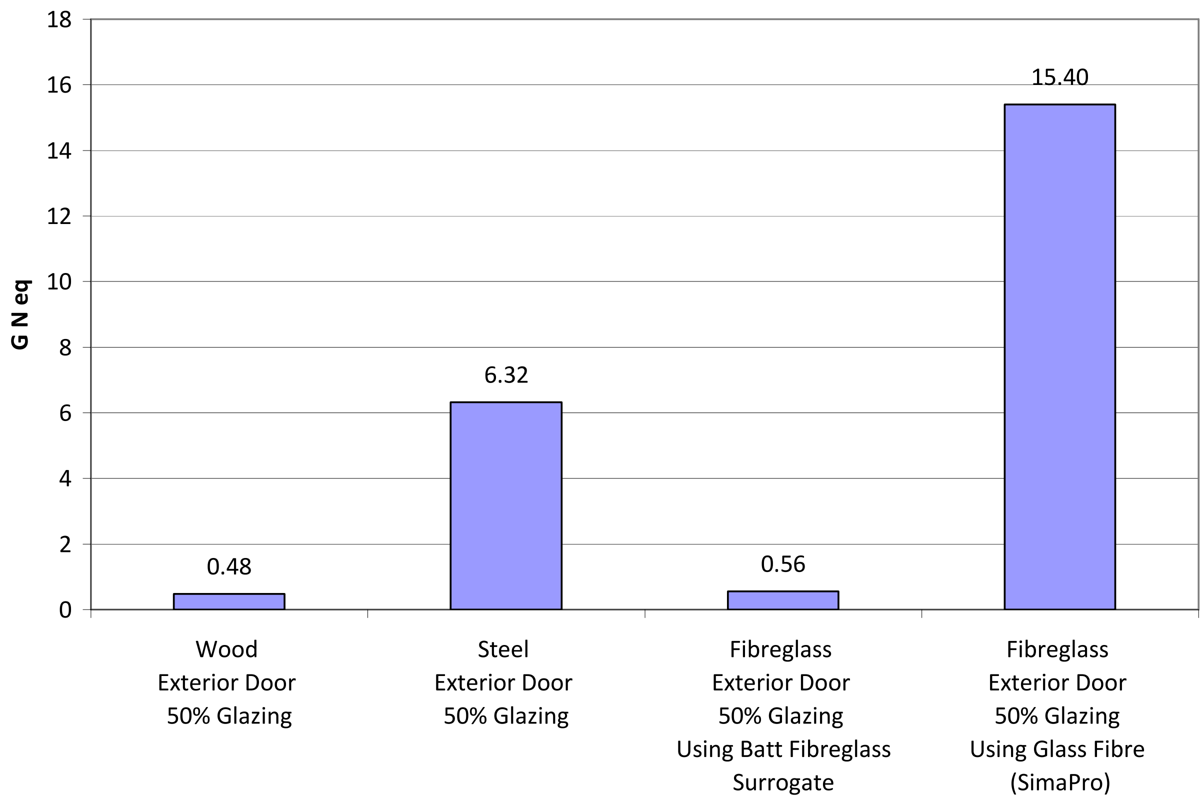

Figure 6 Eutrophication potential[11] by door type

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

[11] This is a measure of the addition of mineral nutrients such as nitrogen and phosphorous to soil or water (which can lead to ecosystem and diversity disruptions) due to the product, typically reported in equivalent units of kilograms of nitrogen but reported here in grams as the amounts are so small.

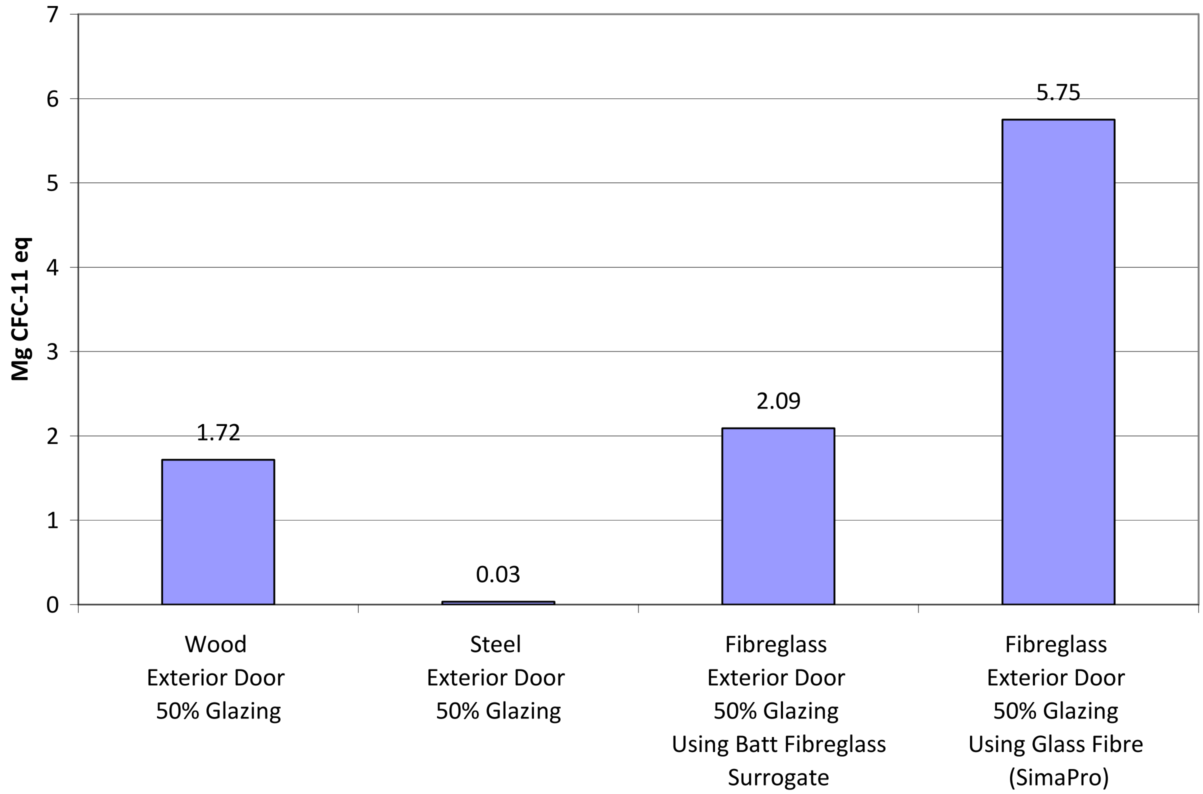

Figure 7 Ozone depletion potential[12] by door type

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

[12] This is a measure of effect on the ozone layer due to the product, typically reported in equivalent units of kilograms of CFC-11 (a chlorofluorocarbon and outmoded refrigerant) but reported here in milligrams as the amounts are so small.

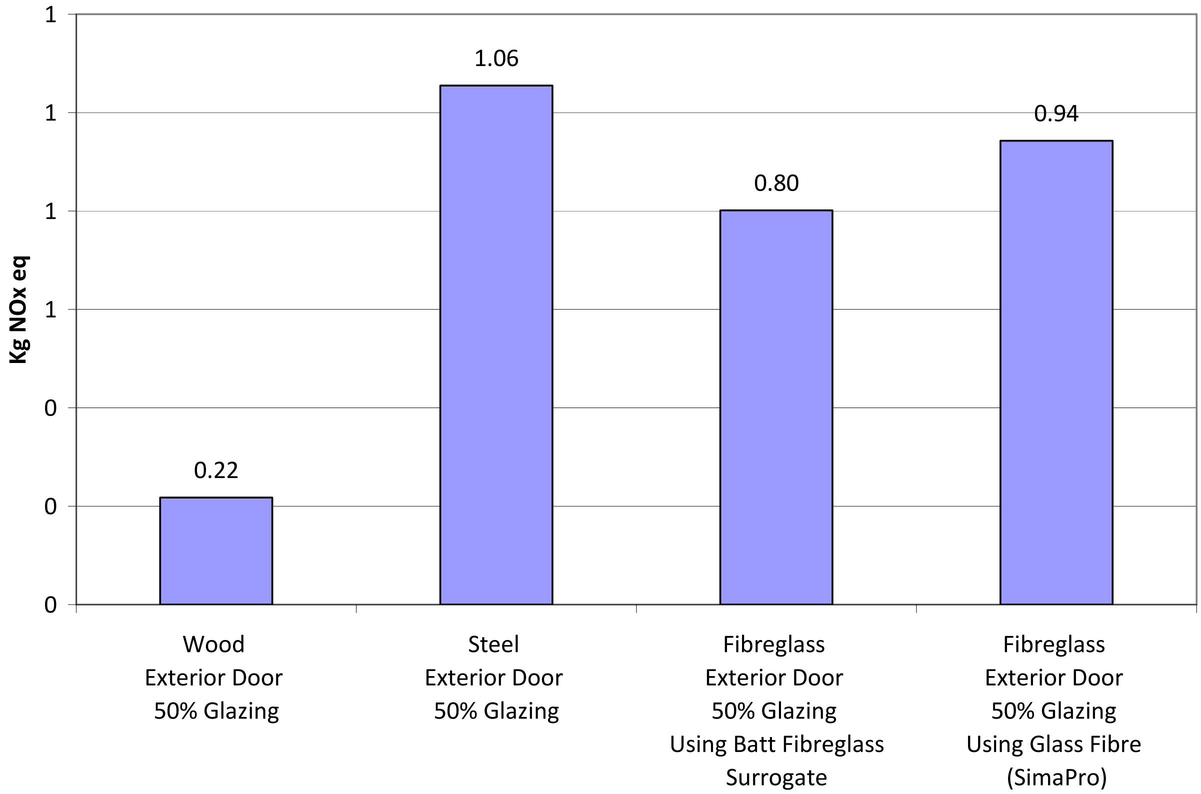

Figure 8 Smog potential[13] by door type

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

[13] This is a measure of effects on smog formation due to the product, reported in equivalent units of kilograms of nitrogen oxides.

Table 2 Bill of materials for Athena doors

Material	Unit	Solid Wood Exterior Door 0% Glazing	Solid Wood Exterior Door 50% Glazing	Steel Exterior Door 0% Glazing	Steel Exterior Door 50% Glazing	Fiberglass Exterior Door 50% Glazing Using Batt. Fiberglass Surrogate	Fiberglass Exterior Door 50% Glazing Using Glass Fibre (SimaPro)
Batt. Fiberglass	m^2 (25mm)	-	-	-	-	32.177	-
Expanded Polystyrene	m^2 (25mm)	-	-	3.255	1.995	1.659	1.659
Galvanized Sheet	Tonnes	-	-	0.062	0.047	-	-
Glass Fibre	Tonnes	-	-	-	-	-	0.02
Glazing Panel	Tonnes	-	0.020	0	0.024	0.024	0.024
Laminated Veneer Lumber	m^3	-	-	-	-	0.022	0.022
Nails	Tonnes	0.002	0.002	0.002	0.002	0.002	0.002
Small Dimension Softwood Lumber, kiln-dried	m^3	0.082	0.063	-	-	0.029	0.029
Solvent-Based Alkyd Paint	L	-	-	0.480	0.295	0.295	0.295
Water-Based Latex Paint	L	0.701	0.430	-	-	-	-

Table 3 Impacts by life cycle stages, wood door with 50% glazing

Summary Measure	Total Effects	Manufacturing Effects	Construction Effects	Maintenance Effects	End - Of - Life Effects	Operating Effects
Primary Energy Consumption (MJ)	**467.78**	442.60	20.80	See note	4.38	See note
Weighted Resource Use (kg)	**278.80**	278.23	0.47	See note	0.10	See note
Global Warming Potential (kg CO2 eq)	**44.61**	44.56	0.04	See note	0.01	See note
Acidification Potential (moles of H+ eq)	**20.95**	20.93	0.01	See note	2.79E-03	See note
HH Respiratory Effects Potential (kg PM2.5 eq)	**0.55**	0.55	1.52E-05	See note	3.31E-06	See note
Eutrophication Potential (kg N eq)	**4.81E-04**	4.81E-04	9.76E-08	See note	2.75E-08	See note
Ozone Depletion Potential (kg CFC-11 eq)	**1.72E-06**	1.72E-06	1.64E-12	See note	4.63E-13	See note
Smog Potential (kg NOx eq)	**0.22**	0.22	2.82E-04	See note	6.08E-05	See note

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

Table 4 Impacts by life cycle stages, steel door with 50% glazing

Summary Measure	Total Effects	Manufacturing Effects	Construction Effects	Maintenance Effects	End - Of - Life Effects	Operating Effects
Primary Energy Consumption (MJ)	**6,634.25**	6,507.34	119.14	See note	7.77	See note
Weighted Resource Use (kg)	**640.39**	637.50	2.71	See note	0.18	See note
Global Warming Potential (kg CO2 eq)	**288.18**	288.10	0.06	See note	0.02	See note
Acidification Potential (moles of H+ eq)	**115.24**	115.20	0.03	See note	4.82E-03	See note
HH Respiratory Effects Potential (kg PM2.5 eq)	**1.58**	1.58	3.32E-05	See note	5.76E-06	See note
Eutrophication Potential (kg N eq)	**6.32E-03**	6.32E-03	1.46E-07	See note	4.18E-08	See note
Ozone Depletion Potential (kg CFC-11 eq)	**3.32E-08**	3.32E-08	2.48E-12	See note	7.04E-13	See note
Smog Potential (kg NOx eq)	**1.06**	1.05	6.28E-04	See note	1.07E-04	See note

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

Table 5 Impacts by life cycle stages, fibreglass door with 50% glazing (batt fibreglass as fibreglass surrogate)

Summary Measure	Total Effects	Manufacturing Effects	Construction Effects	Maintenance Effects	End - Of - Life Effects	Operating Effects
Primary Energy Consumption (MJ)	**1,633.05**	1,567.60	58.41	See note	7.04	See note
Weighted Resource Use (kg)	**451.75**	450.26	1.33	See note	0.16	See note
Global Warming Potential (kg CO2 eq)	**153.49**	153.37	0.11	See note	0.02	See note
Acidification Potential (moles of H+ eq)	**68.37**	68.33	0.03	See note	4.39E-03	See note
HH Respiratory Effects Potential (kg PM2.5 eq)	**1.58**	1.58	4.03E-05	See note	5.25E-06	See note
Eutrophication Potential (kg N eq)	**5.57E-04**	5.57E-04	2.56E-07	See note	3.93E-08	See note
Ozone Depletion Potential (kg CFC-11 eq)	**2.09E-06**	2.09E-06	4.31E-12	See note	6.62E-13	See note
Smog Potential (kg NOx eq)	**0.80**	0.80	7.50E-04	See note	9.68E-05	See note

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

Table 6 Impacts by life cycle stages, fibreglass door with 50% glazing (glass fibre from SimaPro as fibreglass surrogate)

Summary Measure	Total Effects	Manufacturing Effects	Construction Effects	Maintenance Effects	End - Of - Life Effects	Operating Effects
Primary Energy Consumption (MJ)	**2,055.14**	2,013.49	36.12	See note	5.53	See note
Weighted Resource Use (kg)	**492.53**	491.58	0.82	See note	0.13	See note
Global Warming Potential (kg CO2 eq)	**177.09**	177.02	0.06	See note	0.01	See note
Acidification Potential (moles of H+ eq)	**78.23**	78.20	0.02	See note	3.47E-03	See note
HH Respiratory Effects Potential (kg PM2.5 eq)	**1.38**	1.38	2.40E-05	See note	4.14E-06	See note
Eutrophication Potential (kg N eq)	**0.02**	0.02	1.52E-07	See note	3.23E-08	See note
Ozone Depletion Potential (kg CFC-11 eq)	**5.75E-06**	5.75E-06	2.55E-12	See note	5.43E-13	See note
Smog Potential (kg NOx eq)	**0.94**	0.94	4.47E-04	See note	7.63E-05	See note

Note: This is an approximation of cradle-to-grave data. As discussed in the text, it does not include maintenance effects over the life of the doors and does not include all manufacturing effects. Source: Athena Sustainable Materials Institute. Data is for a single door.

5.4 Operating energy

To calculate the net energy impact of substituting one door for another requires that we know both the embodied energy difference between the two doors as well as the operating energy impact of the swap. Performing an operating energy simulation is beyond the scope of this paper.

A MEMPR staff member suggested to us that an energy simulation would be performed by MEMPR, in a parametric energy consumption calculation for a typical house where door properties were varied. On

May 13, 2009 Andrew Pape-Salmon of MEMPR sent us a brief report prepared by engineering co-op student Dian Ross presenting results of an energy simulation using the software package HOT2000 to compare the effect on overall energy consumption in a typical house due to different doors.

An operating energy calculation can theoretically supply several key pieces of data. By varying the door parameters in a house model, one could identify the proportional contribution of doors to the total heating and cooling loads. Depending on the sophistication of the modeling software, one may also be able to separately quantify the conductive effects and the convective effects. One could thus develop a sense of relative impacts of U-value of doors, air sealing around door frames, user behaviour regarding door opening and closing, and so forth. In other words, this would be useful to understanding the relative impact on house performance from factors under the control of the door manufacturer (e.g., conductive heat transfer) versus factors not within the control of the door supplier. If HOT2000 does not have all of these capabilities, it would be useful to undertake a comprehensive parametric study with more sophisticated software.

The report provided by MEMPR does not contain enough detail to provide a definitive comparative basis between operating energy and the LCA data reported here, as we were not given full data on the input files and the results and thus cannot fully assess the applicability of the results. However, a table in the MEMPR report, containing net energy consumption results for "no door" scenario versus various door options will be addressed here for general discussion purposes. Relevant results are summarized in Table 7. In that analysis, a wood door is modeled with a U-factor of 2.5[14]. Two alternative door U-values were modeled: 2.0 (the current Energy Star threshold and the basis for the BC regulation) and 1.0 (a proposed new Energy Star threshold for 2010). Insulated steel and fibreglass doors can clear the 1.0 threshold without glazing; when these doors have glass, they typically exceed 1.0[15].

Table 7 MEMPR energy simulation results, Vancouver climate

Type of Heating	Annual energy savings per door	
	Changing door from U 2.5 to U 2.0	Changing door from U 2.5 to U 1.0
Electric	170 MJ	520 MJ
Gas	190 MJ	570 MJ

In this HOT2000 model, it would appear that the doors are modeled as solid (no glazing), whereas the LCA data described in this report is given for doors with 50% glazing as most exterior doors are glazed to various degrees. See Figure 9 for Athena-based LCA data on wood, steel and fibreglass (SimaPro proxy) doors with no glazing.

[14] Test results according to National Fenestration Rating Council (NFRC) protocols by WESTLab for BC Door Company give a value of 2.28 for a six-panel wood door with no glazing. This would suggest that the energy savings as shown in Table 7 may be high and thus the "payback" for a non-wood high-performance door may be longer.

[15] According to a sampling of tested products listed in the NFRC directory: http://www.nfrc.org/getratings.aspx

As shown in Figure 1 (glazed doors) and Figure 9 (doors with no glazing), the wood doors have the lowest embodied energy; however, they result in higher energy consumption in a typical house according to the MEMPR study. By comparing the change in embodied energy to the change in operating energy when one door is substituted for another, we can calculate the "payback" for an added energy "investment" during door manufacturing. For example, consider the substitution of an insulated solid steel door with a U-value of 1.0 for a solid wood door with a U-value of 2.5. From Figure 9 we see that the steel door requires 8,010 MJ more energy than the wood door to manufacture and install. From Table 7 we see that, for a gas-heated typical house in Vancouver, that steel door will result in energy savings of 570 MJ per year. This means that the steel door has an energy "payback" of 14 years in this situation. For fibreglass, the "payback" is a bit more than three years.

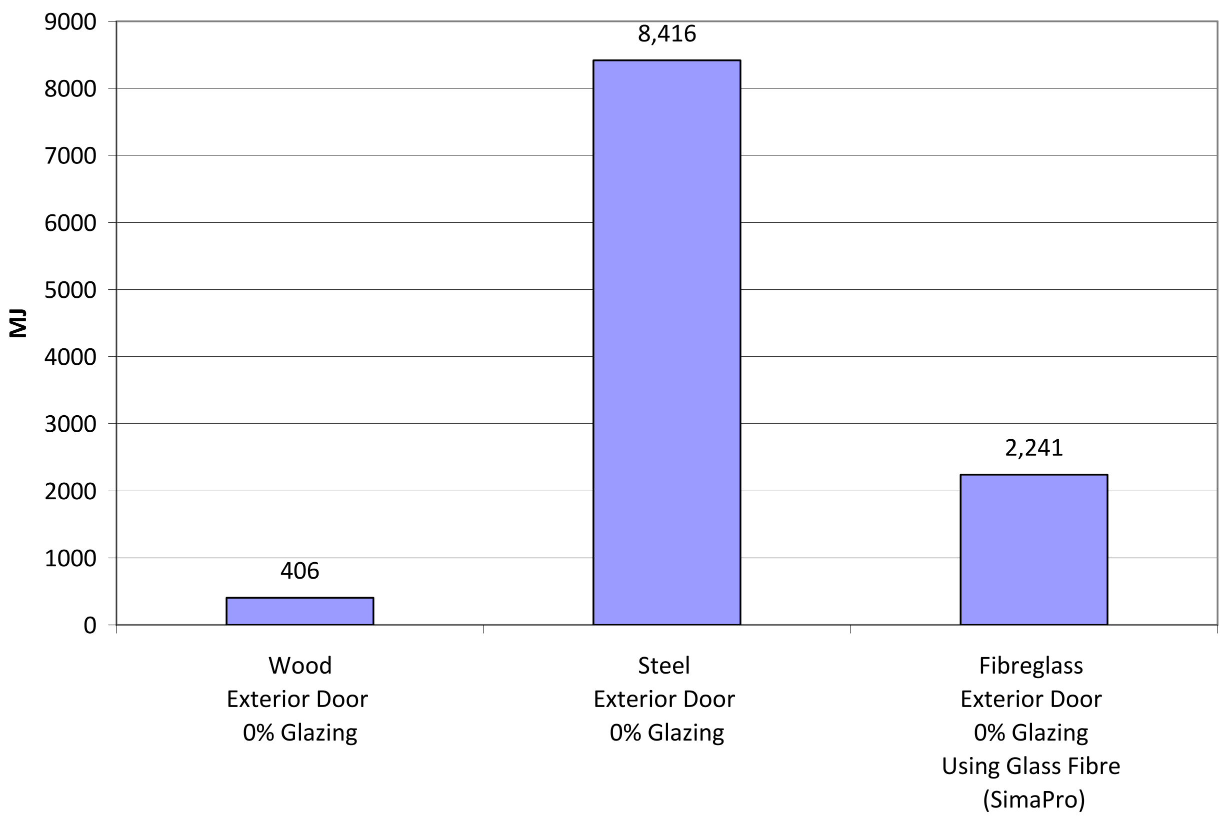

Figure 9 Embodied energy, three doors, no glazing

The payback will be different if we consider doors with glazing. Adding glazing to a door significantly increases the U-value of insulated steel and fibreglass doors while reducing the U-value of wood doors[16]. In other words, the various doors get closer to each other in thermal performance as glazing is added, meaning that the operating energy savings for a steel door or fibreglass door over a wood door are much reduced. This is not compensated for by a proportionally-similar reduction in the difference between embodied energy across the three door types – the differences in embodied energy when glass is added are only somewhat smaller. Our hypothesis is that the embodied energy payback period for high performance non-wood doors would get longer were a glazed door modeled in HOT2000.

6 Discussion and Conclusions

This paper addresses energy consumption related to doors from a life cycle perspective and suggests that embodied energy and operating energy effects due to construction products need to be considered together when there is a regulatory objective of reducing total energy use. If not, there is a risk that a market change in the use of building materials may inadvertently cause an *increase* in total energy consumption.

The partial LCA data presented here, drawn from the Athena databases, clearly shows that wood doors have substantially lower embodied energy than insulated steel and fibreglass doors. Energy simulation results from MEMPR show that steel doors will require *at least* 14 years of use in a house to offset their added embodied energy versus wood doors. For fibreglass, the payback is at least three years. Note that the LCA data on fibreglass presented here is the least reliable of the three doors; there is considerable uncertainty involved in this information and one should not draw general conclusions about fibreglass doors from this report.

A focus on energy consumption alone may lead to market changes that have adverse affects in other equally-important areas of environmental or health concerns. Life cycle assessment attempts to broaden the environmental decision space by addressing issues such as air and water pollution, depletion of resources, respiratory impacts, greenhouse gas emissions, solid waste, and so forth. In a world becoming more sophisticated in its evaluation of environmental impacts, it is less common to emphasize one impact measure while excluding the others. If fact, it is even difficult to put a sustainability "weight" on each of the environmental impacts, in those cases where we might wish to boil all impact measures down to one single index.

Additional sustainability and social topics that go beyond LCA and are of relevance in this door discussion include carbon sequestration by wood products, local economic and social impact of a vibrant forest products industry, the Canadian cultural relevance of wood in construction, material "authenticity," the use of renewable materials over non-renewables, and Canada's standards and practices in sustainable forestry. The cultural and economic relevance of wood products in BC cannot be overemphasized. More important to the discussion here are the environmental characteristics of wood products that are not reflected in a narrow criterion such as U-value and may far outweigh the total environmental impact of a low U-value. The climate change benefits of an increase in the use of wood are well-documented; wood products store more carbon than is released in their manufacturing (making them a net-negative carbon

[16] From a sampling of various data sources, including NFRC tested-product tables, Washington State energy code default value tables, and BC Door test data.

product) and their use over non-wood substitutes leads to a substantial avoidance of greenhouse gas emissions since wood has a far lighter greenhouse gas manufacturing footprint than most other materials. Non-wood raw materials also tend to be imported, bringing with them significant transportation footprints plus adherence to industrial environmental regulations that may be substandard compared to North American practices.

To address the full range of sustainability issues within an energy regulation is likely not foreseeable in the near future. In the long run, an LCA-based performance compliance regulatory approach might be the ideal substitute for the range of energy and sustainability regulations and guidelines available today.

Current energy codes and standards in North America often include a performance path in addition to a prescriptive path. This allows creative designers to explore innovative approaches involving trade-offs. A door exceeding the 2.0 U-value threshold could be included in house, if a compensation were made elsewhere that resulted in the same net energy consumption were a 2.0 U-value door installed. Performance approaches typically require a designer to model the building with simulation software. More simplistic approaches are also possible, perhaps via an effective total-envelope weighted U-value calculation.

Ideally, energy codes would take into consideration the embodied energy in construction products, thereby addressing the *total* energy involved in products choices and introducing a new version of a payback calculation. Energy paybacks are typically expressed in terms of the cost of an upgraded product versus its energy savings. Another approach to the payback concept is comparing any added energy investment in an upgraded product to its resultant lifetime savings, as discussed in the previous section.

Efforts by the wood door industry to improve the U-value of its products might best be undertaken within a few constraints. First, an LCA approach will ensure that the other environmental metrics aren't adversely impacted for the sake of improved thermal performance. Second, the scale of a research-and-development effort might be keyed to the level of impact that doors have in overall house energy consumption. In other words, it might not be worthwhile to expend investment in a part of the house with relatively little impact on total energy use. While doors typically have a much lower resistance to heat flow than most other elements in the envelope, they constitute a small fraction of the total envelope.

The MEMPR report suggests a potential Renewable Resource Credit (RRC) be introduced to the energy regulation, which would function as an offset regarding maximum allowable U-value. Such a credit (which might be more appropriately named an Embodied Energy Credit) could perhaps be used as an adjustment factor to the actual U-value of a door. A door with a U-value above the 2.0 threshold could thus be granted an adjustment down to 2.0 if it could demonstrate that its embodied energy is below a given threshold. Embodied energy for doors could be deemed according to a table of default values (perhaps using Athena's databases) or could be demonstrated by manufacturers via credible LCA product data. This is an interesting proposition to address embodied energy in a feasible and simple manner. It would be a ground-breaking energy regulation feature and well-worth further examination.

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