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Canada

Real Property GHG Life-Cycle Cost Analysis (GHG LCCA) Guidance

Centre for Greening Government

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Contents

1 Purpose 4
2 Policy Context 4
3 Scope 5
4 Roles and Responsibilities 6
5 Conducting a GHG LCCA 6
5.1 Life-Cycle Cost (LCC) Scenarios and Incremental Net Present Value (NPV) Calculation 7
5.2 Single-Disciplinary Projects 9
5.3 Major Projects: Retrofits, EPCs, Acquisitions and New Buildings 9
5.3.1 Major Project Energy Modeling and Simulation Requirements 9
5.3.2 Energy Modeling Simulation Tools 10
5.3.3 Energy Performance Contracts (EPCs) 10
5.4 GHG Emission Factors 11
5.5 GHG LCCA Tools and Costing Parameters 12
6 Presentation of Results for Project Approval 12
Annex 1: Worked Examples 13
Annex 2: References 21

1 Purpose

To evaluate options for real property investments using a greenhouse gas (GHG) Life-cycle Cost Analysis (LCCA) to determine the best-value option that minimizes operational GHG emissions and energy use. This guidance supports the implementation of the Policy on the Planning and Management of Investments and the Directive on the Management of Real Property by providing a framework for incremental analysis to support the deep decarbonization of federal assets. It supports the TBS best value philosophy by incorporating life-cycle costs including climate related externalities. The methodology integrates a notional cost for future greenhouse gas emissions into real property investment analysis to avoid decisions that could create climate stranded assets.

2 Policy Context

The Greening Government Strategy (GGS)[1] commits the federal government to net-zero real property operations by 2050. To implement net-zero in real property and fleet operations, the Government of Canada will reduce absolute Scope 1 and Scope 2 GHG emissions by 40% by 2025 and by at least 90% below 2005 levels by 2050. On this emissions reduction pathway, the government will aspire to reduce emissions by an additional 10% each 5 years starting in 2025. To achieve these targets, the GGS requires departments and agencies to commit to the following requirements for real property investments:

- All new federal buildings (including build-to-lease and public-private partnerships) will be net-zero carbon[2] unless a life-cycle cost-benefit analysis indicates net-zero-carbon-ready[3] construction
- All major building retrofits, including significant energy performance contracts (EPCs), require a greenhouse reduction life-cycle cost analysis (GHG LCCA[4]) to determine the optimal GHG savings (the life-cycle cost approach will use a period of 40 years and a carbon shadow[5] price of $300 per tonne and be maintained at all project stages)

A life-cycle period of 40 years was selected corresponding to the time before a half-life retrofit is typically considered. The shadow price of $300/tonne is based on consultant studies which looked at the incremental cost to decarbonize specialized building archetypes in the federal government's portfolio of assets.

This document should be read in conjunction with the following TBS polices and directives:

- Policy on the Planning and Management of Investments- Canada.ca (tbs-sct.gc.ca)
- Directive on the Management of Real Property- Canada.ca (tbs-sct.gc.ca)
- Directive on the Management of Projects and Programmes- Canada.ca (tbs-sct.gc.ca)

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[1] Greening Government Strategy: A Government of Canada Directive - Canada.ca

[2] A net-zero carbon, climate-resilient building is one that is located, designed, built and operated to minimize the impacts of a changing climate; highly energy-efficient; and fully powered from on-site and/or off-site clean energy sources. Starting in 2025, these buildings will have at least 30% less embodied carbon in major construction materials.

[3] A net-zero-carbon-ready building is one that could operate as a net-zero-carbon building in the future.

[4] Life-cycle cost analysis (LCCA) is a method for assessing the total cost of facility ownership.

[5] Shadow carbon pricing is a method of investment or decision analysis that adds a surcharge for carbon dioxide that would be released to market prices for projects that involve significant carbon emissions.

- Policy on Financial Management- Canada.ca (tbs-sct.gc.ca)

Investments decisions for real property assets must be based on a custodian's real property portfolio strategy[6]. The real property portfolio strategy is a strategic planning document with a minimum ten-year planning horizon that guides decision-making for a custodian's portfolio. It looks beyond singular assets and describes how a custodian's portfolio will be intentionally and proactively managed to support: the department or agency's mandate, strategic business objectives and forward-looking program requirements; the Government of Canada's enterprise-wide priorities for real property and socio-economic and environmental outcomes (e.g., greening government operations); and sound stewardship and best value to the Crown. The Guide on real property portfolio strategies is available to custodians on GCPedia.

3 Scope

The requirement to conduct a GHG LCCA applies to all custodian departments and agencies[7], and all building archetypes and associated infrastructure including district energy systems.

While the use of the GHG LCCA methodology is required for major retrofits of existing buildings, it is also a useful tool when designing net-zero carbon new construction to determine the best value design. When applied to new construction, the LCCA can support the decision to build to net-zero carbon ready, if immediately building to net-zero carbon is not financially or technically feasible. The GHG LCCA should be conducted for the construction and operational phases of the building lifecycle. The decommissioning phase and embodied carbon considerations are currently not in scope. The methodology applies to all projects whether approved within departmental project approval authority limits or submitted to the Treasury Board for approval. It applies to the following asset types:

- Crown-owned buildings and crown-owned engineering assets
- Built to lease and lease purchase assets
- Public-Private Partnerships (P3) projects
- Energy Performance Contract (EPC) projects

This guidance does not apply to leased or sale-lease-back assets.

The following GHG emission categories should be included in the analysis: scope 1 emissions (from combustion) and scope 2 emissions (district energy and electricity). The purchase of carbon offsets is not an eligible measure to reduce GHG emissions and achieve net-zero at the individual investment level.

The methodology can also be used in more sophisticated analyses where the costs and GHG impacts of various real property asset decisions such as building demolition and replacement/rebuild or building renovation/expansion are compared.

[6] Policy on the Planning and Management of Investments, 4.1.18.1
[7] Crown corporations are encouraged to adopt the GHG LCCA methodology.

4 Roles and Responsibilities

The intent of conducting a GHG LCCA in major real property projects is to ensure that:

1. Sufficient capital is projected for the decarbonization of the asset during investment planning (pre-project approval)
    - ±20% cost estimate stage (class D "Indicative" estimates)
2. Sound technical, financial and GHG analysis is conducted at the Project Definition stage so best value solutions can be presented for decision making
    - ±15% cost estimate stage

All applications for project approval should comply with this guidance including those submitted to TBS and those approved internally within a department. The GHG LCCA should be conducted when developing the Project Definition or equivalent. The results must be incorporated into the project costing before Project Authority (PA)/ Expenditure Authority (EA) is granted. The Project Definition must clearly specify what costs have been included within the PA to account for the reduction of GHG emissions and will be sought with the EA for implementation approval. The major roles in the GHG LCCA methodology are as follows:

Department Project Leader	• Ensures GHG reduction measures are incorporated in the Project Definition • Ensures decarbonization measures are retained throughout the project implementation lifecycle
Department Project Proponent, Consultant or ESCO	• Performs energy modeling and assessment • Conducts the GHG LCCA
Department Corporate Branch or equivalent	• Ensures the GHG LCCA is implemented in the organization (*Updates internal departmental policies and guidance*)
Real Property Portfolio Management	• Ensures investments are consistent with the departmental real property portfolio strategy, investment plan and net-zero climate resilient portfolio plan
Financial and Treasury Board Program Sector Analysts	• Ensures GHG LCCA has been implemented in projects submitted to internal finance branches, and to TBS if seeking project approval • Ensures standardized presentation of results

5 Conducting a GHG LCCA

Life-cycle cost analysis (LCCA) is a method for assessing the total cost of facility ownership. It considers the costs of constructing, renovating, owning and maintaining, repairing or replacing building systems. LCCA is especially useful to compare investment alternatives that fulfill the same functional requirements but differ with respect to initial costs and operating/maintenance costs. A GHG LCCA incorporates climate related externalities by incorporating a carbon cost for GHG emissions over the lifecycle. The GHG LCCA will help determine the degree to which investments that may increase initial cost, but result in reduced GHG emissions, will deliver life-cycle cost savings (for example the installation of a high-performance heating, ventilation, and air conditioning (HVAC) or fenestration system).

The Greening Government Strategy requires that the cost of future GHG emissions is included in this analysis using a Shadow Price on Carbon set at $300/tonne. The shadow price should be used instead of provincial or territorial carbon taxes or other similar regulated carbon pricing schemes.[8]

Departments are encouraged to engage professional consultants to carry out a GHG LCCA. Standing offers are available in each Public Services and Procurement Canada (PSPC) region with qualified consultants who can perform this task.

5.1 Life-Cycle Cost (LCC) Scenarios and Incremental Net Present Value (NPV) Calculation

There are numerous costs associated with acquiring, operating, and maintaining a building or building system. Building-related costs usually fall into the following categories:

- Initial Costs - Design and Construction/Renovation Costs and service infrastructure costs (e.g., increased electrical service capacity)
- Energy Costs and other operating costs (for example maintenance costs) over 40 years
- Recapitalization Costs for equipment and components of the building fabric etc. that must be replaced within the 40-year lifecycle
- Reversionary or Residual Values - Resale or Salvage Values
- Finance Charges - (e.g., contract costs for EPCs)
- Non-Monetary Benefits or Costs (e.g., occupant comfort)

The GHG LCCA should be performed in current dollars considering the rate of inflation, discount rates, and price escalation rates (which should be sourced from departmental finance branches or PSPC Finance Branch). The shadow price on carbon should remain at $300/tonne each year and should not be escalated into the future. However, the discount rate should be applied when calculating the present value of the carbon costs over the lifecycle.

After identifying all costs by year and amount and discounting them to present value, they are added to arrive at total life-cycle costs for each scenario:

Life-cycle Cost[9] = Initial Capital Cost + Recapitalization Costs – Reversionary (Residual Value) + Energy Costs + Other Costs + Carbon Cost

Life-cycle Cost	Total life-cycle cost in present-value (PV) dollars of the given scenario
Initial Capital Cost	PV investment costs (if incurred at base date, they need not be discounted)
Recapitalization Costs	PV capital replacement costs (e.g., HVAC, exterior wall cladding, windows etc.)
Reversionary (Residual) Value	PV residual value (resale value, salvage value) less disposal costs

[8] For consistency one national carbon shadow price will be used in federal projects over the 40 year life-cycle. This position may be adjusted as future strategies on carbon tax and cap and trade systems in place across Canada evolve. It is suggested not to attempt to remove the effects of regional carbon taxes from utility bills (either those related to electricity production or fossil fuel use).

[9] The life-cycle cost will not be equivalent to the project approval amount as it covers a broader scope of costs.

Energy Costs	PV of annual energy costs[8] (over the lifecycle). Note that charges related to the shadow carbon price should be included as a separate item under Carbon Cost (see below).
Carbon Cost	PV of shadow cost of carbon (annual GHG emissions multiplied by $300/tonne shadow price) Note that the shadow price should be used instead of a projected national carbon tax price.[8] The shadow price should not be inflated.
Other Costs	PV of other costs (e.g., contract costs for EPCs), O&M costs over the life-cycle

A minimum of 4 alternative cost scenarios should be developed under the GHG LCCA methodology, over 40 years with a $300/tonne carbon shadow price, as follows:

Scenario 1: **Baseline Costing**

- Represents minimum departmental standards or, where not available, standard market design practices and local code requirements.
  - Meets the functional needs of the project and applicable regulations
  - Provides a baseline for cost comparison purposes only
  - In most cases, this should not be the recommended option, but is required for baseline cost comparison

Scenario 2: **Cost Neutral GHG Reduction**

- To achieve GHG emission reductions that are cost-neutral over 40 years using a $300/tonne carbon shadow price i.e., for an overall life-cycle cost equivalent to the baseline
  - Energy modeling and simulations will be performed on selected bundled measures until the best option is identified which provides the greatest GHG savings with an equivalent or positive incremental Net Present Value (NPV) relative to the baseline scenario
  - Priority should be given to maximizing energy efficiency and resource conservation, before fuel switching alternatives are considered for reducing GHG emissions
  - In most cases, this is the minimum design to be built

Scenario 3: **Maximum GHG Reductions**

- To achieve the maximum GHG emission reduction potential of the project
  - The proponent should evaluate the measures required for the project to reduce the carbon emissions footprint to as close to net-zero as possible
  - Highlights the cost associated with achieving this outcome

Scenario 4: **Optimized GHG Reduction**

- Potential designs that incorporate elements of scenarios 2 and 3 based on best value
  - Determine a fiscally responsible option that optimizes GHG emission reductions versus additional lifecycle costs
  - It is expected that this hybrid optimized design will incorporate all the measures selected for scenario 2 and individual conservation measures identified in scenario 3 that are almost cost-effective and/or lead to significant GHG emission reductions

The incremental NPV of scenarios 2, 3 and 4 should be calculated by subtracting their life-cycle cost from the baseline costing scenario.

Scenario 1, the baseline costing scenario, is for cost comparison only and should typically not be built.

For the purposes of the GHG LCCA methodology, projects are classified under 2 categories, single-disciplinary projects such as equipment replacements, and major projects for example significant renovations or new construction.

5.2 Single-Disciplinary Projects

Single-disciplinary are defined as projects impacting only one building element or system that effect GHG emissions and are not triggered by the major project criteria in section 5.3. Because single disciplinary projects are less complex in nature, they do not necessarily require whole building energy modeling and simulation. Examples of single disciplinary projects are the replacement of a chiller, boiler, air handler, or a window replacement project.

Associated GHG emission savings and incremental net present value (NPV) over 40 years for each analyzed scenario (compared to the baseline costing scenario) will be evaluated using the method in section 5.1. The NRCan RETScreen[10] software can be used to rapidly identify, assess and optimize the technical and financial viability of potential projects.

There are financial and environmental benefits in conducting a GHG LCCA for projects of much lower value as demonstrated by the example in Annex A.

5.3 Major Projects: Retrofits, EPCs, Acquisitions and New Buildings

A major project is defined as a project that is multi-disciplinary in nature, i.e., the project impacts more than one building element or system. Major renovations, acquisitions and newly constructed buildings are major projects and thus require building energy modeling and simulation to assess the energy and GHG performance of design scenarios.

The major project GHG LCCA methodology relies on building energy modeling and simulation to estimate the annual energy consumption and GHG emissions of each design scenario.

5.3.1 Major Project Energy Modeling and Simulation Requirements

Energy modelling and simulation is a virtual representation of the building, specifically of the elements that make up a building. The energy, air, and moisture flows into and out of the building and its elements are considered to predict the building's annual energy requirements. Energy modeling and simulation is commonly performed to verify a building's compliance to an energy code and to estimate the building's annual energy consumption, annual energy costs and annual GHG emissions.

Building energy modeling and simulation is the only accepted tool that is capable of accounting for the interaction between different building elements and of analyzing multiple energy conservation

[10] https://www.nrcan.gc.ca/maps-tools-publications/tools/data-analysis-software-modelling/retscreen/7465

measures simultaneously. Energy modeling and simulation supports an integrated design process among building professionals: architects designing the building envelope, mechanical and electrical engineers designing the heating, ventilation, and air-conditioning (HVAC) and lighting systems, and other members of the design and project teams. It provides the ability to estimate the energy savings, energy cost savings and GHG emission reductions of the energy conservation measures, relative to the baseline scenario, that are considered for each design scenario.

Energy modeling should be conducted at an appropriate level of accuracy depending on the stage of the project. Note the intent of conducting a GHG LCCA in major real property projects is to ensure that:

1. Sufficient capital is projected for the decarbonization of the asset during investment planning (pre-project approval)
   - ±20% cost estimate stage (class D “Indicative” estimates)
2. Sound technical, financial and GHG analysis is conducted at the Project Definition stage
   - ±15% cost estimate stage

5.3.2 Energy Modeling Simulation Tools

A whole building hourly energy simulation software tool that conforms to ASHRAE Standard 140 - Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs should be used at the start of the project. Examples of software tools that are widely used by industry and that conform to ASHRAE Standard 140 include IESVE, eQUEST, CAN-QUEST, OpenStudio/EnergyPlus and Design Builder. Alternatively, the NRCan RETScreen software may be used based on the recommendation of the department delivering the project and based on the energy modelling requirements of the project stage. The professional performing the energy modelling should have experience with the tool selected and understand the tool’s assumptions, validate the inputs provided to the tool and perform quality assurance of simulation results.

Both historical data and future projected climate data should be considered in the GHG LCCA.

5.3.3 Energy Performance Contracts (EPCs)

Energy Services Companies (ESCOs) implement energy conservation measures (ECMs) in federal buildings via an EPC. The ECMs are financed by the energy savings over the term of the contact, the ESCO obtains the upfront implementation capital from the private sector. An EPC contract term is typically up to 15 years as financing costs beyond this period become significant. ESCO returns on investment allow for moderate energy savings to be realized using an EPC. Deeper energy savings and significant GHG reductions can be achieved through additional capital injection by the Crown. This enables the EPC repayment term to be maintained at around 15 years but allows the addition of longer payback measures justified by the carbon shadow price. Recognizing the typical 15 year EPC contract term, the GHG LCCA should still be conducted over a period of 40 years to leverage the best use of the Crown funded portion.

The application of the GHG LCCA in an EPC contract can be summarized as:

Step 1 - Identify the suite of measures that yields a payback within the EPC contact term (typically around 15 years).

Step 2- Apply the GHG-LCCA methodology to evaluate deeper GHG reduction measures considering the 40-yr NPV with application of the shadow carbon price.

Note step 2 measures should be implemented, but the difference in cost between 1 and 2 should be funded by the Crown capital injection portion. If a standard major procurement construction project demonstrates better value and GHG savings, and funding would be available within a reasonable timeframe then it should be considered. Likewise, should the Crown funded portion exceed the value of the core EPC, alternative implementation options such as a major retrofit or replacement should be considered. If the Crown funded portion is significant it would be preferable to integrate it into the EPC performance results that place the burden for delivering the forecasted GHG reductions on the Contractor.

5.4 GHG Emission Factors

The emission factors for fuel, electricity and district heating/cooling provided by the *Federal Greening Government Reporting Guidance* should be used to calculate the GHG emissions of project scenarios.

The intent of the GHG LCCA methodology is to minimize project emissions, as such:

- Fuel switching from electricity to fossil fuel should not be considered, as it is forecast that all electrical grids in Canada will be low emitting by 2040, additionally:
    - The federal government has a commitment to procure 100% clean electricity by 2025.
    - In December 2018, Canada announced regulations to phase-out traditional coal-fired electricity by 2030 as well as greenhouse gas regulations for natural gas-fired electricity.
- Project designs should effectively consider the 40 year life-cycle emissions factor for electricity to be zero.
    - Departments may choose to use the location-based[11] GHG accounting methodology for electricity related emissions in the first few years of a project until 2025, or potentially longer in regions where the government is not procuring renewable electricity locally (i.e., in provinces where the national renewable energy certificate (REC) program is used to displace the emitting portion of the provincial or territorial grid).[12]
        - In this situation, projects should use ECCC projected yearly values for provincial grid electricity emission factors.

[11] The location-based method considers the average GHG intensity of the electricity grids that provide electricity, regardless of any contractual arrangements that an organization has for clean electricity. To quantify indirect emissions using the location-based method, reporting organizations use emission factors that are based on the geographic location of each facility and that correspond to the grid-average emission factor of power-generating facilities that supply power to the grid.

[12] Note these emissions will be displaced in the future as the Greening Government Strategy commits to procuring 100% clean electricity by 2025.

5.5 GHG LCCA Tools and Costing Parameters

A department may use its own tools to conduct the GHG LCCA methodology to produce the required analysis for project approval. The PSPC GHG Options Methodology[13] also provides templates for presenting the results of a GHG LCCA.

Values for discounting and inflation rates should be sourced from corporate finance branches or alternatively PSPC Finance Branch (FB). The discount rate is typically set equal to the cost of borrowing for the Government of Canada and is a function of the life expectancy of the investment. Individual inflation rates should be used for utility costs, maintenance, and construction costs.

The annual carbon cost should not be escalated for inflation during the 40-year lifecycle period. A constant $300/tonne value should be applied. However, future costs should be discounted at the appropriate rate when calculating the present value.

6 Presentation of Results for Project Approval

A summary GHG LCCA financial analysis identifying the recommended option (Figure 1) should be presented to departmental financial analysts and TBS program sector analysts (in cases where departmental delegated authorities are exceeded, and Treasury Board approval is required). When submitted to TBS, the program sector analysts will consult with the Centre for Greening Government on project approval.

Scenario	**1: Baseline Costing**	**2: Cost Neutral GHG Reduction (over 40 years inc. carbon price)**	**3: Maximum GHG Reduction**	**4: Optimized GHG Reduction**
Recommended Option	N	(Y/N)	(Y/N)	(Y/N)
Annual GHG Emissions				
Capital Cost				
Energy Costs				
40 Year Life-cycle cost				
Incremental NPV compared to baseline	N/A			
Percentage increase in Life-cycle Cost	N/A			
Benefits				
Disadvantages				

Figure 1 Presentation GHG LCCA of Results

[13] Guideline - Project GHG Options Analysis Methodology: PSPC, Real Property Services Branch, Technical Services, Greening Government, Climate Action, GHG and Energy: Updated 2020-11-26

Annex 1: Worked Examples

The worked examples demonstrate how the GHG LCCA methodology was applied to specific projects. The GHG LCCA methodology was a component of the project's investment analysis. In each case, the analysis defined the different options available and determined the best value to the Crown, considering capital costs, life-cycle costs and GHG emissions. Based on the analysis, the project team recommended the option with reasonable incremental capital and lifecycle costs compared to a business-as-usual baseline, which achieved significant GHG emission reductions.

- Worked Example 1: Single-Disciplinary Project
- Worked Example 2: Major Project Existing Building Retrofit
- Worked Example 3: Major Project New Construction

Worked Example 1: Single-Disciplinary Project

Single Disciplinary Project Example - Upgrade and recommissioning of Air Handler Unit and Heat Wheel

Description

Install occupancy sensors and upgrade the air handler controls to monitor ventilation demand in the meeting rooms; refurbish the air handler with new supply and return fan motors, variable frequency drives (VFDs), synchronous drive system and upgrade heat wheel; and recommission the meeting rooms' ventilation system.

Options	***1: Status Quo***	**2: Occupancy sensors and VFDs**	***3:* Option 2 plus heat wheel *(Recommended)***
Description	***(Status Quo: Current State of Systems Operations)***	***Occupancy sensors and VFDs***	***Option 2 plus heat wheel***
GHG Emissions (Tonnes eCO2 per year)	79	21	19
Annual carbon shadow cost ($300/ton CO2e)	$23,700	$6,300	$5,700
Energy Savings (GJ per year)	0	892	921
Energy Costs Savings ($ per year)	$0	$23,905	$24,656
Maintenance Costs Savings ($ per year)	$0	$2,400	$2,400
Other Costs (Equipment replacement cost or special maintenance costs during the lifecycle)	$77,150	$77,150	$42,094
Incremental Capital Cost	$0	$75,000	$90,000
LCC ($ Over 40 Years)	$2,263,622	$957,017	$893,827
Incremental NPV ($ Over 40 Years)	$0	$1,306,605	$1,369,795
Simple Payback (Years)	No initial Investment	1.7	2.0

This example demonstrates the benefits on conducting a simple GHG LCCA on a small project.

Note: For single disciplinary projects, the nature of the project dictates the number of options that are relevant and what i s possible

- In this example option 2 already has a positive NPV relative to the status quo.
- Option 3 is also NPV positive in this example and becomes the recommended option
- Option 4 was not completed as the Maximum GHG Reduction (option 3) is NPV positive

Worked Example 2: Major Project Existing Building Retrofit

Major Project Retrofit Project Example – Existing Office Building in Ottawa Ontario.

Description

The major retrofit example is an existing building in Ottawa. The building, built in 1970, has an overall gross floor area of 67,740 m^2 and is composed of an 11-storey tower, 5-storey tower and a 2-storey pavilion. Four design options were investigated for this multidisciplinary project. The significant energy efficiency measures that are bundled for each option are described, with the significant differences from one option to the next highlighted in bold font (in the description row). The advantages and disadvantages of each design option are also provided by the project team.
Option 1 sets the baseline to which all of the other options are compared. The cost neutral option 2 results in GHG emissions reduction of 846 tonnes of CO_{2e} at a lower lifecycle cost than the baseline option and at an incremental capital cost of $14.1M (4.8% of baseline capital cost). The maximum GHG emissions reduction option 3 achieves a net zero carbon design, at an incremental lifecycle cost of $52.6M (7.9%) and an incremental capital cost of $76.0M (25.9%). Option 4, the optimized GHG emissions reduction design achieves a net zero carbon design at an incremental lifecycle cost of $3.2M (0.5%) and incremental capital cost of $28.5M (9.7%). The project team recommended option 4 as it balances fiscal responsibility while also achieving a net zero carbon design.

Options	**1: Baseline Costing**	**2: Cost Neutral GHG Reduction (over 40 years inc. carbon price)**	**3: Maximum GHG Reduction**	**4: Optimized GHG Reduction (Recommended)**
Description	Complies with PSPC Technical Reference for Office Building Design, 2017 Roof upgraded to R30 Low-e double glazing LED lighting with motion and daylight sensors	Complies with PSPC Technical Reference for Office Building Design, 2017 **Walls insulated to R50** Roof upgraded to R30 Low-e double glazing LED lighting with motion and daylight sensors Economizers on fresh air dampers (free cooling)	Complies with PSPC Technical Reference for Office Building Design, 2017 **Walls insulated to R50** Roof upgraded to R30 **Phase changing material to increase thermal mass** Low-e double glazing, curtain wall LED lighting with motion and daylight sensors Economizers on fresh air dampers (free cooling) Variable air volume for central zones with induction system	Complies with PSPC Technical Reference for Office Building Design, 2017 **Walls insulated to R50** Roof upgraded to R30 **Phase changing material to increase thermal mass** Low-e double glazing, curtain wall LED lighting with motion and daylight sensors Economizers on fresh air dampers (free cooling) Variable air volume for central zones with

Worked Example 2: Major Project Existing Building Retrofit

	Economizers on fresh air dampers (free cooling) Variable air volume for central zones with induction system Dedicated outdoor air system Enthalpy wheel energy recovery (75% efficient) Variable speed pumps and fans Energy performance is 27% better than NECB 2011	Variable air volume for central zones with induction system Dedicated outdoor air system **Energy recovery with heat banks (85% efficient)** Variable speed pumps and fans **Fan coils to recover heat from equipment rooms** **Low velocity ventilation system** **Facility heat recovery plant composed of heat recovery chillers, dry coolers, heat pumps, hot and cold gradient tanks and geothermal wells** **Energy performance is 62% better than NECB 2011**	Dedicated outdoor air system **Energy recovery with heat banks (85% efficient)** Variable speed pumps and fans **Fan coils to recover heat from equipment rooms** **Low velocity ventilation system** **Facility heat recovery plant composed of heat recovery chillers, dry coolers, heat pumps, hot and cold gradient tanks and geothermal wells** **Geothermal heat exchange system.** **Energy performance is 74% better than NECB 2011** **Photovoltaic (PV) arrays on-site to the east of site and on the roof of a new parking structure (24,851 m^2 of PV with 1799 kW capacity)** **Regenerative elevator motors**	induction system Dedicated outdoor air system **Energy recovery with heat banks (85% efficient)** Variable speed pumps and fans **Fan coils to recover heat from equipment rooms** **Low velocity ventilation system** **Facility heat recovery plant composed of heat recovery chillers, dry coolers, heat pumps, hot and cold gradient tanks and geothermal wells** **Geothermal heat exchange system.** **Energy performance is 74% better than NECB 2011** **Photovoltaic arrays on-site to the south of existing building and east of site (25,432 m^2 of PV with 1841 kW capacity)**
Annual GHG Emissions (tonnes of CO2e)	1,139	293	-	-
Initial capital cost (includes hard & soft costs, and risk)	$293,516,017	$307,572,137	$369,543,370	$322,049,113
Incremental capital cost (from baseline)	-	$14,056,120	$76,027,353	$28,533,096
Estimated annual energy costs	$2,051,315	$1,211,818	$756,486.00	$775,720
Annual carbon shadow cost ($300/ton CO2e)	$341,700	$87,900	-	-
40 year life-cycle cost	$667,779,461	$658,077,242	$720,393,259	$670,976,941
Incremental NPV compared to baseline (includes escalation and residual value)	-	$9,702,219	($52,613,798)	($3,197,480)

Worked Example 2: Major Project Existing Building Retrofit

Increase in lifecycle cost	N/A	-1.45%	7.88%	0.48%
Advantages	-Minimum departmental commitment met -Design meets LEED Silver or 3 Green Globes	-Best value in terms of life cycle cost with significant GHG emission reductions (74% compared to baseline) -Design meets LEED Gold or 4 Green Globes	-Net zero carbon design -Lowest annual energy cost -Design meets LEED Platinum or 5 Green Globes - Minimum required parking accommodated in new three level structure, with PV arrays installed on roof	-Net zero carbon design with a small increase in lifecycle cost -Very good energy performance (same as option 3) -Design meets LEED Platinum or 5 Green Globes
Disadvantages	-Does not achieve net zero carbon construction	-Does not achieve net zero carbon construction	-Significant increase in capital cost and lifecycle cost	-Higher capital cost

Discount rate	2.750%
Utility inflation rate	2.000%
Construction inflation rate	2.600%

Description: Major renovation of crown-owned building, built in 1970

Location: Ottawa, Ontario

Number of storeys: 11-storey tower and 5-storey tower, with 2-storey pavilion

Overall Gross Floor Area: 67,740 m^2

Major Project New Construction Project Example – New Office Building in Shawinigan Quebec.

Description

The new construction example is an office building in Shawinigan Quebec. The proposed building would have a 3-storey tower connected to 4-storey tower by a 3-storey atrium and have an overall gross floor area of 27,500 m^2. Option 1 sets the baseline to which all of the other options are compared. The cost neutral option 2 results in a lower lifecycle cost than the baseline option, at a minimal $288K incremental capital cost. However, the project team felt that because the building is in Québec which has lower cost non-emitting electricity, a net-zero carbon building is achievable without a significant increase in cost. In fact, option 3a shows that a net-zero building is achievable with a minimal increase in capital cost ($296K) and a decrease in lifecycle cost ($228K). The only difference between option 2 and option 3a is that the natural gas boiler is replaced with an electric boiler. The project team investigated two other options (3b and 3c) to achieve a net zero carbon building, with the goal of improving the building's energy performance and reducing its annual utility costs. Specifically, the building fenestration was changed from double glazed to triple glazed, recognizing that triple glazed windows allow the design to meet the Canadian Green Building Council's (CaGBC) requirement for the Thermal Energy Design Intensity (TEDI). A low TEDI reduces a building's heating and cooling loads and increases occupant comfort. The optimized design option 4a reduces annual GHG emissions beyond the cost neutral design option 2 but does not lead to a net-zero carbon building. The analysis demonstrates that optimized option 4a is not best value for this project, since net-zero carbon can be achieved at a lower capital cost. Finally, option 4b was investigated to demonstrate the impact of reducing the fenestration to wall ratio to the prescriptive requirement in the National Energy Code for Buildings (NECB) for the building location. Although option 4b leads to a lower incremental capital cost and slightly lower lifecycle cost than option 3b, the project team notes that reducing the fenestration area and access to natural daylight risks reducing occupant wellbeing. Based on the analysis, the project team recommends option 3b, as the incremental capital and lifecycle costs are reasonable to achieve a net-zero carbon building that meets CaGBC best practice and addresses occupant comfort.

Options	1: Baseline Costing	2: Cost Neutral GHG Reduction (over 40 years inc. carbon price)	3: Maximum GHG Reduction			4: Optimized GHG Reduction	
			a	*b Recommended*	*c*	*a*	*b*
Description	Condensing natural gas boiler Thermal wheel heat recovery Double glazed fenestration 40% fenestration to wall ratio Envelope insulation meets NECB prescriptive requirements 29% better than NECB	Condensing natural gas boiler Off-peak electric boiler Dual core heat recovery Double glazed fenestration 40% fenestration to wall ratio Envelope insulation exceeds NECB prescriptive requirements by R4 Free cooling	Electric boiler Dual core heat recovery Double glazed fenestration 40% fenestration to wall ratio Envelope insulation exceeds NECB prescriptive requirements by R4 Free cooling	Electric boiler Dual core heat recovery Triple glazed fenestration 40% fenestration to wall ratio Envelope insulation exceeds NECB prescriptive requirements by R4 Free cooling	Electric boiler Geothermal heat pump Dual core heat recovery Triple glazed fenestration 40% fenestration to wall ratio Envelope insulation exceeds NECB prescriptive requirements by R4 Free cooling	Option 2 with geothermal heat pump and triple glazed fenestration	Option 3b but with 33% fenestration to wall ratio (prescriptive requirement in NECB for building location)
Annual GHG Emissions (tonnes of CO2e)	130	60	-	-	-	32	-
Initial capital cost	$110,000,000	$110,288,000	$110,296,000	$111,021,000	$111,724,000	$111,735,000	$110,738,000
Incremental capital cost (from baseline)	-	$288,000	$296,000	$1,021,000	$1,724,000	$1,735,000	$738,000
Annual energy cost	$292,000	$277,000	$306,000	$297,000	$288,000	$274,000	$290,600
Annual carbon shadow cost	$39,000	$18,000	-	-	-	$9,600	-

40 year life-cycle cost	$123,316,231	$122,380,083	$123,088,702	$123,437,446	$123,764,190	$123,462,842	$122,886,886
Incremental NPV compared to option 1 (includes escalation and residual value)	-	$936,148	$227,529	($121,215)	($447,959)	($146,611)	$429,345
Increase in life-cycle cost	-	-0.76%	-0.18%	0.10%	0.36%	0.12%	-0.35%
Advantages	-Minimum departmental commitment met	-Best value in terms of energy reductions and energy costs	-Net-zero at an acceptable cost	-TEDI complies to CaGBC best practice -Better occupant comfort - Net-zero at a reasonable cost	-TEDI complies to CaGBC best practice -Better occupant comfort -Exemplary energy performance	-Operational advantage of having 2 energy sources -Exemplary energy performance	-TEDI complies to CaGBC best practice -Better occupant comfort -Reduced capital cost
Disadvantages	-Does not comply to GHG emission reduction commitments	-Does not comply to PSPC's commitment to achieve a net-zero portfolio and to GC Greening Government Strategy	- TEDI does not comply to CaGBC best practice to achieve net zero carbon and to guidance from Greening Government Strategy	-Minor increase in cost	-Higher cost	-High cost of increased energy performance to achieve maximum reduction of GHG emissions	-Negligible reduction in energy costs over 40 years -Reduction of occupant wellbeing because of reduced fenestration area

Discount rate:	1.782%
Utility inflation rate:	2.000%
Construction inflation rate:	2.400%

Description: New Office Building: 3-storey tower connected to 4-storey tower by a 3-storey atrium

Location: Shawingan, Quebec

Overall Gross Floor Area: 27,500 m^2

Annex 2: References

1. Guideline - Project GHG Options Analysis Methodology: PSPC, Real Property Services Branch, Technical Services, Greening Government, Climate Action, GHG and Energy: Updated 2020-11-26

2. Whole Building Design Guide (WBDG) Life-Cycle Cost Analysis (LCCA) National Institute of Standards and Technology (NIST), Updated: 2016-09-19 https://www.wbdg.org/resources/life-cycle-cost-analysis-lcca#:~:text=%20Description%20%201%20A.%20Life-Cycle%20Cost%20Analysis,evaluation%20are%20Net%20Savings%20%28NS%29%2C%20Savings-to-Investment...%20More%20