The Greenest Building Is the One That Is Never Built: A Life-Cycle Assessment Study of Embodied Effects for Historic Buildings

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ABSTRACT

This paper presents the results of a study performed by the Athena Institute and Morrison Hershfield Consulting Engineers on the embodied environmental effects of existing historic buildings and the benefits of retaining an existing building rather than constructing a new building. The project team applied the concepts of life-cycle analysis and whole-building energy simulation in assessing the material and operational environmental effects of an existing renovated building and a comparable new building. Life-cycle assessment was performed using the freely available Athena® EcoCalculator for building assemblies (AI 2009a), while whole-building energy simulation relied on Natural Resources Canada's Screening Tool for New Building Design (NRCan 2010).

The methodology was applied to four case studies, each a real building in a different Canadian location. The work involved obtaining architectural drawings, utility bills, and renovation histories for each of the four buildings and included site visits, exploration of improvements to the existing buildings (for energy efficiency), and obtaining energy use records. The case studies also included the development and comparison of fictional new buildings using conventional new building assemblies. In the interest of brevity, only one case study is presented in this paper.

The results demonstrate that significant environmental impacts can be avoided by preserving an existing building instead of demolishing it and building a new building, provided there is a focus on energy conservation in historic building renovation. The operating energy analysis supports a conclusion that such embodied effects are unlikely to be overshadowed by operating energy concerns if a building has been properly renovated.

INTRODUCTION

Too often, decisions about whether to keep or demolish a building revolve only around cost considerations without taking account of the environmental implications. As a result, justifying a major renovation may be difficult, as costs are often uncertain and may equal or even be greater than the cost of new construction. There is a need, therefore, to quantify the potential environmental gains available with keeping and renovating a building versus demolishing it and building a new building. Environmental impacts can then be brought into the decision process along with costs and other considerations.

Such quanti• cation requires the use of appropriate data and tools as well as an inherent understanding of building energy and building science, and to that end, this study was designed to create a methodology and a decision-support framework, with related tools, that will make it easier for those concerned with the preservation of historic buildings to readily examine the environmental implications of demolition versus building a new building.

Background

Eco-conscious individuals, groups, and communities around the world are helping to shift popular thinking from a generally accepted concept of defined building lives to a concept of successive life cycles, where renewal and renovation are the start of a new service life for a structure. This shift in thinking leads us to take a closer look at the successive lives and evolving functions that a structure may serve over a longer

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time frame and at the consequent environmental benefits. However, although many agree that it is important to preserve historic and heritage buildings (EI 2000), since 1975 more than 21% of the pre-1920 building stock in Canada has been demolished due to factors such as economic pressures, social and technological changes, and lack of public awareness (CH 2010).

Parks Canada therefore commissioned the Athena Institute, in association with Morrison Hersh• eld, to examine the environmental impacts avoided by renovating and giving new life to three historic buildings that had received funding through the Commercial Heritage Properties Incentive Fund (CHPIF). CHPIF is a tool of the Historic Places Initiative (HPI), a Government of Canada program designed to bring governments, communities, and the private sector together in conserving and celebrating historic places by actively engaging Canadians in their preservation (PACAC 2006). Shortly after this study was commissioned, the Government of Alberta approached the Athena Institute with an interest in undertaking a very similar analysis for two historic buildings in that province. Alberta subsequently decided to separately fund a study of one of those buildings, located in Calgary, and to have it included along with the three Parks Canada buildings in this report.

Project Scope

This paper provides study results regarding the environmental impacts avoided by conserving and rehabilitating historic buildings instead of building new buildings. The case study presented in this paper involves the Birks Building in Winnipeg. An additional three case studies were performed (The Parkdale Fire Station building located in Ottawa, the Lougheed Building in Calgary, and the Chinese Freemasons' Building in Vancouver) as part of the full project, but these additional case studies are not presented in this paper. Note that all four buildings have been renovated as commercial or residential properties and are in use serving various functions.

The project scope encompassed the following key elements:

1. The use of life-cycle assessment (LCA) to estimate two key embodied environmental impacts, primary energy use and global warming potential measured in terms of CO_2 equivalence.
2. Estimated avoided impacts associated with demolition of the existing buildings and construction of new buildings of essentially the same size designed to serve the functions currently being served by the renovated buildings.
3. Differences, if any, in estimated operating energy use for the new versus existing buildings.
4. Identification of any significant impacts incurred to renovate the existing buildings.
5. A qualitative discussion of issues related to the overall "renovate versus build new" decision process.

This study was in the nature of a pilot study designed to investigate a process to examine the environmental side of the equation using readily available tools and to create a methodology, or template, that can be readily applied. It was not intended to provide precise estimates with regard to either the embodied or operating energy aspects but rather to provide reasonable approximations that can be developed without requiring specialized consulting services.

DATA COLLECTION AND IMPACT ESTIMATION PROCEDURES

Data Collection

The following three types of data were required to compare the existing buildings with typical new designs:

- Information necessary to design a typical new building to serve the current functions, with essentially the same usable square footage as the existing building. This includes floor area, exterior wall areas (based on a 3 m height for a typical floor), window areas (based on 40% window/wall ratio), interior wall area (based on the existing plan), and roof area.
- Information regarding renovations for the evaluation of embodied effects incurred to renovate the heritage building.
- Utility bills and other information to assess the relative operating energy performance of the existing building versus a new building.

The initial step to gathering the necessary data was to review available documentation. For the case study, information regarding the conservation work that received funding from CHIF was provided by Parks Canada, including some floor plans and elevations, and engineering reports.

The basic history of the building was available on the Internet. The owner of the building was contacted to arrange site visits and provide additional information, especially information such as utility bills to assist in assessing building energy performance. The site visits served to confirm data provided on drawings and to allow visual inspection of building upgrades related to operations.

New Building Design

The new building design was expressed in terms of common building assemblies (exterior walls, intermediate floors, columns and beams, roofs, interior partitions, and windows) that have been pre-studied using the Athena® Impact Estimator for Buildings (AI 2010a) and are included in the freely available Athena® EcoCalculator for building assemblies (AI 2009a). The appropriate assemblies were chosen based on general construction practices for similar building types and sizes for the geographical location, with the new building designs intentionally kept to the same floor plates and numbers of floors as the existing buildings.

Embodied Environmental Effects Analysis

The Athena Institute used the design parameters provided by Morrison Hershfield from the site visits as inputs to the most recent version of the Athena EcoCalculator (AI 2009a) to generate estimates of the effects of constructing new buildings—effects that were avoided by keeping the historic buildings.

The EcoCalculator comprises a set of Microsoft Excel® spreadsheets that contain environmental impact results for more than 400 common buildings. The user simply indicates the area of a given assembly that will be used in a new building and the spreadsheet instantly shows the estimated total environmental effects associated with the choice. As more assemblies are selected, the EcoCalculator builds an estimate of the total building effects in a summary table.

When EcoCalculator results are generated using Athena's Impact Estimator software (AI 2010a), the analysis takes account of maintenance, replacement, and related disposal effects for all assemblies as relevant (e.g., roofing materials), assuming a 60-year service life for new buildings. These effects are therefore included along with other life-cycle effects associated with the extraction of resources, manufacturing, transportation, and on-site construction. In simplified terms, the Impact Estimator is a more complex and flexible LCA software, where the EcoCalculator is a greatly simplified (and limited) version of the tool that runs in Excel. Both tools rely on the same data, but the EcoCalculator was selected for this work as it is easier to apply and is available at no cost. More detail on the inner workings of the Impact Estimator and EcoCalculator, including assumptions, known issues and errors, age of data, etc., are available from the Athena Institute Web site (AI 2010b).

The environmental effects of building demolition also represent a critical avoided impact when a building is conserved and were taken into account in this study. Per square meter demolition factors were developed based on results of a previous Athena Institute study and applied to the buildings as relevant to generate the results. On the other side of the ledger are those impacts incurred to renovate a building, effects that differ depending on the building and what was done. However, renovation effects were not included for reasons outlined in a later section of this paper but are also not considered critical in terms of the overall avoided impacts analysis.

The EcoCalculator provides estimates of a range of LCA measures consistent with international standards (according to AI [2010b]). For the purposes of this study, the focus was on two of those measures—embodied primary energy and global warming potential.

Primary energy is measured in gigajoules (GJ) and includes all non-renewable energy, direct and indirect, used to transform or transport raw materials into or to products and buildings, including inherent energy contained in raw or feedstock materials that are also used as common energy sources—for example, natural gas used as a raw material in the production of various plastic (polymer) resins. In addition, the measure captures the pre-combustion (indirect) energy use associated with processing, transporting, converting, and delivering fuel and energy. This measures provides a close approximation of the fossil fuel use.

Global warming potential (GWP) is a reference measure. Carbon dioxide is the common reference standard for global warming or greenhouse gas effects. All other greenhouse gases are referred to as having a "CO_2 equivalence effect," which is simply a multiple of the greenhouse potential (heat trapping capability) of carbon dioxide. This effect has a time horizon due to the atmospheric reactivity or stability of the various contributing gases over time. The Intergovernmental Panel on Climate Change (IPCC 2001) 100-year time horizon was used as a basis for the equivalence index:

$$CO_2 \text{ Equivalent kg} = CO_2 \text{ kg} + (CH_4 \text{ kg} \times 23) + (N_2O \text{ kg} \times 296)$$

CASE STUDY—THE BIRKS BUILDING

The Birks Building (Figure 1) is located at 276 Portage Avenue in Winnipeg, Manitoba, Canada. Current tenants include government offices. The building has a gross floor area of 3030 m^2 and a footprint of 855 m^2. The Birks Building was Winnipeg's first permanent facility for the Young Men's Christian Association (YMCA). The YMCA obtained the Portage property in 1890, opening one of the best-outfitted YMCAs in Canada in early 1901. Henry Birks and Sons, a jeweler, moved into the premises in 1909 and had the exterior transformed architecturally in 1910, and in 1914 the interior was renovated into one of the city's most functional and exclusive shops. Major alterations were made in 1928, 1951–52, the late 1960s, and the mid-1970s. The 1951 work included installation of a granite base and Tyndall stone facings around solid bronze show windows on the ground floor. Corner columns and vestibule walls were lined with Travertine marble. In 2006, a major renovation was undertaken and the building is now entirely office space, including government offices.

Figure 1 *The Birks Building.*

The building construction includes cast metal, steel and wood structural elements, load-bearing brick masonry walls, and wood- and metal-framed windows. The building is rectangular in plan and has four floors, with a full basement. The East wall of the building butts up against an adjacent building, while the north and west elevations face main streets and the south elevation faces a laneway.

Heritage Restoration Summary of Work:

- Minimal exterior cladding repair work (done prior to CHIF project—in good condition)
- New insulation (to achieve R20—reported spray polyurethane), air barrier, vapor barrier and interior finish
- All mechanical systems removed, new plumbing air handling, air conditioning, and heating (LEED and CBIP)
- Significant structural upgrades, including repair/ replacement of structural steel columns, beams and joists, and new piles for electrical transformer
- New windows (with insulated glazing [IG] units) installed on the interior (wood frame, IG units in most locations, triple glazing on south elevation), leaving older exterior windows intact (including original metal-frame windows with single-glazed, wired glass; newer wood-frame windows with IG units; and original wood-framed windows with single glazing)
- Windows at grade—from renovation circa the 1990s—including aluminum-framed windows with IG units, which appear to have warm edge spacers
- Area enclosure to create an atrium—existing window frames (which became interior) refurbished, new glazing (aluminum frame with IG units) to exterior
- New transformer and electrical system
- New roofing membrane, insulation, and vapor barrier
- New passenger and freight elevator
- New interior • nishes and one new stairwell while maintaining one stairwell in the original layout

Proposed Typical Replacement Building:

- Four stories with full basement
- Same 855 m^2 floor plate as existing building, height of 12 m (3 m per floor, which is less than existing building)
- Similar interior configuration and 40% window-to-wall ratio
- A full footprint assumed for fourth floor
- Two cladding materials due to the general size and site-specific components—precast concrete cladding on elevations visible from the street (north, west, and south

Table 1. Athena EcoCalculator Results: Replacement for the Birks Building

Building Component	Primary Energy per m^2, MJ	GWP per m^2, Equivalent CO_{2e}kg	Total Primary Energy, MJ	Total GWP, tons CO_2e
Columns and beams	1020	45	3485000	155
Intermediate floors	808	50	2762000	171
Exterior walls 1	907	54	8957000	496
Exterior walls 2	866	44		
Windows	5780	287	3156000	157
Interior walls	406	14	1461000	51
Roofs	8905	301	7614000	258
Whole building			27434000	1287

Table 2. Avoided Impacts Summary: The Birks Building

Building Component	Total Primary Energy, MJ	Total GWP, Equivalent CO_2 tons
Columns and beams	3485000	155
Intermediate floors	2761500	171
Exterior walls	8957000	496
Windows	3156000	157
Interior walls	1461000	51
Roofs	7614000	258
Whole building demolition	478800	273
Total avoided impacts (whole building)	**27913300**	**1561**

elevations), exterior insulation finish system cladding for the east elevation, which is not visible from the street

The embodied greenhouse gas and primary energy of the replacement building and the avoided impacts (by not replacing the building) are presented in Tables 1 and 2, respectively. The avoided GWP impact of the Birks Building (Table 2) is equivalent to the CO_2 emissions from the electricity use of around 500 Canadian homes for one year.

OPERATING ENERGY

Whether or not an existing, renovated building can perform as well as a new building in terms of operating energy can be a key consideration in the decision to keep or demolish the existing building. The Screening Tool for New Building Design from the Office of Energy Efficiency (NRCan 2010) was used to estimate the energy performance of the new buildings, assuming that a typical new building would meet the minimum requirements of the *Model National Energy Code for Buildings* (*MNECB*) (NRC 1998). The *MNECB* was published by the National Research Council of Canada in 1998. The code contains a set of prescriptive energy-efficiency measures that should be included in new commercial buildings.

The screening tool works by comparing a new building design to a reference building, with the latter defined as a building designed to the prescriptive requirements of the MNECB. The reference building is architecturally identical to the proposed design, having the same areas, window-to-wall ratio, fuel types, appliance and electrical usage, and process equipment and insulated to the *MNECB* prescriptive levels applicable to the climatic region and space heating fuel for the location.

The purpose of the screening was not to develop an accurate prediction of annual energy use. Rather, the purpose was to conduct a high-level comparison to the reference building. Many simplifying assumptions were therefore incorporated within the tool, and it assumed typical building use patterns and standards of construction.

The intent for the project was to model the new building and compare the performance to utility bills for the existing building. Although the intent was to provide reasonable approximations not precise estimates, the variables and limitations inherent to the screening tool and EcoCalculator necessitated additional analysis to confirm the reasonableness of the proposed approach. Four scenarios were modeled for each building using the screening tool:

1. **Existing Renovated Building.** A model for the existing building was developed and compared with existing utility bills. The model was then fine-tuned (by adjusting mechanical and electrical system efficiencies or occupancy numbers) to ensure that it matched actual energy use as close as possible. This step was added to obtain an indication of how significant the assumptions and limitations of the model are and how these may impact the results.
2. **Best Renovated Building.** A “best renovation scenario” was then modeled, maintaining the fundamentals of the existing building—floor plate area, building height, window-to-wall ratio, and HVAC distribution system—but encompassing available energy saving options, such as more efficient lights and more efficient boilers, within the constraints and limitations implemented in the model. We did not consider the impacts these types of renovations would have on the historic characteristic of the buildings or the cost implications of implementing these upgrades. This scenario was included to determine if the fundamental structure of a historic building imposes limitations on the energy performance of the building.
3. **Typical New Building.** The new building design was modeled as originally planned. This model incorporated the new building height and new window-to-wall ratio. The model was based on the reference building within the screening tool, with minor alterations that are typically observed within new construction (such as the use of variable-speed fans).
4. **Best New Building.** The new building design was also modeled assuming the best available energy saving options. This model encompassed the same fundamentals as the typical new building—floor plate area, building height, window-to-wall ratio, etc.—but encompassed readily available and reasonably typical energy saving options. This model represented the best energy performance that could be achieved in a new building. This scenario was included to allow a comparison between the energy consumption of a typical building and one that attempts to achieve energy conservation, and this comparison showed a potential range of energy usage in new buildings. A comparison of the potential improvements for a new building to the potential improvements of the existing building also allowed an analysis of the limiting factors of the existing historic building. Note that the “best new building” was limited to systems that are both readily available and reasonably conventional (such as triple glazing, condensing boilers, etc.). This building was intended to display a very efficient new building but not serve as a truly “best” building (as “best” would use near zero energy but be cost prohibitive).

Data Gathering

A significant amount of detailed information and knowledge of building construction is necessary to accurately analyze operating energy usage. Obtaining detailed data for the existing buildings took time and commitment from all parties, including the building owners and designers of record for the renovation (architectural, mechanical, and electrical). We experienced challenges in contacting the correct individuals to obtain the data and constraints associated with the time and expense necessary to locate and copy the information as well as with the motivation for the owners and designers to provide this information. While much of the data was eventually obtained, a significant number of assumptions and averages were necessary to obtain results from the screening tool. Notable assumptions for the Birks Building include the following:

- **Windows.** Determination of the properties (U-factor, solar properties) of existing windows is difficult. Published values from ASHRAE (2005) and knowledge of performance of historic windows on other projects were utilized to estimate performance of some window types. Note that air leakage was not a variable considered, as the modeling software used does not allow consideration of window air leakage (we do not support this assumption but present it as a limitation of the software).
- **Air Leakage.** The screening tool assumes typical air infiltration rates for new buildings, which are generally more airtight than historic buildings. Therefore, the window U-factor was adjusted to emulate the effect of increased infiltration and uncertainties in the actual envelope construction until the results were similar to the actual utility bills.
- **Wall/Roof Construction.** Intrusive test openings were not performed, and available drawings were assumed to be accurate. Some assumptions on insulation performance values were made, as the exact brands of materials were not known.
- **Lighting.** In many of the buildings the lighting was installed by the tenants and the layout and details of fixtures were not available. Lighting loads were based on available documents, our on-site review, and general experience and understanding of typical lighting practices in renovated buildings. The lighting loads were adjusted to emulate the electricity utility bills.

Results of the Screening Tool

The screening tool results for the existing renovated building were used as the benchmark for comparison with the best renovation, typical new building, and best new building scenarios. It is important to emphasize that numerous assumptions that affect the reliability of the results had to be made at several stages of the modeling procedure, including for the new buildings and analysis of actual energy consumption for the existing buildings. Although this affects the reliability of the figures, trends in the increase and decrease of energy consumption between the different scenarios are consistent with expectations based on our knowledge of the facilities.

The comparative results of the screening tool were generally similar for all four buildings (AI 2009b), indicating that the energy consumption of the existing renovated buildings would (or could) be relatively similar to the energy consumption results expected for a typical new building. This is not surprising given that the recent renovations at the buildings employed up-to-date construction practices. The results may also reflect the positive energy use implications of the high mass envelopes typical of historic buildings. As well, the relatively low window-to-wall ratios for historic buildings definitely have a positive impact on energy consumption.

The poorer performance of the best new building appears to be due to the higher glazing ratio assumed for the typical new building. The Birks Building had a glazing-to-whole-wall ratio of 26%, whereas the new building was assigned a glazing ratio of 40% (to maintain consistency with the EcoCalculator and typical design). This change in the amount of glazing had a significant impact on energy use.

The results of the screening tool for total energy consumption (GJ) of the existing renovated building (see Table 3) was within 10% of the measured consumption from the utility bills. This is considered an acceptable margin, based on the limitations of the screening tool and utility bills.

The existing renovated building appeared to consume less energy than the typical new building for the Winnipeg location (see Table 4). This was consistent with expectations, as some energy saving initiatives were included in the renovations.

The most notable finding was that the physical constraints of a heritage building do not appear to limit the potential for reasonably good energy performance of a building. The biggest limitation may be the level of intervention for the renovations of the historic building. In this analysis, one of the

Table 3. Total Operating Energy Consumption (per year)

	Existing Renovated Building	Best Renovated Building	Typical New Building	Best New Building
GJ	2790	1506	2982	1631
CO_2e	11,000	5900	11,800	6400

Note 1: CO_2e numbers are presented under the assumption that all heating and cooling are provided by electricity. This assumption is valid for the existing renovated building but may not be valid for the other (fictional) scenarios.
Note 2: CO_2e numbers are taken from the Athena Impact Estimator for Buildings (AI 2010) and are valid for a Winnipeg, Manitoba, location. Manitoba electricity is typically considered fairly "clean" and has a relatively low CO_2e/GJ ratio. These results could be more than ten times larger for other areas in North America.

Table 4. Per Cent Difference From Existing Renovated Building

	Best Renovated Building	Typical New Building	Best New Building
GJ and CO_2e	46% less	7% less	42% less

primary limiting factors to energy savings for the typical new building may have been the applied 40% window-to-wall ratio.

We caution that these conclusions are based on data that contains inherent assumptions and limitations that may be significant enough to skew the data. Each project must be considered uniquely and a determination must be made for each project on the validity of the modeling for that specific case. In the four case studies, one had energy simulation results that varied from the measured results by enough to bring to question the validity of the conclusions. In that case, the potential difference in energy use (due to the variability between actual and measured energy) could range from a 5% increase in energy to a 27% decrease (instead of the 11% decrease noted from the direct comparison).

Although the conclusions appear reasonable based on our experience and knowledge of the buildings, the limitations of the CBIP screening tool introduced significant variables. It appears that these variables may be significant enough to have impacted conclusions that are based on the results of the screening tool. A full energy model could provide potentially more accurate results, but it would be considerably more time consuming and would still be subject to the limitations imposed by not knowing actual infiltration rates, envelope construction, and profiles of use.

ISSUES AND SPECIAL CONSIDERATIONS

In addition to assessing the environmental implications of preserving the case study building, a fundamental objective of this project was to develop a basic approach or template that can be readily applied to other historic buildings. As might be expected in a pilot study of this nature, we had to address specific unforeseen issues by making assumptions or adopting specific analysis procedures. The subsections that follow focus on key issues or considerations that will have to be dealt with in future studies by applying common approaches. Note that there are many other issues that should be considered, such as capital and operating costs and social and cultural impacts. These impacts are important but beyond the scope of this paper.

Avoided Demolition Impacts

To avoid having to undertake detailed studies of the impacts from demolition of an existing building, we drew on an earlier study, "An Environmental Life Cycle Assessment of a Typical Office Building," undertaken for Public Works and Government Services Canada in the 1990s (AI 1995). The study estimated the energy associated with demolishing structural office systems in two geographic regions of the country for various material recycling and reuse scenarios. The resulting per square meter estimates reflect the use of diesel fuel by trucks, heavy machinery, and on-site electricity generators during demolition activities.

The estimated values taken from that study and applied in this project are as follows:

- primary energy = 0.14 GJ/m^2
- global warming potential = 0.08 Eq. CO_2 tons/m^2

While not precise, these demolition energy values can be applied with reasonable confidence to any cast-in-place structure, are probably acceptable for steel structures, and undoubtedly overstate the impacts for wood structural systems. At some point, it would be useful to undertake a more detailed assessment of demolition impacts going beyond the structural systems to include all envelope components, intermediate floors, and transport to landfills, etc. The results will undoubtedly show that the above estimates understate this aspect of avoided impacts and are therefore conservative from a preservation decision perspective.

Renovation Impacts

The impacts of existing renovation were not included in the study. Again, this category poses problems because different buildings will undergo renovation to different degrees and only a detailed building-by-building analysis can provide reasonable estimates. The problem is complicated by the fact that historic buildings will typically have undergone renovation over a period of many years, with the latest work building on what came before. In most situations, the estimate of renovation required when a decision is made to preserve a building is unlikely to be so extensive as to significantly change the avoided environmental impacts aspect of the decision process.

Attached or Adjacent Building Issues

Historic buildings may be either attached to other buildings are have other buildings very close to them. In such situations, some exterior walls in a replacement building would not have 40% windows as is assumed in the EcoCalculator assemblies. In other cases, an existing building may be separated from its neighbors by sufficient distances that all walls would have windows at, or approaching, the 40% level. For the purposes of this study, we have assumed the same floor plate for the new buildings as for the existing buildings and that the new buildings would not be attached to, or even be too close to, a neighbor. Applying the EcoCalculator external wall assembly data assumes the 40% window-to-wall ratio in all exterior walls. Since windows typically have a higher per square meter embodied energy and global warming potential compared to opaque walls, this approach overstates the avoided impacts for any situation where the window-to-wall ratio would be significantly less than assumed.

New Building Interior Configuration

In the case studies, the interior configurations of the new buildings were assumed to be essentially similar to those of the existing buildings. This assumption affected the number of interior partitions included in the new building energy and global warming potential estimates. The problem is how to determine what would be built if there is a marked departure from the existing configuration—for an office building, for example. Would it be an open plan with minimal private office space, a series of fixed private offices, or moveable floor-to-ceiling partitions? This issue could easily be resolved by simply adjusting the EcoCalculator inputs if it was known or suspected that a specific interior configuration was likely.

The Air Space Issue

The last issue we want to at least mention here is the treatment of the air space above an existing building, especially in a dense urban area. This aspect of the decision process was well beyond the scope of the study and was not something that could be taken into account using the EcoCalculator or other available tools. At the same time, it can be a critical aspect of the debate about whether to keep a historic building.

Historic buildings typically fall toward the low-rise end of the height spectrum, with the highest of our case study buildings at six stories. In urban areas, the air space above such buildings is very valuable and, indeed, using that space and increasing densification is often cited as a sustainability justification for building new buildings. For example, it helps prevent urban sprawl with attendant reduced transportation and underground infrastructure construction. And if we look at the per square meter environmental effects of replacing a five-story building with a thirty-five-story office tower, we will see quite different numbers compared to the estimates we have presented here using the avoided impacts approach.

There is no easy answer to this part of the decision process unless a municipality has regulations in place that allow a transfer of air space from a historic building to a new development on a different site. But this aspect should not be forgotten or ignored, and the real answer may be to ensure that municipalities do indeed provide for transfer. In addition, the air space issue and its resolution have broader social, aesthetic, and cultural implications that should be taken into account.

ANALYSIS TEMPLATE

Following is a summary of the basic analysis steps for estimating embodied avoided impacts. Note that the authors acknowledge that operating effects of the building are very important and should be considered, but a common obstacle in this type of analysis is the development of a reasonable estimate of embodied effects (there are many ways to estimate operating effects), so the methodology below focuses on embodied effects only.

1. Obtain floor plans, elevations, and information regarding the history of the building, specifically repairs and renovations completed.
2. Visit the site to confirm the accuracy of drawings and verify the scope of the renovations. Review the site and building location for constraints or limitations that may impact the design of the new building, such as buildings immediately adjacent to the existing building. Review typical construction assemblies for the geographical area.
3. Determine assembly areas for the replacement building: structural (footprint by number of floors), exterior wall areas (based on existing wall lengths and new building height (3 m per floor), window areas (based on 40% window to wall ratio), area of interior walls, roof area (based on footprint).
4. Use the free version of the Athena EcoCalculator (AI 2009a) for assemblies for the relevant geographic region and building height: low-rise (under four stories) or high-rise (five stories and above).
5. Select assemblies from the EcoCalculator for the new building based on constructions used in the geographical location, size of building, type of building, site, etc.
6. Enter areas for the new building of each major assembly category (e.g., Exterior Walls) into the EcoCalculator. The impact totals will indicate their combined environmental impact.
7. Due to underlying assumptions inherent within the EcoCalculator, a 40% window-to-wall ratio must be used. To do so, take 40% of the total exterior wall area of the new building. The result becomes the area to be entered in the Windows assembly category.
8. After entering assemblies for each category, the small chart at the top of the screen will indicate the environmental impacts by building component within each category as well as for the whole building.
9. In order to calculate demolition effect factors, determine the gross area (square feet) of the new building. The gross area of the building should then be multiplied by the following factors:
    a. Primary energy related to demolition = functional square footage of building × 0.14 GJ/m^2
    b. Global warming potential related to demolition = functional square footage of building × 0.08 Eq. CO_2 tons/m^2
10. The GWP results from the new building can then be entered into the United States Environmental Protection Agency’s Greenhouse Gas Equivalencies Calculator (EPA 2009). This free tool provides the user with more tangible, “humanized” results, such as the number of homes for which emissions from electricity use would be equivalent to the avoided CO_2 emissions for a given building.

CONCLUSIONS

The project was intended as the development and testing of a methodology and not as research on the specific buildings on which the methodology was tested. Accordingly, conclusions should not be presented on the specific case studies or their results but rather on the success of the methodology. Conclusions we reached include the following:

1. The most notable conclusion is that tools and methods are available to more accurately understand the material and

operational environmental impacts of existing historical buildings as compared to alternative new constructions.

2. An understanding of the environmental impacts of historic buildings and comparable new buildings requires numerous assumptions. Accordingly, the methodology presented should only be used by persons knowledgeable of building energy use and building envelopes and capable in the use of the various tools suggested.
3. Renovated historic buildings can function comparably to new buildings using common environmental measures such as energy intensity and global warming contributions.

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