# DEEP RETROFIT & FUEL SWITCH PROJECTS FOR EXISTING COMMERCIAL BUILDINGS: CASE STUDY DEVELOPMENT

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Prepared by: Kaushalkumar Upadhyaya - UBC Sustainability Scholar 2024

Mentor: Ashley St Clair and Abhijeet Singh
Green and Resilient Building Team
City of Vancouver

## Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability and climate action across the region.

This project was conducted under the mentorship of the City of Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of the City of Vancouver or the University of British Columbia.

## Territorial Acknowledgement

The author acknowledges that the work for this project took place on the unceded traditional territories of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh (Squamish), and səlilwətaɬ (Tsleil-Waututh) Nations.


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## Note

This Executive Summary is an abbreviated version of the report.

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## Introduction:

The building sector in Canada is a significant source of greenhouse gas emissions, accounting for 13% of the national total (Blue Raidin, 2024). In Vancouver, the combustion of natural gas for heating and hot water purposes in buildings contributes to 55% of the total carbon emissions (City of Vancouver, n.d.). To achieve meaningful reductions in carbon pollution, it is imperative to implement innovative strategies in the heating, cooling, design, and construction of buildings. There are early adopters in the Lower Mainland who have completed deep retrofit upgrades on commercial buildings, but the performance of these systems, including the user experience, has not been documented and made publicly available.

This report presents a series of case studies documenting the retrofitting and fuel-switching experiences of four commercial buildings in the Lower Mainland. These buildings, including a swimming pool, an office building, a district hall, and an educational institute building, have successfully transitioned from fossil fuel-based systems to high-efficiency electric or dual-fuel alternatives. The case studies delve into the motivations behind these retrofits, the technical details of the implemented solutions, the challenges encountered during implementation, and the lessons learned. They highlight the importance of thorough planning, stakeholder collaboration, and a deep understanding of system controls for successful project execution.

## Methodology:

The City of Vancouver mentors played an integral role in the case study selection process, providing expertise and access to industry contacts. Interviews were conducted with various stakeholders involved in the deep retrofit projects, including owners, mechanical consultants, consulting firms, and other relevant parties. The interviews followed a semi-structured format, utilizing a prepared interview question database as a guide while also incorporating insights from preliminary research, including review of feasibility study reports.

The series of interview questions aim to gather comprehensive information about a retrofit project. Starting from pre-project inquiries about the project's overview, decision drivers, and contractor selection, it moves on to implementation challenges, electrical upgrades, equipment replacements, and control integrations. The post-implementation phase focuses on success factors, maintenance issues, lessons learned, occupant benefits, permitting challenges, visual documentation, and detailed energy performance data comparison before and after the retrofit, including equipment specifications.

In addition to interviews, the case study preparation involved extensive research, encompassing feasibility study reports, case study examples from relevant organizations, technical data sheets of equipment under consideration, and retrofit-related reports from research institutions. Field visits were conducted whenever possible to visually assess the retrofit projects and gain first-hand insights into the challenges and opportunities encountered during the retrofit process.

The data collected from interviews and research was analyzed using Microsoft Excel and RETScreen Expert software. Regression analysis was employed to identify correlations between energy consumption and factors like building occupancy, weather conditions, and equipment performance.

A mathematical model was developed to quantify the financial and environmental impacts of the building retrofit over a 20-year period. By analyzing pre- and post-retrofit natural gas and electricity consumption data, the model calculated net financial savings (considering natural gas reductions, increased electricity use, and potential carbon taxes), as well as the greenhouse gas emission reductions achieved through natural gas conservation. This comprehensive analysis demonstrates the long-term value and sustainability of the retrofit investment.

## Case Study 1: Swimming Pool Domestic Hot Water Fuel Switch

A swimming pool facility replaced its gas-fired domestic hot water (DHW) system serving the showers only. The existing 82% efficient natural gas boiler was replaced with a CO2 heat pump with a COP of 3.8. Key drivers for the project included achieving a significant reduction in greenhouse gas (GHG) emissions, as well as addressing aging equipment.

The first phase of the retrofit involved down-sizing the heating demand by replacing the 2.5 GPM higher-flow showerheads with 1.5 GPM lower-flow models. In addition to reduced water usage, this step lowered the DHW system capacity requirements by 40%, resulting in a reduced capital cost and lower electrical requirements for the retrofit heat pump solution.

The second phase of the retrofit entailed installing a CO2 heat pump. The heat pump supplies two 250-gallon primary storage tanks arranged in series to enhance stratification. The second primary storage tank includes a 54kW electric heater, providing a low-cost source of redundancy in case of heat pump failure. Additionally, a third 250-gallon tank, equipped with an 18kW electric heater, acts as a swing tank to separate recirculation losses from the primary storage.

A critical factor contributing to the project's success was a thorough understanding of both the controls and the overall system. One of the significant challenges with CO2 or single-pass heat pumps is the requirement for low-return water temperatures to maintain system efficiency. The use of stratification is a useful strategy to be used in this scenario for low water inlet temperature to the heat pump.

Key lessons learned include the importance of understanding system controls of the system works and ensuring proper integration with the building automation system (BAS).

## Case Study 2: Office Building Space Heating Fuel Switch

An existing 1976, 4-storey, 50,000 square foot office building replaced its end-of-life chiller with an air-source heat pump and electric boiler system. The project aimed to reduce GHG emissions and improve the building's heating and cooling system.

The existing building received heat via gas-fired boilers located in an adjacent building, connected via underground pipes. The existing building also utilized a chiller, an air handling unit with fan coils, and high-temperature perimeter baseboard heating.

The new heat pump with variable speed drive serves as the primary heating source for the building, supplying low-temperature heating water at 113°F. During periods of high heating demand, the new high-temperature electric boiler plant supplies backup heat with a high temperature water at >160°F to the existing perimeter radiation units. This strategy optimizes energy usage and manages operating costs by utilizing the electric boiler only when necessary.

A key consideration during the retrofit process was the potential utilization of cooling coils for supplementary hot water circulation. While cooling coils can effectively serve dual heating and cooling purposes, the converse is not applicable. The project was successful in improving system reliability and efficiency, with no reported maintenance issues after completion. Key lessons learned include the importance of engaging experienced consultants, utilizing skilled contractors, and implementing rigorous design review and oversight processes.

The results of the retrofit include:

1. Annual natural gas savings of 4,178 GJ
2. Annual GHG emission savings of 209 tons

## Case Study 3: District Hall Electrification Retrofits

An existing 1994, 70,000 square foot district hall building underwent a comprehensive retrofit, replacing the chiller and cooling tower with an air-to-water heat recovery heat pump, replacing non-condensing boilers with high-efficiency condensing boilers for back-up, and upgrading various HVAC (Heating, Ventilation, and Air Conditioning) components. The project aimed to reduce GHG emissions, improve energy efficiency, and enhance occupant comfort and acoustics.

The technology selection process encompassed a comprehensive evaluation of several factors such as electrical and structural capacity, and consideration for future climate scenarios. The project avoided the need for electrical upgrades due to previous energy efficiency initiatives. The primary challenges encountered during the installation process stemmed from contractor capacity limitations which resulted in timeline extension beyond the initial projection. A comprehensive building permit was obtained for the project, eliminating serious issues related to specific permits such as structural approvals.

Key lessons learned include the importance of prioritizing demand reduction, conducting thorough assessments of structural limitations, and adopting an integrated planning approach.

The results of the retrofit include

1. Annual natural gas savings of 1,886 GJ
2. Annual GHG emission savings of 94 tons

## Case Study 4: Educational Institute Building Retrofit

An existing 1961 educational institute building underwent a phased retrofit, starting with the installation of electric infrared radiant heaters and an electric hot water tank, followed by the implementation of a heat-pump variable refrigerant flow (VRF) system. The project aimed to reduce carbon emissions, replace aging equipment, and improve occupant comfort (e.g., addition of cooling to areas previously without).

The existing building consists of a double-height workshop area with two-level wings on each side that contain offices, classrooms, locker rooms, and the mechanical room. Serving the wings, the building previously had two 80% efficient gas-fired boilers providing hot water to two air handling units (AHU) and perimeter hydronic radiators, as well as two gas-fired RTUs (Rooftop Units) and a gas-fired MUA (make up air units) (make up air units). The double-height centre of the building was served by 6 infrared radiant gas heaters (no ventilation or cooling in this space). The domestic hot water tank had a 11.7 kW heating capacity, with a 60-gallon tank. Before the retrofit project, an electrical upgrade was completed at the 400 Amp panel, bringing 300 kW of additional power capacity to the building. In the first retrofit phase, the gas-fired infrared heaters were upgraded to eWave longwave infrared electric heaters (output of 370,000 Btu/h). Control of the new heaters is fully integrated into the direct digital control (DDC) controller and is operated based on space temperature, occupancy sensing, and a weekly schedule.

The second phase of the retrofit saw the installation of high-efficiency outdoor VRF heat pumps (25 tons and 8.5 tons) with ceiling ducted indoor units (seven and three, respectively). The AHU and MUA were equipped with new electric heaters (AHUs: 30 kW, 20 kW; MUA: 34 kW).

The existing domestic hot water unit was replaced with a lower capacity electric tank and higher-capacity storage (9 kW, 80-gallon storage).

The project had done a major electrical upgrade before starting both phases of the project highlighting the importance of checking electrical capacity first. The installation of electrical infrared heaters requires careful consideration of mounting heights due to operational characteristics underscoring the difference between gas infrared and electrical heaters. Also, Motion sensors were integrated into the system to optimize energy efficiency by activating the heaters only when occupants were present.

The installation of the new variable refrigerant flow (VRF) system on the roof leveraged existing ductwork, though it necessitates a building permit which required architectural review and input.

Key lessons learned include the importance of ensuring adequate electrical service capacity, designing a well-integrated control system, and obtaining permits well in advance.

## Summary

These case studies demonstrate the feasibility and benefits of deep energy retrofits in buildings. By replacing fossil fuel-based systems with high-efficiency electric alternatives, building owners can significantly reduce GHG emissions, improve energy efficiency, and enhance occupant comfort. The lessons learned from these projects highlight the importance of thorough planning, stakeholder collaboration, and a deep understanding of system controls for successful project execution. These insights can guide other building owners and stakeholders in their pursuit of deep energy retrofits, contributing to a more sustainable and resilient building sector.

# References

Blue Raidin, A. B. (2024, 01 17). *Deep Retrofit Supply Chain Analysis*. Retrieved from Pembina.org: https://www.pembina.org/pub/deep-retrofit-supply-chain-analysis

City of Vancouver. (n.d.). *Climate action through buildings*. Retrieved from https://vancouver.ca/: https://vancouver.ca/green-vancouver/buildings.aspx#

City of Vancouver staff, a. p. (n.d.). Feasibility report, technical reports