The Centre Block Rehabilitation Net-Zero Carbon Feasibility Study

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Abstract

Centre Block, perhaps Canada's most iconic national landmark, was built between 1916 and 1927. It has remarkable heritage value to the country and the rehabilitation of the building is a massive multidisciplinary project expected to take 10 years. Sustainability, along with Heritage and Security, has been identified as one of the top three priorities for the project. This paper presents the methods and results of a preliminary net-zero carbon feasibility study completed for the project. Energy efficiency measures were developed by the project team and combined into design packages with the goal of reducing GHG emissions as much as possible as per the Federal Government's Greening the Government strategy.

Challenges, such as meeting the heritage and security requirements for the high-profile building, are discussed. The results indicate that a net-zero carbon design based on energy efficiency, recovery of waste heat, and on-site renewable energy is possible.

Introduction

Centre Block is the main building on Parliament Hill in Canada's capital, Ottawa, Ontario, and is one of Canada's more recognizable buildings. Centre Block contains the House of Commons, the Senate, and other high heritage spaces of great historical and ceremonial importance to Canada. The construction of Centre Block began in 1916, following a fire which destroyed the first iteration of the building. When constructed over 100 years ago, the building was designed with state of the art structural, mechanical, and electrical systems; however, it has not undergone a major renovation since the initial construction.

WSP, as part of the joint venture CENTRUS, has been hired as the engineering designer of the rehabilitation of Centre Block. As part of this rehabilitation design, the Sustainability and Energy Group was tasked with a net-zero carbon study of the building project. The Centre Block Rehabilitation (CBR) Net-Zero Carbon Feasibility Study was completed for the client, the owner of the building, Public Services and Procurement Canada (PSPC). This report will discuss the methodology and results of this study.

Methods of Net-Zero Carbon Study

The methodology of the CBR Net-Zero Carbon Feasibility study follows the procedure in the PSPC guideline document "Guideline - Project GHG Options Analysis Methodology" (PSPC) for reducing greenhouse gas emissions (GHG) of the PSPC building portfolio. The methodology outlined in this guideline states that the reduction of GHG emissions in PSPC's portfolio is to follow the following procedure, in this order:

- Reduce building loads
- Optimise system efficiencies
- On-site renewable energy generation
- Offset remaining emissions

This procedure prioritizes improvements to the building which reduce loads–such as building envelope improvements and internal gain reductions–then looks to optimise the systems to better react to building loads with improved HVAC strategies and equipment efficiencies. Only then are renewable energy production or carbon offsets considered.

The PSPC methodology outlines four option packages to be created. These are:

- Option A: Design to Meet Minimum Departmental Commitments (Baseline option)
- Option B: Design to Achieve Cost-neutral (25 years) GHG Emission Reductions
- Option C: Design to Achieve Maximum GHG Emission Reductions
- Option D: Hybrid GHG Emissions Reduction Design

Consistent GHG emission factors must be used to have a meaningful comparison between carbon studies. For this reason, the GHG emission factors for the electrical grid, district energy systems, and other energy sources are consistent with previous PSPC Building Portfolio Carbon Studies.

It should be noted that a 50-year life is used for the life cycle analysis of the CBR Net-Zero Carbon Feasibility Study, which differs from the standard 25-years. Centre Block is already over 100 years old and is expected to last much more than 25-years into the future.

Energy Modelling Software Selection

It was decided that the energy modelling software to be used on the CBR Net-Zero Carbon Feasibility Study would be Integrated Environmental Solutions Virtual Environment (IES VE). This decision was made based on the strengths of the software, namely: the building geometry builder is powerful and allows for continuous editing; the thermal mass of the envelope and associated transient effects are accounted for; and ApacheHVAC (the component of IES VE for building custom HVAC systems) allows for in-depth and highly customizable HVAC analysis. IES VE also allows for future integration with the design team with built-in tools to support the mechanical and electrical designers with building load calculations as well as the potential for Building Information Model (BIM) integration. There are some challenges associated with IES VE that needed to be overcome. There is a steep learning curve for users of IES-VE (especially with ApacheHVAC) and the simulation run time is relatively long (some of the more complex models take several hours to run).

IES VE software is used for the building energy model, in combination with external calculations carried out in other software tools. For example, a plant model was created in Microsoft Excel to account for a complex system which could not be simulated directly in IES VE. Ground Loop Design (GLD) software was used to simulate the performance of geo-exchange systems that were investigated in the CBR Net-Zero Carbon Feasibility Study.

History and Methods of Energy Modelling

Investigation of Centre Block in its Present Condition

The first step of the energy modelling work for the CBR Net-Zero Carbon Study was to create a model of the building in its current condition, matching the results to available energy billing/metering information. The construction of the building began in 1916 and therefore it was difficult to compile modern and complete building information to produce the energy model. A combination of architectural as-built drawings and energy audit reports, along with energy bills was used to produce the energy model. Figure 1 shows the geometry of the IES VE energy model of the existing building.

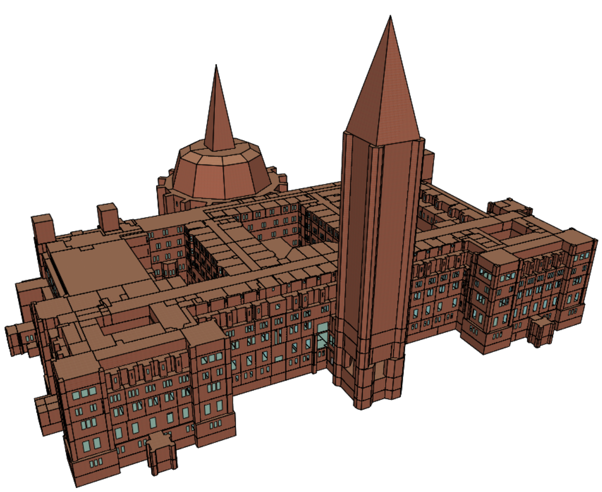

Figure 1: The geometry of the IES VE energy model of the existing Centre Block.

During the initial investigation, there were interesting discoveries which are quite unique to this building. For one, the building was designed with ventilation and cooling provided to roughly 40% of the building. The spaces provided with ventilation and cooling are generally the large gathering spaces such as the House of Commons, the Senate, and large committee rooms.

The HVAC system design is rudimentary relative to modern systems. Air handling units (AHUs) are designed with a high outdoor air fraction (in the range of 80% and higher) and run continuously at constant volume.

The rest of the building generally does not receive cooling and ventilating services and is designed with steam radiators for heating. As a result, every office was originally designed to have direct access to a window for ventilation and daylighting. This was accomplished with the design of 3 large courtyards in the centre of the building, which provides nearly every office an exterior wall with an operable window. Operable transoms over the doors leading onto the corridors were used to allow cross ventilation of the offices by natural ventilation.

The masonry walls are also unique as they are very thick – over 3 feet thick in some places – and therefore provide a substantial thermal mass which must be accounted for in the model. There is no insulation in the exterior walls.

Heating and cooling are primarily supplied by a District Energy System (DES), which serves chilled water for cooling and steam for heating. The DES is slated to be renovated in the coming decade, but as is, offers heat at a high GHG intensity due to the inefficiency of steam boilers as well as delivery losses associated with the distribution of steam.

The combination of the above design aspects causes Centre Block to have a very high heating load, and in combination with the high GHG intensity of the heat delivered by the DES, leads to the building having a GHG intensity (GHGI) of over 90 kg eCO_2/m^2.

The Centre Block Rehabilitation project provides the unique opportunity for groups that generally work in silos on standard projects to interact and support each other to produce high quality, thoughtful work. In the case of the Sustainability & Energy Group, it allows for access to and support from the building sciences group, mechanical and electrical group, and the architectural group.

The building sciences group provides support in the investigation and analysis of the building envelope assemblies such as the masonry walls, glazing, and mansard roof. Building sciences provide thermal performance information and analysis for the current building envelope assemblies, and analysis to provide potential future performance of these assemblies. Building sciences also carries out hygrothermal analysis of proposed assemblies to determine the effects of insulating the heavy stone and masonry exterior walls.

The mechanical and electrical groups provide feedback on the feasibility of HVAC and lighting/equipment-related ideas and measures. They provide support in understanding the conditions of the current building through their investigations, but also in developing HVAC designs. As the project progresses into schematic design, the energy model supports the mechanical team by providing mechanical loads calculations and analysis of the energy efficiency and performance of various proposed HVAC options.

The architectural group supports the Sustainability and Energy Group in understanding the future design of the Centre Block. This includes updates on the building envelope shape (such as the potential addition of skylights covering the courtyards) and the functional program of the Centre Block and the new construction Parliament Welcome Centre (PWC).

Modern Design of the Centre Block and Visitor Welcome Centre (Baseline Design: Option A)

The next step in the CBR Net-Zero Carbon Feasibility study was to create a design for the baseline Option A. The baseline (Option A in the PSPC methodology) is defined by the guidelines as demonstrating a 24% improvement over the National Energy Code of Canada Buildings 2015 (NECB-2015) (NRC, 2015) for rehabilitated buildings and a 28% improvement for new construction buildings. During the process of creating the Option A design, the energy model was updated to include architectural updates of the future design. The potential updates include the closing in of the courtyards of Centre Block by covering them with skylights and adding an underground building in the front lawn of Parliament Hill called the Parliament Welcome Centre (PWC).

The potential architectural updates drastically change the electrical, heat, and cool load profiles relative to the current Centre Block. Closing in the courtyards change the exterior walls facing onto the courtyards to interior walls facing onto a conditioned courtyard. This changes the building from being heating load dominated with most offices exposed to the exterior, to a more traditional office profile with increased cooling loads in interior office spaces. The addition of the below-grade PWC also drastically changes the load profile. The conditioned floor area of the combined CB and PWC building is nearly doubled, and the PWC is cooling dominated throughout the year. This is due to the fact that PWC is entirely underground and heat loss through the building envelope is limited. Cooling loads are dominated by high internal gains and heating loads are minimized by energy recovery ventilators. As a result, the majority of the heating demand from PWC is for dehumidification purposes (reheat). The large increase of floor area with a modern new construction building (PWC) has the effect of increasing electrical consumption.

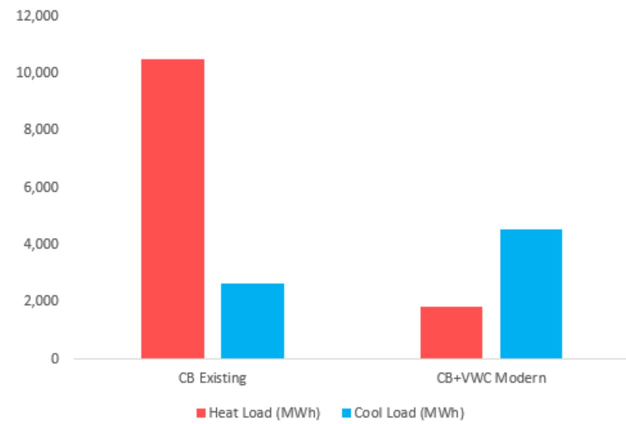

Figure 2: Annual heat and cool loads (MWh) from the IES VE energy model of existing CB compared to the baseline design (Option A) of the CBR Net-Zero Carbon Feasibility Study

These architectural changes invert the CB and PWC annual load profile from the existing CB being a heating dominated building to an overall cooling dominated building which creates unique challenges, and opportunities, in the Ottawa climate. Figure 2 shows a summary of the heat and cool loads for the baseline design (Option A) of the CBR Net-Zero Carbon Feasibility study in comparison with the loads of CB existing. It can be seen that overall heat load is vastly reduced, while the cool load increases with the additional floor area of the PWC.

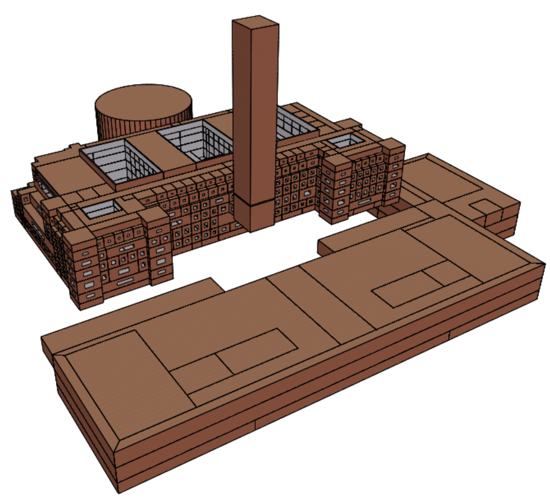

Figure 3: Geometry of the IES VE energy model used in the CBR Net-Zero Carbon Feasibility Study. Includes the CB potential skylights over courtyards and a core-and-shell representation of the potential PWC design.

Figure 3 shows the geometry of the IES VE energy model that was used in the CBR Net-Zero Carbon Feasibility Study. It includes the potential skylights over the courtyards, as well as a core-and-shell representation of the PWC design.

The CBR Net-Zero Carbon Feasibility Study provides other challenges that are uncommon in most energy modelling projects: heritage concerns, security concerns, and the provision of a modern and comfortable occupant experience in a building which did not have modern HVAC services in mind in the original design. Many of these considerations have the potential to be in conflict with an energy efficient design and therefore innovative design solutions and compromises need careful consideration.

The Centre Block was designed before modern services were included in building designs. This means that there are no plenums in dropped ceilings to distribute services through the building. There are magnificent carvings and finishing on many of the walls and ceilings in rooms and corridors which further complicate distribution of ducts, pipes, cables, and sprinklers and prevent the installation of insulation in the walls. Heritage constraints greatly complicate the integration of diffusers and zonal mechanical equipment.

The challenges listed above create difficulties in providing modern and comfortable occupant experience in the building including proper ventilation per ASHRAE 62.1 and thermal comfort. Therefore, strategies which minimize space required for distribution of services were prioritized. For example, a dedicated outdoor air system (DOAS) was identified early in the design process as the ventilation strategy because of the reduced duct size require for distributing ventilation to the spaces.

Development of Measures

To meet the low carbon targets of the CBR Net-Zero Carbon Feasibility Study, all aspects of the building need to be investigated for potential improvement. As per the PSPC methodology, the primary focus is to reduce the building loads, then focus on efficiencies, before exploring renewable energy, and finally carbon offsets. To meet the targets the Sustainability and Energy Group created a list of measures of building improvements. These measures touch on many aspects of the building including the energy and carbon performance of the building, but also the sustainability of the building and surrounding landscape. The measures also incorporate the wellness of the occupants of the building. The number of measures total over 200. The energy and carbon measures focus on the improvement of building envelope, reducing internal loads/gains, improving airside HVAC and efficiency, maximizing HVAC plant performance, and adding renewable energy production.

The building envelope was investigated in conjunction with the building sciences team. The building sciences team determined the thermal performance of the building assemblies that were being proposed through detailed calculations which accounted for thermal bridging of new and old structural components in complex assemblies. They helped design practical envelope assemblies and calculated the associated thermal performance. The masonry walls as is, with no insulation, are found to have a thermal transmittance of approximately U(SI)-1.0. Most of the thermal resistance is due to the thickness of the masonry. Building sciences investigations included insulation layers to give the wall construction effective thermal transmittance as low as U(SI)-0.5. They also carried out hygrothermal analysis of the moisture performance of the walls in specialized software Wärme Und Feuchte Instationär (WUFI). Analysis of the potential risks and benefits of insulating the stone and masonry walls is ongoing. The assemblies that were investigated for sustainability measures include the masonry walls, roof, glazing, skylights, and the underground assemblies of the PWC. Air leakage testing of the existing assemblies has been performed by the building sciences group to get a better understanding of the effects of infiltration. Unsurprising, the existing envelope was found to be extremely leaky.

The internal gains that were investigated in the measures of the CBR Net-Zero Carbon Feasibility Study were the lighting and plugs loads, namely IT and multi-media loads. Measures are based on high-performance LED lighting design with the support of the electrical design team and a lighting consultant. General plug loads were not investigated; however, reductions in central building IT and multimedia loads are explored. The IT load of the standard design assumes a standard copper distribution of network services, which has an associated electrical load in the IT closets. This internal gain was calculated based on a list of expected equipment for IT services, and then compared to studies for similar buildings (Sarfraz and Bach, 2018). The Sustainability and Energy Group created a measure, with the support of the electrical design team, to investigate a passive optical network distribution. In this measure, the internal gains from IT equipment are vastly reduced, which has a great impact on the overall energy usage of the building.

The airside HVAC systems measures explore ventilating strategies and room conditioning equipment. The heritage and security limitations of the project defined the ventilating strategies that could be realistically included in the project design. For example, a dedicated outdoor air system (DOAS) with fan coils in spaces is incorporated into the baseline design (Option A) to reduce duct sizes because distribution of larger ducts would have significant impacts on the heritage character of the building. Energy efficiency of the decoupled ventilation and conditioning strategy is advanced further with zone equipment such as radiant heating, radiant cooling, and chilled beams. Improved energy recovery ventilator (ERV) effectiveness is also investigated.

The status quo plant for the CBR project would be to connect to the DES and be supplied Hot Water (HW) and

Chilled Water (CHW) as per building demands. This plant design limits the potential carbon performance of the project because the DES heat is produced with a high carbon fossil fuel (natural gas). As a result, a key element of the strategy of the CBR Net Zero Carbon Feasibility is to reduce, and possibly eliminate, the building's reliance on natural gas for heat.

It was determined early on in the project that the annual cooling loads of CB and PWC outweigh the annual heating loads. This occurs for several reasons. The courtyards of CB are potentially to be covered with skylights which converts many perimeter spaces to internal spaces. PWC is an underground building with little to no external exposure. The merger of the geometric features of these buildings, combined with the high internal gains of both buildings, results in a relatively low annual heating load and a relatively large annual cooling load. A large portion of these loads were determined to occur simultaneously. This is a unique situation for a building project in Ottawa, Ontario (ASHRAE Climate Zone 6), which the Sustainability and Energy Group harnessed by recommending plant strategies to reduce the building's reliance on natural gas heating from the DES.

The primary plant measure recommended is the implementation of a waste heat recovery loop. This is the heart of the low carbon strategy proposed in the CBR Net Zero Feasibility Study. This measure reduces the GHG emissions of the project significantly, but also unlocks the use of other plant strategies. The measure includes a tempered water loop, named the Heat Recovery Loop (HRL), distributed between CB and PWC. IT closet cooling equipment and refrigeration equipment reject heat directly to this loop through distributed water loop heat pumps. A chiller is installed in PWC to meet the cooling demands for the PWC and reject heat into the HRL. Heating for CB and PWC is provided by a central loop-to-loop heat pump which provides hot water by acquiring and upgrading heat from the HRL. Additional heating and cooling are provided by the DES as needed. The HRL allows the heat rejected from the cooling loads of CB and PWC to be reused to offset the heating demand of the buildings during periods of simultaneous heating and cooling loads. This measure reduces CB's demand on DES Heat, which as a result significantly reduces the GHG emissions.

The IES VE software plant capabilities do not have the capability to directly model this plant set. As a result, a workaround calculation is done in Microsoft Excel. Hourly loads on HW loops and CHW loops are collected in IES VE. These loads were input into the Excel calculator where the heating and cooling energy provided by the heat pump and the DES are calculated along with the electrical demand of the heat pump compressors.

Figure 4 shows an annual heat map of the useful heat energy that can be recovered from cooling processes in CB and PWC. The chart is created by comparing hourly results from the IES VE model of the heat and cool loads. Energy is recovered only when there is a heating load concurrent to the heat rejection load.

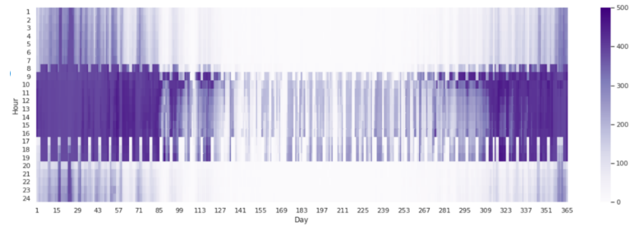

Figure 4: A heat map of useful heat recovered from the HRL (kW).

The inclusion of the HRL allows the design to incorporate other strategies to the plant design. One of these measures is a geo-exchange system which allows for seasonal storage of rejected heat that cannot be used instantaneously at that hour. The geo-exchange analysis is done in Ground Loop Design (GLD) software based on the hourly heating and cooling loads for the building.

Figure 5 shows the GHG intensity of delivered heat for the existing Centre Block and the four design options produced by the CBR Net-Zero Carbon Feasibility Study. The dramatic reduction from the existing Centre Block to Options B, C, and D can be attributed to the fuel switch from natural gas-fired steam boilers used in the current DES to high efficiency electric heat pumps being proposed.

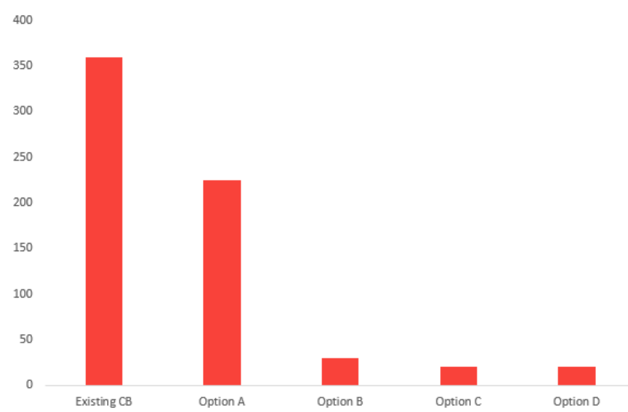

Figure 5: GHG intensity of delivered heat (g eCO2 / kWh) of the existing Centre Block and four design options produced in the CBR Net-Zero Carbon Feasibility Study.

Another strategy that utilizes the HRL is heat sharing to nearby buildings within the Parliamentary Precinct. If there is heat rejected that is beyond what is useful for CB and PWC, it can be shared with nearby buildings when they have a demand for heating. The shared thermal energy of the CBR project is accounted for as offset heat from the natural gas DES. The study accounts for this as Renewable Thermal Energy and receives credit in terms of carbon emission offsets and energy cost reductions relative to what the buildings would have purchased from the DES.

Renewable energy technologies are included in the measures of the CBR Net-Zero Carbon Feasibility Study. Firstly, the shared heat, as discussed in the section above, is accounted for as Renewable Thermal Energy.

More traditional electrical renewable energy sources are also investigated, such as: building integrated photovoltaics, wind power generation, and run-of-river turbines due to the proximity to the Ottawa river. Of these, the most feasible is the inclusion of building integrated PV.

Other miscellaneous measures are investigated. Some of these measures do not necessarily reduce energy consumption of CB and PWC but may provide demand reduction or carbon benefits. Examples include battery storage to offset peak electrical demand and diurnal heat storage in phase change materials. Both measures do not reduce total energy usage, but peak energy demand, energy costs, and equipment sizes are reduced. These measures, especially battery storage, have a benefit of reducing peak electrical demand, which significantly reduces electricity costs due to the Global Adjustment (GA) fee structure. By reducing peak electrical demand during the Independent Electricity System Operator (IESO) peak hours, the project can reduce the GA charges, which make up the majority, of the electricity costs.

Life Cycle Cost Analysis

Once the measures were formalized and written up, the descriptions were shared with the Construction Manager (CM), a joint venture of PCL and Ellis Don, for costing. The CM provided the Sustainability and Energy Group with the upgrade cost of each measure relative to the baseline package (Option A).

The individual measure costs were analysed with a Life Cycle Cost (LCC) calculator created by the Sustainability and Energy Group using a 50-year life cycle.

Each measure is analysed individually to determine the net present value based on the energy and carbon savings determined by the energy modelling work.

Development of Option Packages and Results

Once the CBR Net-Zero Carbon Feasibility Study of the individual measures was completed, along with the costing from the CM as well as the internal LCC analysis, the measures were combined into the three option packages (Option A, Option B, and Option C) as per the definitions of the PSPC Methodology. Energy modelling and LCC analysis was done on each of the option packages as a whole to confirm compliance. The Sustainability and Energy Group were successful in producing the three packages:

- Option A (The baseline design): 24% energy improvement over NECB
- Option B: Life Cycle Cost Neutral relative to Option A
- Option C: A net-zero carbon design, or better

The three Option packages, along with individual measures, were presented to the client in a series of workshops. The client was given the opportunity to discuss what was liked and disliked about the packages and give feedback on what they thought could reasonably be incorporated in the building design. With this information, the Sustainability and Energy Group then developed the recommended Option D. Option D was developed as a hybrid option between Option B and Option C and is relatively close to life cycle cost neutral over the 50-year life while incorporating effective and beneficial measures from the Option C net-zero package.

Option D achieved a net-zero carbon design. This is primarily due to:

- Load reduction through improving the thermal performance of the building envelope
- Load reduction through the reduction of internal gains
- Load reduction through the use of energy recovery on ventilation air
- Recovering waste heat from the cooling dominated buildings and repurposing it for the heat load
- Fuel switching for heating energy: using high efficiency electric heat pumps instead of a DES based on natural gas boilers
- Promoting thermal energy sharing and energy storage

Conclusion

The Centre Block Rehabilitation Net-Zero Carbon Feasibility Study completed by the Sustainability and Energy Group was successful. Over 200 sustainability and energy measures were created and examined for the purposed of creating 4 design options (Options A, B, C, and D) as per the PSPC methodology. While Centre Block, as it stands today, has an annual GHGI of over 90 kg $eCO2 / m^2$, the feasibility study was able to achieve a net-zero design option. The high performing design options from the feasibility study accomplished net-zero carbon primarily by reducing thermal loads, reducing internal gains, and a high-performance plant which reuses waste heat.

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