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Strategy-Sustainability and Greening Feasibility Study-Major Renovation at 25–55 St Clair Ave East Toronto, Ontario

FINAL REPORT

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EXECUTIVE SUMMARY

Public Services and Procurement Canada (PSPC) is committed to a government-wide mandate to upgrade and maintain its federal portfolio of buildings, and to meet the challenges of sustainability that will contribute to GHG reduction, and a carbon neutral portfolio by 2030. This Study of 25-55 St. Clair Avenue East in Toronto, reflects the work of a multi-disciplinary team of architects, engineers, schedulers and cost consultants in a comparative analysis of three distinct options to increase long term sustainability, and to approach a carbon neutral design. The design considerations incorporate National Building Code (specifically, the National Energy Code for Buildings – NECB-2015), National Performance Standard for Office Buildings 2016, Workplace 2.0, and exceed the minimum green building commitments established by PSPC for the retrofit of existing structures. All three alternatives have achieved gains in approaching a carbon neutral strategy for retrofit. Option A - PSPC Half-Life design achieves NECB 2015 performance; Option B - Deep Energy/GHG Retrofit and the Maximum Site Carbon Neutral design utilize building envelope improvements and mechanical and electrical innovations to significantly better that performance; Option C - Maximum Site Carbon Neutral design targets additional energy efficiencies including extensive on-site generation through photovoltaic systems, and geothermal and surface (basement) thermal storage to reduce energy consumption annually and reduce emissions. Table 1 indicates the options results.

Scenario	Construction Cost* (M$2016)	Life-Cycle Cost** (M$2016)	GHG reduction vs. Current Building	Energy savings vs. NECB-2015
A. Half-Life Major Retrofit	144.1	230.4	24%	3%
B. Deep Energy/GHG Retrofit	155.8	237.4	77%	59%
C. Maximum Site Carbon Neutral	165.0	243.3	88%	72%

* - Hard and soft construction costs are adjusted to 2016 dollars

** - Life-cycle costs include hard and soft construction costs and operations and maintenance costs over 25 year study period.

Table 1. Summary of Options - Results

Option C - The Maximum Site Carbon Neutral design - has the greatest capital cost, but is the most innovative in conservation measures, on-site production and storage of energy. Consequently, it has the most significant GHG reduction at an additional 6% life-cycle cost. This is the best option for demonstrating the potential in reducing GHGs (achieving over 93% reduction vs. a typical Ontario Office Building) and is the recommended approach for 25-55 St. Clair if its purpose is to be a flagship towards a carbon neutral future.

Option A - The Half Life Major Retrofit - has the lowest capital and life cycle cost, achieves a good GHG reduction, and virtually matches the NECB-2015 in energy performance. If the lowest life-cycle cost is the PSPC goal, this is a good option.

Option B – The Deep Energy/GHG Retrofit – is a safer middle ground that achieves the most cost-effective gains in efficiency. If this option is pursued, further reductions in capital cost (i.e. to make the option life-cycle cost neutral to option A) could be achieved by exploring less expensive improvements to the walls. This approach was deemed too risky in this phase of study, but with further analysis could be a viable solution and help to optimize the design.

1.0 APPROACH TO SUSTAINABLE GOALS

The National Real Property Services Business Plan (2016-2019) requires that a carbon neutral portfolio is to be achieved by 2030, with reduction targets of at least 17% by 2020 across the portfolio. The major renovation of the 25 - 55 St. Clair Avenue East, Toronto, will contribute to the goal of carbon neutrality. This study explores and evaluates the cost-benefit of significant energy conservation measures including the possibility of on-site carbon neutrality.

The Canada Green Building Council (CaGBC), recently published, "Building Solutions to Climate Change: How Green Buildings Can Help Meet Canada's 2030 Emissions".[1] The report outlines ways to meet the federal government's 2030 target of a 30 per cent reduction below 2005 levels of Green House Gas (GHG) emissions by 2030. Among the action items of this report are:

- Define Carbon Neutral and develop metrics for use by the Canadian industry;
- Identify pathways for the industry to move toward net zero construction and retrofit; and,
- Develop a standardized verification and monitoring protocol to ensure performance targets are being met and maintained over the life of a building.

Based on this work, Public Services and Procurement Canada (PSPC) has developed a broad definition of Carbon Neutral (i.e. Zero Carbon) that will apply to this project:

> *Carbon neutral for the Department is defined as a highly energy efficient building and portfolio that produces on-site, or procures, enough carbon-free renewable energy to meet building operations energy consumption annually. The Department will focus on reducing emissions internally to reduce the number of offsets and credits required.*

Using this definition, for the purpose of this study, Carbon Neutral will be further defined as follows:

1. ***One unit (kWh) of renewable energy produced on-site is equivalent to one unit (kWh) of natural gas energy used on-site.*** This assumption also means that renewable energy generated on-site is estimated to be equivalent to 2.1 units of on-site electricity use (i.e. electricity use in Ontario is expected to generated 55% fewer carbon emissions than natural gas over the study period).[2]

2. ***Renewable Energy Credits (RECs) cannot be used to offset emissions.*** Though the department definition does allow for off-site procurement to contribute to the balance, PSPC is seeking to procure RECs for their entire portfolio, so the decision-making process for this building will be limited to conservation and on-site generation.

3. ***Respecting (1) and (2), a Carbon Neutral building is one that generates enough renewable energy on-site to offset its site annual equivalent carbon emissions on a yearly basis.***

With these points in mind, this study will compare three different energy performance options and will evaluate comparative energy modeling and life-cycle cost also including the price to offset carbon emissions. Standard assumptions and variances in the options analysis include:

- 25-year life cycle
- First cost of alternate/modified building systems (i.e. relative first costs)
- Utility costs, with appropriate escalation rates. Electricity escalation is subject to sensitivity analysis between 0% and 8% escalation, while the other utilities (gas and water) have not been studied for sensitivity.
- Other relevant operating cost differences (e.g. differences in maintenance)
- System service life estimates and associated replacement over the study period

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[1] CaGBC, "Building Solutions to Climate Change: How Green Buildings Can Help Meet Canada's 2030 Emissions Targets". Ottawa: 2016. (11). http://www.cagbc.org/.

[2] The available National Energy Board data have been used to create a long-term trend of Ontario electricity-related carbon emissions factors for the study. Currently this long-term trend is estimated at 2.1:1 (i.e. 2.1 units of electricity for each unit of generation and 1 unit of natural gas).

- The estimated cost of carbon over the study period. [3]

Description of Options

The three study options are:

> **a) PSPC Half-Life Major Retrofit.** This option represents the design prepared in early 2016 for the Major Building Retrofit, to which this document is an annex. The National Energy Code for Buildings 2015 performance (NECB-2015) is the current reference code for new construction energy performance and this option is expected to come very close to achieving the NECB-2015 target.
>
> **b) Deep Energy/GHG Retrofit.** This option targets a performance which exceeds the NECB-2015. Effort has been made to include conservation and generation strategies which target low-carbon while attempting to achieve a life-cycle cost similar to the Half-Life Major Retrofit design. This option would also access a higher amount from incentives through applicable programs (e.g. the City of Toronto's High-performance New Construction Program (HPNC).
>
> **c) Maximum Site Carbon Neutral.** This option targets energy-efficiency and on-site renewable generation to maximize the ability to achieve a Carbon Neutral design as defined above. Consideration will be given to the constraints of the site, which will limit the production of electricity.

Note: All three options are in compliance with PSPC SDS Commitments by meeting or exceeding LEED 2009 NC Silver.

The following four chapters summarize the Current Building (i.e. pre-retrofit) and the three options described above, providing a detailed comparison of the various energy conservation and generation strategies employed in each case.

[3] Three prices of carbon have been investigated - $0/tonne, $50/tonne fixed over the study and $50 escalating to $250 by 2030 (then fixed at $250 for the rest of the study). This final scenario aligns approximately with the National Round Table on the Environment and The Economy 2009 report: "Achieving 2050: A Carbon Pricing Policy for Canada".

2.0 EXISTING CONDITIONS

The 25-55 St. Clair Avenue East Feasibility Study and Investment Analysis Report (January 05, 2016) describes the existing building condition. The following is a building conditions summary, to provide context for the options for upgrade.

2.1 ARCHITECTURE, ENVELOPE AND STRUCTURE

Architectural and Structural

25-55 St. Clair was constructed in 2 phases. Built in 1950, 25-27 St Clair is 10 storeys with one basement level; the structural system is cast-in place concrete beams and columns supporting precast concrete floor panels, with cast in place floors on the ground and basement. Built in 1958, 55 St Clair is a 10 storey structure with three levels of underground parking. There are cast in place floors for the basement, ground and second floors and concrete-encased steel beams and columns supporting precast concrete floor panels at the levels above the second floor.

Masonry Walls

Masonry wall cladding combines face brick on shelf angles with concrete block backup, and limestone veneer with thicker bond stones bonded directly to a brick back-up wall. Some of the bond stones bear partially on the slab edge. There is no true cavity between the brick cladding and the back- up wall, although there is a nominal gap. The walls are parged on the backside, but are uninsulated and there is no air or vapour barrier.

Windows and Curtain Wall

There are continuous strip windows (aluminum framed, glazed from the interior, non-thermally broken with single and some sealed units), as well as aluminum framed units set in masonry openings glazed from the interior (non-thermally broken with single and some sealed units). There is a large area of steel framed curtainwall on the north elevation of 55 St. Clair, aluminum framed, non–thermally broken with single and some sealed units.

Thermal Bridging

At most locations, existing shelf angles have little to no separation from the supporting slab or structure. Not isolated or insulated, they act as conduits for heat loss between interior and exterior.

Characteristics of Floor Plate

The building floor plate is very deep, and the plan of the enclosed offices and special purpose spaces does not take advantage of natural light from the north and south sides. The east and west sides are constrained by neighbouring buildings.

Elevators

The single overhead geared traction freight elevator was recently retrofitted to Variable Voltage Variable Frequency (VVVF) drive. All 7 passenger elevators are in the process of being upgraded.

2.2 MECHANICAL

Air Handling

Central Air Handling Units (AHUs) for heating, cooling and ventilation are predominantly located in the penthouse mechanical room. Additional AHUs on the main level and basement level serve the respective floors. Some AHUs have Variable Inlet Vane (VIV) capacity control. There are no Variable Frequency Drives (VFDs). The air is distributed on the floors through a mix of Variable Air Volume (VAV) boxes or through a constant air volume system. Perimeter systems include induction units, two-pipe fan coils, and convectors. The central AHUs use outside air for cooling when conditions permit.

Cooling

Cooling is provided by two centrifugal water chillers located in the basement with the associated cooling tower located on the roof. Split systems have been provided for various 24/7 cooling loads including the elevator machine rooms and tenant data closets.

Heating
Heating is provided by five hot water and two steam boilers located in the basement. The five gas-fired heating boilers were replaced over the course of Nov 2015 – Oct 2016. They generate 180 F (82 C) water for building hot water heating systems. Steam boilers still serve some local heating units and air handlers that have not yet been replaced. Some hot water pumps are provided with Variable Frequency Drives (VFDs), but the central system does not appear to be set up to modulate flow based on demand.

Humidification
Steam for heating is provided by two steam boilers located in the basement, whereas, steam for humidification is generated by steam generators located in the penthouse.

Domestic Hot Water
There are two boilers for the domestic hot water system located in the basement.

Controls
The controls system combines pneumatic and electronic controls.

2.3 ELECTRICAL

Lighting
Lighting has been revised during numerous renovations, including low voltage control and luminaire retrofits and replacements. The general lighting is in good condition, but not consistent in type and voltage throughout the building. The building is lit from T8 Linear Fluorescent, compact fluorescent and HID luminaires, controlled by a relay system and breakers.

Power Systems
Electrical systems vary due to several partial renovations. Some systems have been replaced in the last five years but others have surpassed their expected lives. The existing transformers produce heat, in turn requiring more energy for cooling.

2.4 ENERGY PROFILE

The existing building was modelled in Integrated Environmental Solutions Virtual Environment (IESVE 2016) simulation software to determine its energy performance. National Energy Code for Buildings (NECB) standard operating schedules for office spaces were used, as were default receptacle loads. Estimates for lighting and performance of mechanical systems were based on equipment of the age and use in the existing building. Occupancy was based on existing office space use. Typical schedules and outside air and infiltration were modified to align modelled building energy use with historical metered energy consumption. The results of the energy analysis are presented as follows:

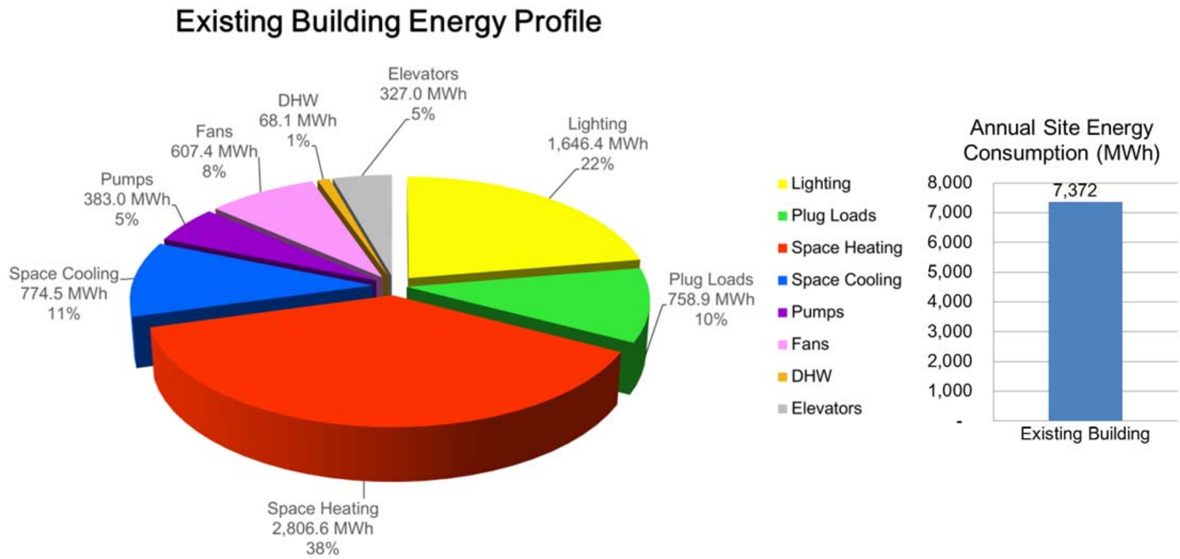

Figure 1. Existing Building Energy Consumption

Existing Building Summary – Annual (3 year average)			
Total Energy	Energy Use Intensity (EUI)	GHG Emissions	Energy Cost
7,371,892 kWh	205 kWh/m^2	920 tCO_2e	$776,848

Table 2. Existing Building Energy Profile Summary

The Existing Building was modelled to provide some context to the energy model as it was to be used to predict actual energy cost savings. Modelled energy consumption was compared against actual utility consumption reported for Mar 2015 – Feb 2016.

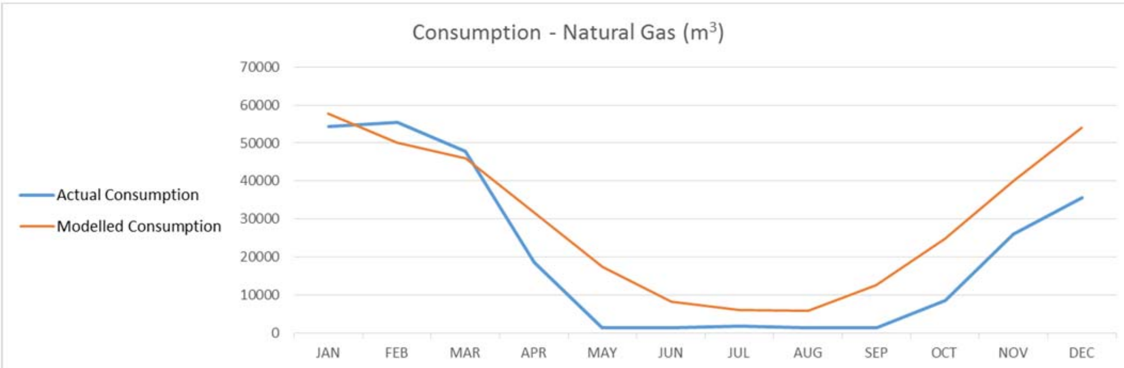

Figure 2. Graphical Comparison of 2015/2016 Actual Natural Gas Consumption Vs Modelled Existing Building Gas Consumption

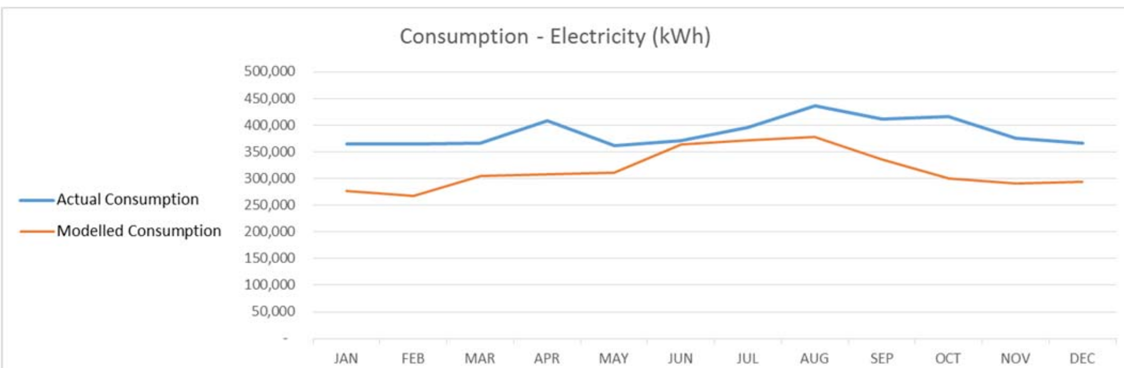

Figure 3. Graphical Comparison of 2015/2016 Actual Electricity Consumption Vs Modelled Existing Building Electricity Consumption

Although not fully calibrated to actual operating conditions and equipment use, these graphs provide a reasonable monthly energy consumption comparison of the two sets of data. The Existing Building energy model assumes typical plug loads and office operating schedules from the National Energy Code for Buildings (NECB), and a statistically generated Canadian Weather for Energy Calculations (CWEC) typical weather file as per standard modelling practice.

3.0 OPTION A: PSPC HALF-LIFE MAJOR RETROFIT

The 25-55 St. Clair Avenue East Feasibility Study and Investment Analysis Report (January 05, 2016) describes in detail the PSPC Half-life Major Retrofit. The planning included meeting energy as well as non-energy targets for building stabilization, applicable building codes, minimum sustainability requirements (e.g. LEED certification), and compliance with Workplace 2.0. The mandate of this option was to provide building renewal within budget limitations. The renovation plan included replacing mechanical and electrical equipment that had reached or exceeded its expected life while reusing or retrofitting building infrastructure such as the heating boilers and chilled water lines as requested to control expenditures. The following list summarizes the changes proposed to the existing building for the Half-Life Major Retrofit.

3.1 ARCHITECTURE, ENVELOPE AND STRUCTURE

- Seismic upgrade of the building structure;
- Replacement or repair of the existing expansion joints in floors and walls between 25 and 55 St Clair;
- New post and girt system at new curtain wall and windows in order to resist the wind load (such framing would be approx. 10kg/m2 of wall);
- Masonry: structural and architectural brick and limestone cladding wall repair as described in the December 2015/January 2016 Feasibility Study and subsequent reporting (R-3);
- Shelf Angles: replacement to improve on thermal bridging;
- Windows: removal of all windows and installation of new thermally broken (minimum 9 mm) aluminum framed windows with double glazed argon filled sealed units (U-0.24, SHGC 0.38) and double silver low-e coating to achieve effective U-0.34 at glazing areas;
- Curtain Wall: removal of curtain wall and installation of new thermally broken (minimum 9 mm) aluminum framed curtain wall with standard 4” mineral wool in metal back pan, to meet minimum effective R-5.0 at spandrel areas;
- Sealants: removal of existing and install new sealants;
- Roof: removal of existing and install new built up roof to meet NBC: with R-20 rigid board insulation. A white roof will be incorporated to achieve LEED NC 2009 credit SSc7.2 – Heat Island Effect: Approx. 35% of roof area reinforced in order to support M/E roof-top units, and the area around the penthouse subject to snow accumulation.

3.2 MECHANICAL

- New AHUs centralized in the penthouse to meet new building loads with VFDs to reduce fan energy usage during part occupied and unoccupied hours;
- Variable Air Volume (VAV) air distribution to reduce fan energy usage during part occupied and unoccupied hours and provide control to all occupied zones of the building;
- New convective/radiant hot water heating system to save on fan energy when compared to the existing induction/fan-coil units;
- New miscellaneous force flow or unit heaters in service and entrance areas to save on energy when compared to the existing miscellaneous heating units;
- Addition of VFDs and controls to existing hot and chilled water pumps to reduce on pumping energy during part load, where not already provided;
- Relocation of existing five(new) boilers from basement to penthouse to reduce lengths of venting;
- Addition of steam boiler for humidification to replace current steam generators;
- Replacement of two existing chillers with two new chillers to meet current cooling loads and to replace refrigerants nearing end-of-life;
- Replacement of the existing cooling tower to match new chilled water load;
- Replacement of pneumatic controls to modern Direct Digital Control (DDC) system to allow for better and automated control of all existing and proposed systems that may allow a reduction in energy usage;
- New potable water fixtures with low-flow fixtures to reduce hot and cold water consumption.

3.3 ELECTRICAL

- A new base building light-emitting diode (LED) lighting system will be provided for the open offices, collaborative spaces, and enclosed offices. Support spaces, such as meeting rooms of various sizes, will be provided with new base-building LED lighting with separate dimming control and motion detection. Motion sensors will turn the luminaire off when there is no occupant present. LED lighting systems will be utilized in all spaces including lobbies and support spaces to include decorative luminaires, coves and functional luminaires as the application requires.
- Direct/Indirect suspended LED luminaire(s) to suit meetings (table) function on a separate dimming control and motion sensor. Dimmable perimeter/accent lighting to support presentations function on a separate dimming control will be considered.
- Additional LED lighting and power for special client needs including video conference services, etc.
- LED task lighting for work stations.
- Exterior lighting will be upgraded to energy efficient LED. Parking garage lighting will be replaced with outdoor rated low glare LED luminaires. These measures will reduce lighting power while still providing suitable lighting for security and safety.
- The base building lighting control will be a Digital Addressable Lighting Interface (DALI) system to control the lighting to get the best energy savings while providing the users the flexibility and comfort of personal lighting control. This system will give each luminaire the opportunity of having a separate address, will provide a full complement of dimming (which is readily available from LED lighting) and will allow the interface and mapping of numerous controls to specific lighting fixtures. The lighting system will interface to the building network and/or telephone system and will allow the users to also control their own lighting in their spaces via phone or network.
- Workstation task lighting will be provided with a switch to allow for user control.
- Daylight sensors in perimeter zones will detect daylight penetration through windows, and will dim specific light fixtures accordingly for energy savings.
- For other methods to save energy, occupancy and/or vacancy sensors will be mapped to various light fixtures to turn the lights off when the spaces are unoccupied after 15 minutes.
- A time clock will also be part of this system which will schedule specific levels of illuminances as a function of the time of the day. As well, the time clock will also allow the building operators to control lighting in public spaces, exterior lighting and in unattended spaces automatically without the need to go into the spaces. Exterior lighting will also be on a central photocell system to adjust to daylight conditions. This measure will save further energy, particularly on cloudless days. Parking luminaires will be zoned to motion sensors that will reduce lighting to 30% if the space is unoccupied after 15 minutes.
- In terms of power improvement, capacitor banks will be implemented as per the study to reduce reactive/unproductive energy, which is caused by motors, etc. and in turn reduce power consumption from the hydro bills. High-efficiency transformers will reduce losses through the winding(s).
- As per Workplace 2.0 Standards, users will be provided laptops in lieu of PC towers and monitors, unless there would be a requirement for high speed processor and/or larger screen for graphic application. With 90W to 100W laptops in comparison to 300W PC towers plus energy consumption from the monitors, this will contribute greatly to the energy reduction strategy.
- Upgrade of Hybrid Building Automation System (BAS) for electrical systems (please refer to mechanical section for details as the system is shared by both disciplines).

3.4 ENERGY PROFILE

The described changes to the building were modelled in IESVE 2016 simulation software to predict the retrofitted building's energy performance. NECB standard schedules for office spaces were used, as were default receptacle loads. Estimates for lighting and performance of mechanical systems were based on typical high efficiency equipment described. Occupancy was based on the Workplace 2.0 occupancy standards considered in the major retrofit report. The results of the energy analysis are presented as follows:

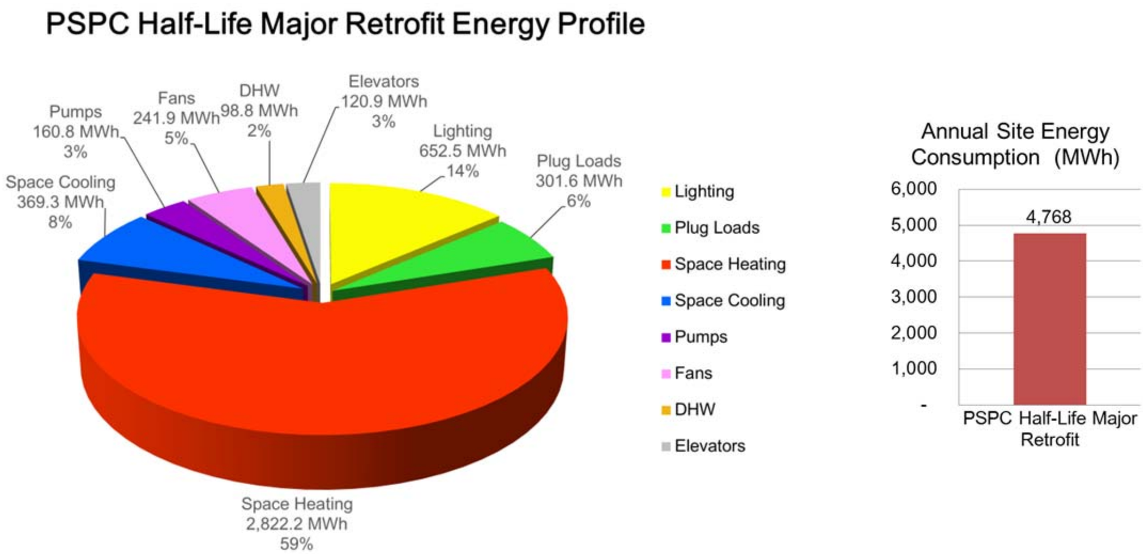

Figure 4. Half-Life Major Retrofit Energy Consumption

PSPC Half-Life Major Retrofit Summary – Annual (modelled)			
Total Energy	Energy Use Intensity (EUI)	GHG Emissions	Energy Cost
4,768,129 kWh	133 kWh/m^2	701 tCO$_2$e	$355,007

Table 3. PSPC Half-Life Major Retrofit Summary

3.5 COST IMPACT

Detailed construction cost estimates for the Half-Life Major Retrofit program have been provided in the Appendices. The January 2016 estimate for CM Delivery, Building Retrofit has been updated based on decisions described in this report, including thermal performance improvements to the exterior, updating the mechanical estimate, including revised heating plant, cooling plant and air distribution systems. Electrical estimates include the addition of task lighting. Seismic upgrades have been included in the base rather than the optional costing, and reinforcement of façade by post and girt systems have been included since January 2016. Life Cycle Costing, not previously calculated in January 2016 has been for the total life cycle capital maintenance and operating costs over the 25-year period for the PSPC Half-Life approach, using a rapid escalation on the carbon tax from $50 to $250 by 2030 and fixed thereafter.

PSGC Half-Life Major Retrofit Cost Impact		
NPV of Hard & Soft Construction Costs (2016 Dollars)	NPV of Capital Maintenance & operating costs with a rapid escalating carbon tax $50 to $250 over 25 year life cycle (2016 Dollars)	Net Present Value (NPV)(2016 Dollars)
$144,104,033	$86,274,354	$230,378,387

Table 4. PSPC Half-Life Major Retrofit Cost Impact

Please note all Hard & Soft Construction Costs as well as Capital Maintenance & Operating costs above are reflected as a discounted value in 2016 dollars, over the life cycle of the project.

3.6 SCHEDULE IMPACT

A project schedule including Procurement, Project Approvals, Design, Documents, Packages and Construction is provided in the Appendices. The January 2016 schedule for CM Delivery, Building Retrofit has been updated based on decisions described in this report including updating the status of the project to 24 November 2016. The required end date for Substantial Completion remains (Client Move in) fixed at 25 March 2021. There is a critical path (zero float) through the project of minus twelve days which gives a forecast completion of 14 April 2021. The cause of this overall negative slack is shared between front end activities (IAR & TB Submission) and the growing complexity of the project

The addition within the schedule of the structural and seismic package activities plus the refinement of the curtain wall logic and durations contribute to the criticality. If the required end date is to be met, slippage must be recognised and mitigated to avoid effects to the end date.

4.0 OPTION B: DEEP ENERGY/GHG RETROFIT

In this option the strategic reuse of existing equipment was abandoned in favour of what could be justified from a lifecycle and energy performance perspective. In developing the Deep Energy/GHG Retrofit, several systems were considered including:

- Extent of building envelope improvements that could be incorporated into the renovation;
- Incorporation of low temperature hot water heating into the design;
- Moving heat from the building core to perimeter during off-hours in the heating season;
- Possible sources of heat rejection for heat recovery;
- Methods to reduce ventilation rates while maintaining interior environment;
- Lighting and lighting power reduction;
- Incorporation of additional control systems to reduce energy consumption;
- Addition of rooftop photovoltaic (PV) system: low rooftop ballasted system.

The following summary lists the modifications to the Half-Life Major Retrofit, added to the building project to achieve the Deep Energy/GHG Retrofit:

4.1 ARCHITECTURE, ENVELOPE AND STRUCTURE

- Masonry: remove cladding systems, then replace with new brick and limestone cladding; remove then replace with new all brick and block back-up, and interior plaster finishes; achieve new rain screen wall system design with minimum R-12 thermal performance using rigid insulation with new stud and gypsum wall finish;
- Windows: replacement window glazing similar to Half-Life but upgrade to achieve effective U-0.34;
- Curtain Wall: replacement curtain wall similar to Half-Life, but with upgrade by installation of insulated sandwich panels to achieve effective R-18.0 at spandrel areas;
- Roof: remove existing and install new built up roof with R-30 rigid board insulation. Approx. 35% of roof area to be reinforced in order to support M/E roof-top units, and the area around the penthouse subject to snow accumulation.
- The floor of the existing penthouse will require structural and acoustical upgrade to ensure adequacy for the new chillers, boilers and pumps to approx. 20kg/m2 over 50% area.

4.2 MECHANICAL

The mechanical systems have been designed to provide considerable energy savings when compared to the PSPC Half-Life Major Retrofit.

- Replace existing recirculating central air system with a Dedicated Outdoor Air System (DOAS) with heat and humidity recovery to separate ventilation from heating/cooling and reduce fan energy consumption;
- Provide cooling/heating Fan Powered Boxed (FPBs) with ECM motors throughout all floors to eliminate perimeter heating and to transfer warm air from the core to the exterior;
- High induction grilles and diffusers for perimeter zones to increase ventilation effectiveness thereby decreasing minimum outside air quantities to the respective spaces;
- Replace miscellaneous force flow or unit heaters with low temperature variable volume units to save on energy usage compared to the PSPC Half-Life Major Retrofit;
- New hot and chilled water pumps with VFD-controlled units to reduce energy required for distributing chilled and heating water;
- New high-efficiency condensing space heating boilers to reduce gas consumption and generation of GHGs;
- New heat reclaim chiller to move excess heat from building core to perimeter;
- New premium efficiency chiller to reduce energy usage and use modern refrigerants;
- Relocation of chillers from basement to penthouse to reduce pumping energy between the chiller and cooling tower;
- New modern Direct Digital Control (DDC) system to allow for better and automated control of all existing and proposed systems that may allow a reduction in energy usage;
- New high-efficiency condensing DHW boilers to reduce gas consumption and generation of GHGs;
- Refer to the Deep Energy/GHG Retrofit Appendix for further details.

4.3 ELECTRICAL

The electrical, lighting and lighting control systems have been designed to provide considerable energy savings when compared to the PSPC Half-Life Major Retrofit.

- Base building ceiling troffers: new HE high efficiency luminaire types shall be used. The lumen per watt efficiency is increased over standard specification grade LED luminaires. The advantage of this is that either fewer luminaires might be considered for a space or lower wattage consumption will take place with the same number of luminaires to provide the amount of lighting needed for the application.
- Ceiling motion sensors: configured to aggressively reduce to 5 minutes from 15 minutes for luminaire instruction. For workspace ceiling lighting, the luminaires would each have a luminaire on board sensor. This would allow for further adjustments of the luminaires with more sensors detecting motion.
- Task lights: with individual motion sensors to turn off task lights when no user is present.
- Relay control for 50% of all office and meeting room receptacles to enable remote switching of plug loads according to a time schedule. This achieves energy savings by switching off plugged-in devices inadvertently left on by occupants during unoccupied hours.
- Exterior lighting with dimming: luminaires to have lower light levels during night time when there are different requirements for occupancy. Depending on location, certain luminaires can be fitted with individual sensors to enhance this effect and take advantage of borrowed light and reduce energy accordingly. Exterior lighting in selected areas will have higher light levels between 6PM and 12:00AM and lower light levels between 12AM and 6AM.
- Energy and usage metering system: integrated to measure occupant utilization of systems. To achieve this, the electrical distribution network must be strategically segmented between power, lighting, HVAC etc. to measure the associated electrical values for those individual systems. Refer to the Mechanical section for further details on measurement for other energy aspects of mechanical systems.
- Parking garage and stairwells: luminaires will have individual motion sensors. Parking luminaires will be reduced to 30% in unoccupied spaces after 5 minutes.
- Ballasted rooftop photovoltaic (PV) solar array for on-site electricity generation: this system rests on top of the roof with no mechanical attachment to the roof to keep it in place. To address uplift from wind load, concrete block ballast is used. Premium efficiency PV panels on standard 10 degree slope racks will result in an estimated array size of 200 kW.

4.4 ENERGY PROFILE

For description of model, see Section 3.4.

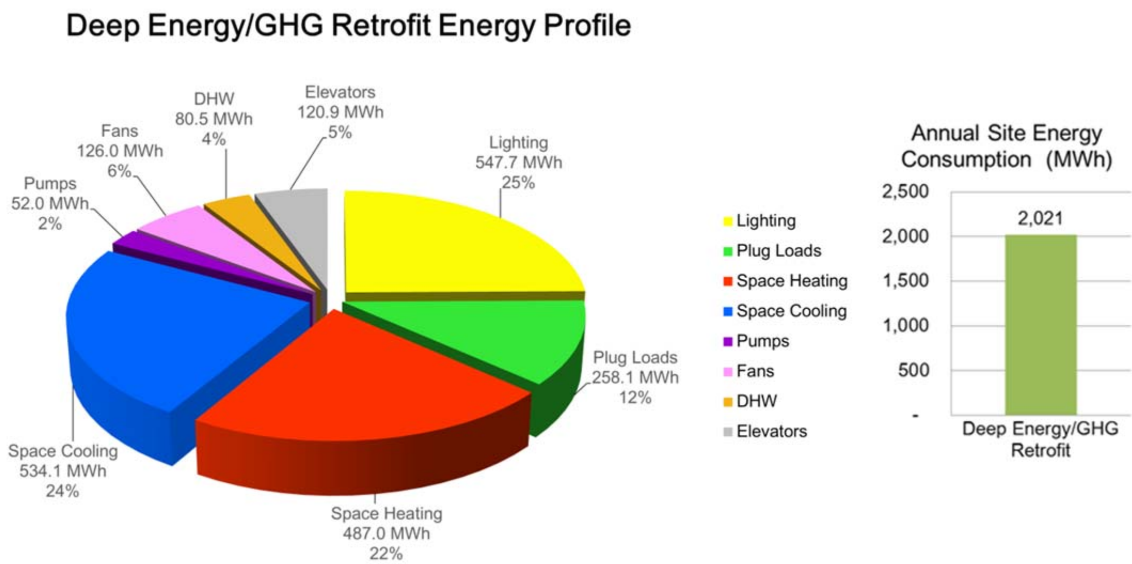

Figure 5. Deep Energy/GHG Retrofit Energy Consumption

Deep Energy/GHG Retrofit Summary – Annual (modelled)*			
Total Energy	Energy Use Intensity (EUI)	GHG Emissions	Energy Cost
2,021,438 kWh	56 kWh/m^2	213 tCO_2e	$243,662

** Performance metrics include the benefit of on-site PV*

Table 5. Deep Energy/GHG Retrofit Summary

4.5 COST IMPACT

Detailed construction cost estimates for the Deep Energy/GHG Retrofit has been provided in the Appendices. The estimate for the Deep Energy GHG Retrofit includes factors additional to the Half-Life Major Retrofit that correspond to the program of requirements described by the Architectural, Building Envelope, Structural, Mechanical, and Electrical disciplines. These factors include: improved thermal performance specifications to the roofing, exterior wall insulation and window spandrel panels; the complete removal of the exterior brick/limestone cladding and backup concrete masonry and replacement with new brick/rigid insulation and new brick back up and new perimeter; interior framing and drywall. Mechanically the improved performance relates to improved energy efficiency by way of introducing heat recovery systems, use of high efficiency chillers and heat recovery chiller, condensing domestic water boiler. Electrically, the energy usage is reduced through the use of reduced lighting power density, use of premium LEDs, vacancy sensors and receptacle controllers. The low level ballasted PV roof top solar panel system is included. The factors that have influenced the Life Cycle Cost include more energy efficient systems as well as the reduced electrical cost over the 25 year study. Tables 6describes the estimated Construction Cost and estimated total life cycle capital maintenance and operating costs over a 25-year period for the Deep Energy/GHG Retrofit approach, using a rapid escalation on the carbon tax from $50 to $250by 2030 and fixed thereafter.

Deep Energy/GHG Retrofit		
NPV of Hard & Soft Construction Costs (2016 Dollars)	NPV of Capital Maintenance & operating costs with a rapid escalating carbon tax $50 to $250 over 25 year life cycle (2016 Dollars)	Net Present Value (NPV)(2016 Dollars)
$155,789,553	$81,567,156	$237,356,710

Table 6. Deep Energy/GHG Retrofit Cost Impact

Please note all Hard & Soft Construction Costs as well as Capital Maintenance & Operating costs above are reflected as a discounted value in 2016 dollars, over the life cycle of the project.

4.6 SCHEDULE IMPACT

A project schedule including Procurement, Project Approvals, Design, Document, Packages and Construction is provided in the Appendices. The construction schedule for the Deep Energy/GHG Retrofit includes new factors additional to the Half-Life Major Retrofit corresponding to the program of requirements described by the Architectural, Building Envelope, Structural, Mechanical and Electrical disciplines. These factors include: the carryover of the slipped activities (IAR & TB Submission) throughout 2016; and the growing complexity of the project that continues to contribute to the critical path through the project of minus twelve days. The end date (Substantial Completion) remains fixed at 25 March 2021. Windows and Curtain Wall remain part of the project critical path of minus twelve days. The brick and cladding removal and replacement package was added starting August 2018 (Documents) and has sufficient slack.

5.0 OPTION C: MAXIMUM SITE CARBON NEUTRAL

The planning includes bettering the Deep Energy/GHG Retrofit, to maximize the ability to meet carbon neutral design. The following summary lists the modifications to the Deep Energy/GHG Retrofit to achieve the Maximum Site Carbon Neutral design.

5.1 ARCHITECTURE, ENVELOPE AND STRUCTURE

- Masonry: remove and replace masonry and CMU back up to create rain screen as described in Deep Energy/GHG Retrofit, and to achieve the thermal performance required to achieve R-28;
- Windows: new glazing to triple-glazed sealed units with krypton fill (U-0.12) in a high-performance curtain wall/window frame (e.g. Kawneer 1600 UT) to achieve an effective U-0.15 overall; vision glass to reach double Low-E with a thermal factor of U-0.12;
- Curtain Wall: replacement curtain wall similar to Deep Energy with insulated sandwich panels to achieve effective R-20 at spandrel areas;
- Roof: baseline roofing systems same as Deep Energy;
- Addition of geothermal wells: Past geotechnical studies indicate bedrock at approx. 40m (131ft) below street level. The slab on grade will be removed and replaced to allow placement of pipes and wells. It should be assumed that 10% of the area will be dug down to 300mm below the slab on grade to achieve required headroom for drilling; no adverse effect of drilling on the existing footings is anticipated;
- Addition of thermal storage water tank at the lowest level: According to the original structural drawings, the existing mechanical room has soil behind all walls and under the slab; the condition should be reviewed, however it appears that there should not be need for reinforcement of the existing structure.

5.2 MECHANICAL

The mechanical systems have been designed to provide further energy savings when compared to the Deep Energy/GHG Retrofit.

- Distribute outside air using VAV boxes to eliminate fan energy associated with FPBs;
- Provide cooling to spaces using chilled ceilings to eliminate fan energy associated with FPBs;
- Provide heating to spaces using low level (wall mounted) perimeter heating to make use of low temperature heating water and eliminate energy associated with FPBs;
- Water to water heat pump to provide both cooling and heating for the building that will reduce/eliminate dependency on natural gas to produce hot water for heating;
- Heat storage from geothermal boreholes drilled below the lowest level of the parking structure and a built-in place storage tank to store heat and limit use of the cooling tower;
- A cooling tower to reject waste heat in peak summer weather;
- High-efficiency condensing boiler used only for backup heating during times that thermal storage is at capacity;
- Electric humidification generator to reduce GHG generation from gas fired steam boilers;
- Refer to the Maximum Site Carbon Neutral Appendix for further details.

5.3 ELECTRICAL

The electrical, lighting and lighting control systems have been designed to provide further energy savings when compared to the Deep Energy/GHG Retrofit.

- Raised-rack rooftop photovoltaic (PV) solar array: this system consists of a custom metal column and truss racking system to raise the base of the PV array by 7 metres to match the maximum height of rooftop obstructions. The racking system will allow full use of available roof area. Premium efficiency PV panels fixed to angled frames will result in an estimated array size of 380 kW.
- In lieu of introducing DC to AC inverters for PV panels to connect them to the building AC power distribution, a parallel DC power grid has been evaluated. An increasing number of devices (phone chargers, IP phones, Wi-Fi access points, laptops, LED lighting, etc.) and equipment (IT network, Security, Security Cameras, etc.) require DC power, and use converters to connect to the AC power grid. The conversion process results

in energy loss as heat. The introduction of a DC power system will eliminate the requirement for conversion and reduce energy losses by 5-8%. The DC Lighting system will utilize a specific digital control system designed for a DC Lighting infrastructure.

5.4 ENERGY PROFILE

For description of model, see Section 3.4.

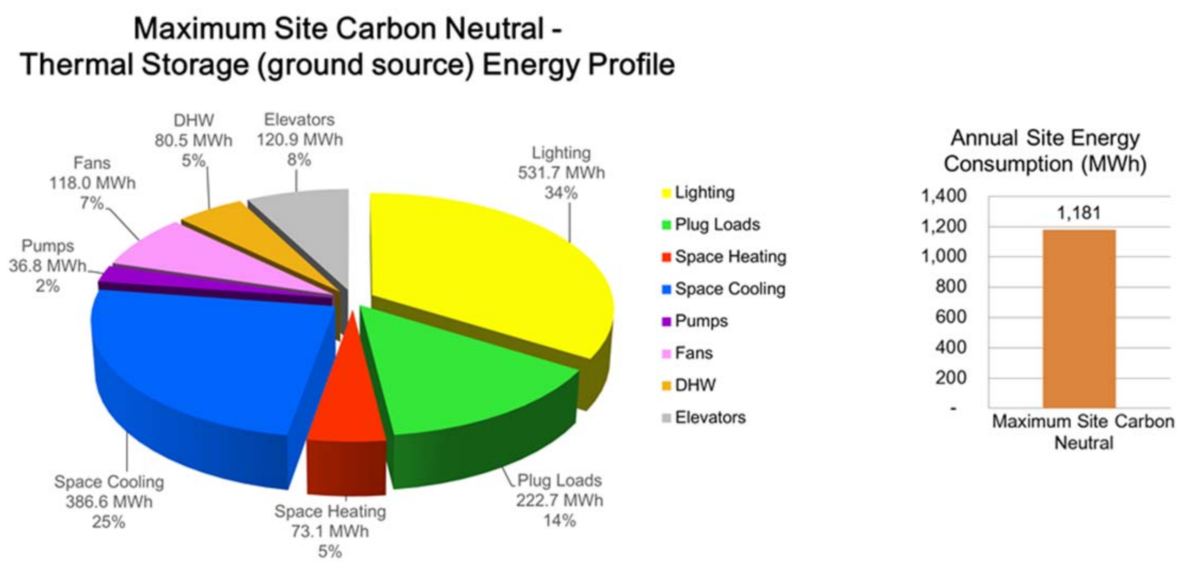

Figure 6. Maximum Site Carbon Neutral Energy Consumption

Maximum Site Carbon Neutral Retrofit Summary– Annual (modeled)*			
Total Energy	Energy Use Intensity (EUI)	GHG Emissions	Energy Cost
1,180,738 kWh	33 kWh/m^2	103 tCO_2e	$180,096

** Performance metrics include the benefit of on-site PV*

Table 7. Maximum Site Carbon Neutral Retrofit Summary

5.5 COST IMPACT

Detailed construction cost estimates to the Maximum Site Carbon Neutral Retrofit level have been provided in the Appendices. The construction cost estimate for the Carbon Neutral Retrofit includes factors additional to the Deep Energy Retrofit that correspond to the program of requirements described by the Architectural, Building Envelope, Structural, Mechanical, and Electrical disciplines. These factors include: improvements to insulation properties through the use of higher performance insulation to the exterior envelope walls, triple glazed windows with krypton gas, high performing specification low-E windows, improved U-value rated glazing, improvement thermal insulation to windows and high specification insulation to spandrel panel. Mechanically, there is: improved air distribution control with VAVs, electric humidification generator, perimeter heating via convectors/radiators and passive chilled ceiling. Ultralow-flow plumbing fixtures have been used. This option includes for the combined use of geothermal and water tank thermal storage as well as DC power. These added carbon reduced features all bring improved energy consumption through thermal storage via water storage in the basement and geothermal wells, requiring less heating costs. A raised rack PV to the roof is included which reduces the electrical costs over the life cycle study, but increases initial capital cost. The various factors influenced Life Cycle Cost in the following way. The carbon reducing and electrical components included in this study reduce the net present value of the study over the 25 years; however, the initial capital outlay is still more significant and is not necessarily the best value. It does provide a more energy efficient building, but at a cost premium. The following chart describes the estimated Construction Cost and estimated total life cycle capital maintenance and operating costs over a 25-year period for the Maximum Site Carbon Neutral approach, using a rapid escalation on the carbon tax from $50 to $250 by 2030 and fixed thereafter

Maximum Site Carbon Neutral Retrofit Study		
Hard & Soft Construction Costs	Capital Maintenance & operating costs with a rapid escalating carbon tax $50 to $250 over 25 year life cycle	Net Present Value (NPV) (2016 Dollars)
$164,991,140	$78,341,531	$243,332,671

Table 8. Maximum Site Carbon Neutral Retrofit Cost Impact

Please note all Hard & Soft Construction Costs as well as Capital Maintenance & Operating costs above are reflected as a discounted value in 2016 dollars, over the life cycle of the project.

5.6 SCHEDULE IMPACT

A project schedule including Procurement, Project Approvals, Design, Documents, Packages and Construction is provided in the Appendices. The construction schedule for the Carbon Neutral Retrofit include new factors additional to the Deep Energy Retrofit that correspond to the program of requirements described by the Architectural, Building Envelope, Structural, Mechanical and Electrical disciplines. These factors include: the carryover of the slipped activities (IAR & TB Submission) plus the growing complexity of the project continues to contribute to the project critical now in the Maximum Site Carbon Neutral option is a total of minus thirty-two days. The end date (Substantial Completion) remains fixed at 25 March 2021. Windows and Curtain Walls continue to influence this minus thirty path due to duration.

6.0 COMPARATIVE RESULTS

6.1 ANNUAL ENERGY USE INTENSITY

In Figure 7 below we have summarized the Energy Use Intensity (EUI) of the studied scenarios. The two bars in blue are based on actual energy use data, while the other bars reflect modeled results or results derived from models.

A typical Ontario Office Building built in the 1920s is shown to the far left of the graphic, compared in blue to the average performance of 25 & 55 St. Clair over the past three years (Current Building). The current facility has excellent intensity performance due to its north-south orientation, low window to wall ratio and to improvements made to the HVAC and lighting systems over its service life to date. Its intensity is also low due to the relative space usage efficiency (i.e. the ratio of occupied to gross floor area is lower than the average newer office building).

In deep red is depicted the NECB-2015 reference case. The model prepared for this case was based on ASHRAE 90.1-2010 (for LEED purposes), but the results of that model have been modified by equivalency rules to estimate an NECB-2015 result.

The PSPC Half-life option is shown in purple and is performing close to the NBC-2015 result.

The orange bar depicts the Deep Energy/GHG Retrofit option, which includes a ballasted photovoltaic system. The Deep Retrofit performs very well compared to the NECB-2015, achieving over 55% savings and an impressive EUI of 56 kWh/m², including PV.

The final bar in deep green depicts the Maximum Site Carbon Neutral option (with racked PV). This option is the best performer with an EUI of 33 kWh/m², including PV.

6.2 ANNUAL CARBON EMISSIONS

A similar graph depicting carbon emissions is provided in Figure 8. The trends are similar, but important differences exist when comparing the energy and carbon results.

The PSPC half-life has more electricity conservation than natural gas conservation, so it does not perform as well. The other studied options have additional savings for the opposite reason – they conserve significant amounts of natural gas and even come close to removing natural gas usage entirely. Switching to electricity for heating takes advantage of the 2.1:1 ratio of emission of natural gas vs. electricity discussed in the introduction. For every 1 unit of natural gas burned, you can use 2.1 units of electricity and the emissions would be the same.

Overall, the best option shows an 88% reduction when compared to the current building performance. Compared to the Typical Ontario Office, this case achieves a 93% reduction in carbon emissions.

The savings in terms of Greenhouse Gas Emissions (both %-reduction and intensity) as compared to the current building performance are shown in Table 9.

Scenario	Carbon Savings vs. Current Building	Absolute Carbon Savings (kg CO2e/m²)
A - PSPC Half-Life	24%	6 (of 27)*
B - Deep Energy/GHG	77%	20
C - Max Site Carbon Neutral	89%	23

** - The Current Building has an average of 27 kg of CO2-equivalent emissions per m² per year*

Table 9. Savings vs. Current Building

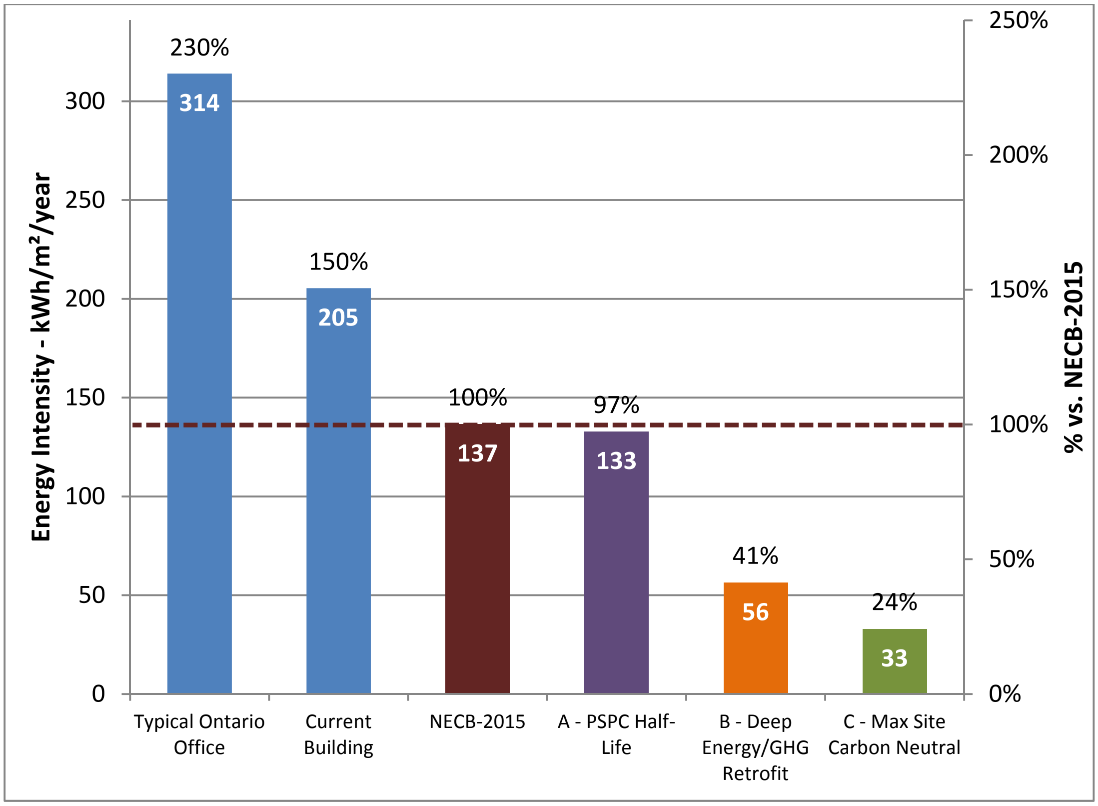

Figure 7. Annual Energy Use Intensity (kWh/m²/year) and % Performance vs. NECB-2015

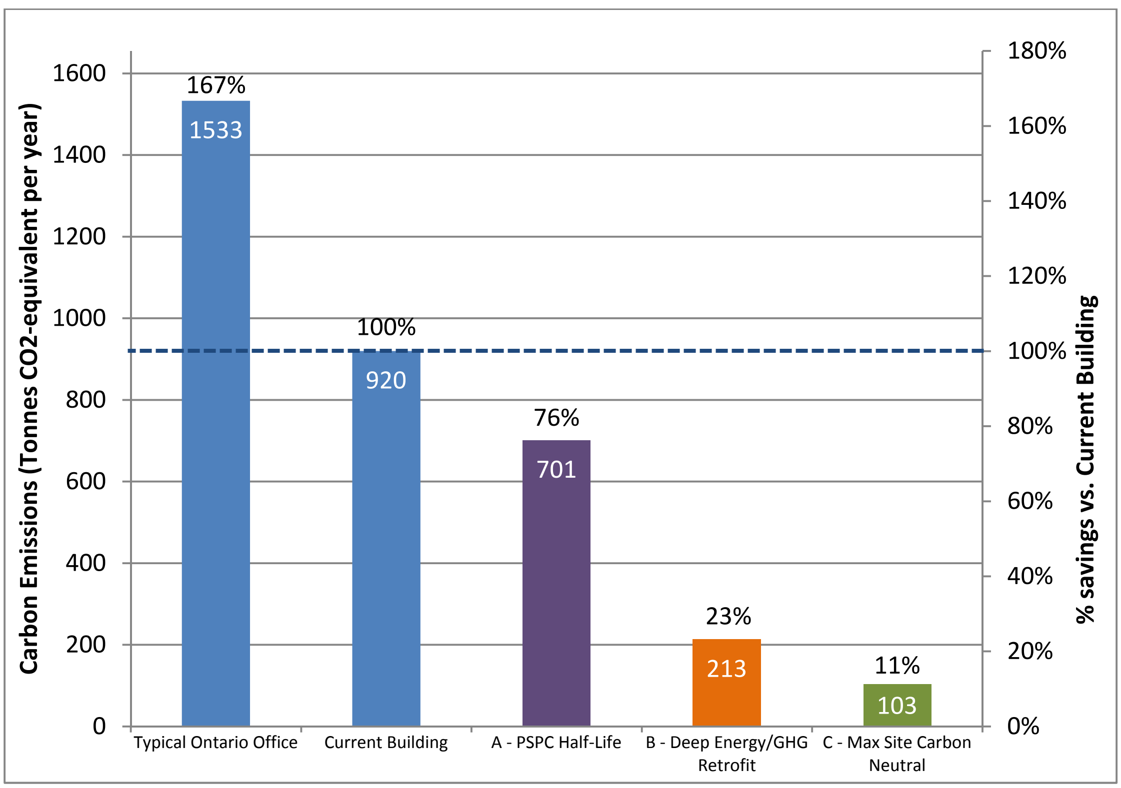

Figure 8. Annual Carbon Emissions (Tonnes CO_2-equivalent emissions per year) and % Performance vs. Current Building

6.4 COMPARATIVE LIFECYCLE COSTS

Table 10 and Table 11 compare the first costs and life-cycle costs for all studied options.

Table 10 includes the capital cost compared to the full life-cycle cost and Table 11 provides a breakdown of the life-cycle cost to understand better the implications of reduced utility and carbon costs vs. additional costs for construction and replacement of more expensive systems.

Both the Deep Energy/GHG Retrofit and Site Carbon Neutral options have significantly higher capital costs that the Half-Life design. The long-term energy savings and carbon cost avoidance do not sufficiently compensate for this extra capital over 25 years, making the Half-Life the better choice from a purely cost-benefit perspective.

Though the capital is an extra $7.6M for the Carbon Neutral case, the energy savings of this option compensates for the difference compared to the Deep Retrofit design, resulting in a difference of life-cycle cost of only $5.9M

Scenario	Construction Cost (M$2016)	Incremental Constr. Cost (M$2016, %-Half-Life)		Life-Cycle Cost (LCC) (M$2016)	Incremental LCC (M$2016, %-Half-Life)	
A - Half-Life Major Retrofit	144.1			230.4		
B - Deep Energy/GHG Retrofit	155.8	11.7	8.1%	237.4	7.0	3.0%
C - Maximum Site Carbon Neutral	165.0	20.9	14.5%	243.3	12.9	5.6%

Table 10. Comparison of Capital Cost and Life-Cycle Cost (uses $50-250 carbon + 4% escalation)

Scenario	Construction Cost* (M$2016)	Replacement** (M$2016)	Maintenance*** (M$2016)	Utilities^ (M$2016)	Carbon^^ (M$2016)
A - Half-Life Major Retrofit	144.1	49.3	19.9	13.1	3.9
B - Deep Energy/GHG Retrofit	+11.7	+1.9	(0)	(3.9)	(2.7)
C - Maximum Site Carbon Neutral	+20.9	+1.5	(0)	(6.1)	(3.3)

* - Hard and soft construction costs
** - Replacement of capital over the life cycle
*** - On-going maintenance costs, excluding utilities
^ - Natural gas, electricity, and water. Electricity escalated at 4%, others escalated at standard PSPC inflation (~2%)
^^ - Carbon tax at aggressive scenario - $50 in 2021 to 250 by 2030

Table 11. Breakdown of Life-Cycle Cost with + (higher) or (#) (lower) vs. Half-life

To confirm these observations, sensitivity analysis was performed on the carbon pricing (3 scenarios) and escalation of electricity (5 scenarios). These results are shown in Figure 9. The figure shows the average life-cycle cost across the three carbon pricing schemes and a trend line for each design across the five escalation rates. The average for the three carbon pricing schemes was used, since the difference in price did not affect the overall conclusion

The figure provides three important observations:

1. Option A - The half-life scenario is the most cost-effective within the sensitivity range. It would require an electricity escalation rate greater than 13% to make the Carbon Neutral and Deep Retrofit cases equal in life-cycle cost to the Half-Life design (i.e. by extrapolating the trend line to 14%, the NPVs would be equal).

2. Option B - The Deep Retrofit achieves a better life-cycle performance over all of the studied range compared to the Carbon Neutral option, but the gap narrows significantly towards the upper end of the escalation range.

3. Option C - The Carbon Neutral case is the flattest line and the least subject to variability in electricity costs, but is still the highest life-cycle cost in all scenarios.

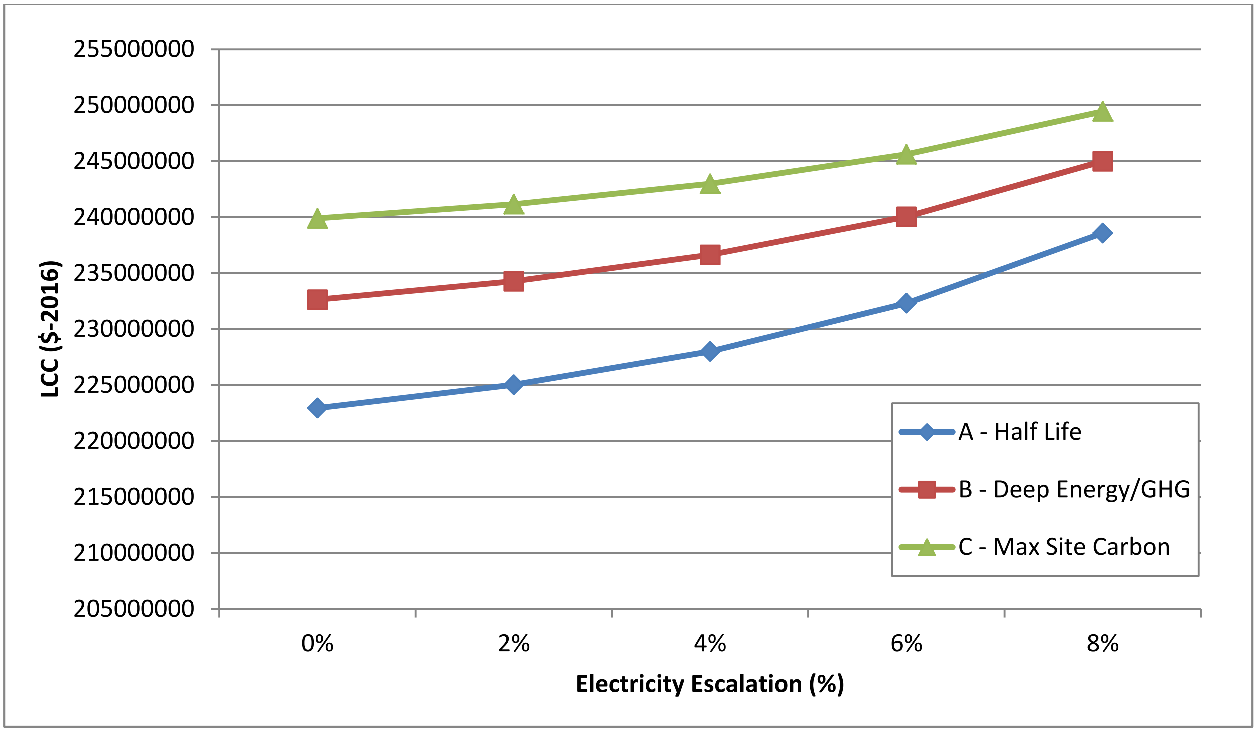

Figure 9. Life-cycle cost vs. Electricity Escalation (average of carbon cost scenarios)
Note: Graph is truncated to emphasize difference in the three trend lines.

6.5 COMPARATIVE SCHEDULE IMPACTS

The required end date of 25 March 2021 (CRA Move In) continues to be fixed in all options. It should be noted that the December 2015 and January 2016 schedules showed key critical (zero slack) activities such as Investment Analysis Report (was completing 12 December 2016, now 2 February 2016 slip six weeks) and TB Approval (was completing 10 April 2017, now 15 June 2017 slip eight weeks) now delayed. Delay such as this effectively squeezes the rest of the schedule against the fixed end date.

As you move through each of the new options each of which has its own schedule, some mitigation has occurred. However with each option, additions and complexity elevate the risk.

It is recommended that progress monitoring and reporting be initiated with the aim of recognising and mitigating slippage. It should ensure that regular team meetings provide schedule progress and immediate period forecasts and necessary action taken to stay on schedule. Another recommendation would be to ensure that a suitable Planning and scheduling system specification be part of the Prime Consultant and Construction Managers RFP documents.

7.0 RECOMMENDATIONS

If the goal of PSPC is to achieve carbon neutral in their portfolio - and if the increased capital ($20.9 million) and life-cycle cost ($12.9 million) are manageable - then it is our recommendation to pursue the Maximum Site Carbon Neutral option, but seek out efficiencies in photovoltaic, thermal storage and HVAC system costs during schematic and detailed design. The additional risks associated with this option are not significant, and this facility would make a good exemplar of what is possible to achieve in major renovation of a building of this type and vintage.

If the goal is to target a reasonable carbon reduction (i.e. 24% as compared to the Current Building), achieve near-equivalent performance to the NECB-2015 and have the lowest NPV, then the Half-life Major Retrofit is the best of the three options and should be selected.

If a more balanced approach is desired, the Deep Energy/ GHG Retrofit is a good option, with only 3% increase in life-cycle cost for an 8% additional investment. In this case, further work is recommended in the early concept/schematic design phase to explore a life-cycle-cost neutral design. This work will likely include scaling-back the extent of the wall system improvements. Such an option was discussed during this study, but not pursued due to the potential risk associated with “repairs only” in combination with additions of insulation and vapour barrier to the enclosure. With further analysis, these risks can be better understood and a more economical solution proposed to optimize the life-cycle cost.