Environmental and Economic Assessment of Multi-Unit Residential Building Retrofits in Toronto:
A review of challenges and lessons learned in project delivery

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Lastly, please note that any errors and omissions are the sole responsibility of the authors.

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Executive Summary

Toronto Community Housing Corporation (TCHC) has completed eleven multi-unit residential building (MURB) deep energy retrofits from 2016-2021. The retrofits fall under two funding categories: Category 1 and Category 2. Category 1 retrofits underwent a series of energy conservation measures (ECMs) that were completed concurrently over the course of approximately 1 year. Category 2 retrofits also utilized various ECMs, but the measures were staggered over a few years (approximately 4 to 5 years). Category 2 retrofits include over-cladding as an ECM. Only some Category 1 projects include localized over-cladding repairs.

The purpose of both Category 1 and Category 2 retrofits was to implement ECMs for the building envelope and building systems to reduce overall energy use and greenhouse gas (GHG) emissions, while also addressing capital needs. Since the retrofits were conducted in occupied social housing buildings, tenant consultation and engagement were an important part of the design and construction process.

The nine Category 1 building retrofits reduced building energy use intensity (EUI) by 16% in 2020 compared to pre-retrofit levels, an average of 58 ekWh/m^2/year. This correlates to GHG intensity savings of 20% or an average of 0.011 MTCO_2e/m^2/year. The two Category 2 buildings reduced EUI by 26% in 2020 compared to pre-retrofit levels. This equates to an average of 99 ekWh/m^2/year. Additionally, GHG intensity for Category 2 buildings decreased by 33% or an average of 0.02 MTCO_2e/m^2/year. It should be noted that Category 1 data has been weather normalized, whereas Category 2 data was taken directly from utility bills. In both Category 1 and 2 buildings, the GHG reductions are predominately attributed to reductions in the use of natural gas for space heating. These energy savings resulted in $283,930 worth of cost savings from Category 1 and $66,210 for Category 2.

Building envelope ECMs (holistic over cladding, roof replacement, window retrofits) were most effective at reducing EUI and greenhouse gas intensity (GHGI). Additionally, mechanical equipment upgrades with higher efficiencies use less energy to heat, cool, and provide ventilation to the building. Electrification of these systems further contributed to the reduced GHG emissions. Water consumption reductions were primarily realized by Category 2 projects. The plumbing fixture upgrades and heating and domestic hot water (DHW) upgrade ECMs were implemented in these projects. These two ECMs are likely the most impactful to actual water savings.

The key outcomes from the projects can be used to inform future social housing retrofits. Interviews with the project managers and designers highlighted the importance of tenant engagement as part of an effective delivery. Appropriate communication with tenants can result in higher tenant satisfaction and cooperation, and a smoother implementation process. It was also found that including post-construction monitoring in the commissioning scope can allow for improved data collection and analysis of building performance post-completion. Additionally, in all cases, the research found that pre-qualifying vendors and/or adopting a qualifications-based selection as part of the procurement process is paramount for project success.

Overall, both the Category 1 and Category 2 retrofits reduced the environmental impact of TCHC buildings. The retrofits allow for reallocation of TCHC funding through cost savings and improve occupant comfort and quality of life.

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1.0 Introduction

Toronto Community Housing Corporation (TCHC) has completed eleven multi-unit residential building (MURB) retrofits from 2016-2021. The retrofits fall under two groups, Category 1 and Category 2. Category 1 encompasses nine building retrofits that were completed concurrently over approximately one year. Category 2 includes two building retrofits where ECMs were completed in succession over a period of approximately four to five years. Category 2 retrofits include over-cladding as an energy conservation measure (ECM).

Both Category 1 and 2's design and construction management were internally managed within TCHC's Facilities Management team. This team is comprised of four groups:

1) Design and Engineering
2) Construction and Preservation
3) Smart Buildings and Energy Management
4) Capital Engagement and Conservation Program

The construction procurement approach for Category 1 and 2 projects were different. Due to tight construction timelines for the Category 1 funding stream, the construction procurement approach for these projects was to retain a third-party construction manager whose sole responsibility was to execute the construction of these projects and complete within timelines under CCDC 5 contract. For Category 2 projects, the project delivery was a typical design-bid-build approach with the construction procurement and management directly handled by TCHC under the CCDC 2 contract.

The purpose of the retrofits was to implement ECMs for both the building envelope and building systems to improve energy efficiency and reduce greenhouse gas (GHG) emissions from TCHC buildings, while also addressing capital needs. Since the retrofits were conducted in occupied social housing buildings, tenant consultation and engagement were an important part of the design and construction process.

1.1 Project Scope

This report assesses the technical and economic effects of the completed retrofit projects, including:

- technologies implemented,
- pre-retrofit and post-retrofit energy and water performance,
- project delivery process,
- lessons learned.

1.1.1 Research Questions

The research focused on the following research questions:

1. What are the utility bill savings and related paybacks of the installed measures?
2. What has been the engagement approach with occupants?
3. What is the project delivery process of installing these measured in occupied buildings? What challenges were encountered?

Additionally, the report provides recommendations on research measures that represent the most value across the portfolio of buildings.

2.0 Literature Review

A brief review of relevant literature was completed to inform the study. The review focused on residential building energy use globally, in Canada, and in Toronto.

2.1 Residential Building Sector Energy Use in Canada

Buildings are a significant source of global greenhouse gas (GHG) emissions. According to the International Energy Agency, the residential building sector alone was responsible for 17% of global GHG emissions in 2019 (International Energy Agency, 2020). Buildings play an important role in global sustainability initiatives.

In 2019, the City of Toronto adopted a GHG emissions reduction plan. The plan committed to achieving a 65% reduction compared to 1990 levels by 2030 and reach net zero by 2050 (City of Toronto, 2019). TransformTO completed a study in 2017 that found that 52% of total city GHG emissions come from buildings. The residential building sector accounts for 51% of these total building emissions (City of Toronto, 2017).

Space heating accounts for 64% of total residential building energy use. The other contributors to energy use are water heating (17%), appliances (13%), lighting (3%), and space cooling (2%) (Natural Resources Canada, 2018).

The City of Toronto must address residential energy use to meet their climate goals. Reducing GHG emissions from space heating will be an important step in achieving these goals as it is the single largest contributor to GHG emissions.

2.2 Conducting Retrofits in Occupied Residential Buildings

The research focuses on identifying the major challenges in retrofit project delivery in occupied residential buildings and ways that these might be overcome. The Tower Renewal Partnership was created by the Centre for Urban Growth and Renewal to create guidelines for apartment tower retrofits. The goal of the program is to ensure affordable, healthy, safe, and high-quality living conditions (Centre for Urban Growth and Renewal, 2020).

Tenants can provide valuable feedback throughout the process. A tenant engagement strategy should involve communication before, during, and after a retrofit. Before the retrofit, tenants should be brought into the decision-making process. A tenant stakeholder group can provide input on issues in the building, and the design as it develops. During the design phase, tenants can provide feedback on design choices. During construction, a “Tenant Liaison” should be incorporated into contractor requirements. The liaison is responsible for scheduling and logistical challenges between the tenants and the contractor. After the project is completed, tenants should be asked for feedback and identify issues so they can be addressed (Centre for Urban Growth and Renewal, 2020).

When residents remain in the building, projects must be designed to mitigate disruption (noise, suite entry, elevator wait times, etc.). Tenants may be required to leave their apartments temporarily during the retrofit or the suite may need to be accessed by the construction team. The Tower Renewal program identifies the need for a “Design Assist” program where retrofit designs are peer reviewed by other experts in the field. It involves review of designs that are mid-stream so that recommendations are made with enough time for changes to be made. The goal is to reduce disruption to tenants (Centre for Urban Growth and Renewal, 2020).

Another way to mitigate disruption to tenants is through minimizing construction times. The Affordable Housing Renewal pilot project in British Columbia aims to retrofit using the "Energiesprong" approach. Energiesprong is a Dutch initiative aiming to deliver net-zero retrofits in a week or less. This is achieved by completing design and pre-fabrication of components off-site, allowing installation with minimal disruption to occupants (Heerema, 2017).

3.0 Methodology

This section describes the methodology for the analysis of energy and water utility data, along with methodology used for determining key outcomes and recommendations from project delivery interviews with TCHC team members.

TCHC provided utility data, energy audits, measurement and verification reports, as-built drawings, and commissioning reports for all buildings. For all buildings, implemented ECMs were verified through analysis of as-built drawings and measurement and verification (M&V) reports. During the research period M&V reporting for Category 2 projects was ongoing and reports were not available. Implemented ECMs were verified by TCHC.

3.1 Building Occupancy

Building occupancy rates were calculated based on the number and size of units in the building. Based on recommendations from TCHC, the occupancy rate was determined using Equation 1. The total building occupancy is the sum of the number of suites for each occupancy level (one-bedroom to five-bedroom), multiplied by the number of bedrooms + 2. For example, a two-bedroom unit would assume an occupancy of four people.

$$Building\ occupancy = \sum_{n=1}^{5} number\ of\ suites * (n+2) \qquad (1)$$

Where: n = number of bedrooms

3.2 Energy and Water Consumption Analysis

Category 1 projects used weather normalized consumption data as analyzed by Watershed Technologies Inc. in Measurement and Verification Reports provided by TCHC. Category 2 projects used raw utility data as weather normalized data was not available. Due to the different timelines and nature of the consumption data, the analysis differed slightly as described in Section 3.2.1 and Section 3.2.1

Additionally, the GHG emissions factors used are shown in Table 1. Note that these values are from the Canadian National Inventory Report (NIR) and reflect annual average emissions for Ontario in 2019. The NIR considers regional variations however it is noted that the time of use of electricity can significantly affect GHG emissions from electricity use.

Table 1: Ontario average GHG conversion factors from the Canadian National Inventory Report (2021)

Convert From	Convert To	Value	Reference
m^3 Natural Gas	$MTCO_2e$	0.001888	National Inventory Report 2021
kWh Electricity	$MTCO_2e$	0.000030	National Inventory Report 2021

(Environment and Climate Change Canada, 2021)

3.2.1 Category 1 Projects

Category 1 projects include nine building retrofits that were completed concurrently over approximately one year. These buildings were numbered and labelled as Buildings 1 to 9.

Both pre-retrofit and post-retrofit consumption data was taken from each building's Measurement and Verification report created by Watershed Technologies Inc. Both pre- and post-retrofit data has been weather normalized.

Pre-retrofit (baseline) utility data for all buildings was developed using historical utility consumption data from July 2014 and June 2015. Post-retrofit data for all buildings was developed using 2020 consumption data. The year 2020 was used as it was the first full year where each building's ECMs were completed.

Summarized yearly pre- and post-retrofit electricity, natural gas, and water consumption data is found in Appendix A.

To determine yearly reductions in electricity, natural gas, and water consumption, post-retrofit values were subtracted from pre-retrofit values, as shown in Equation 2. Note that a negative value would indicate a decrease in consumption (savings).

$$Reduction\ in\ metric = (Post - retrofit\ value)\ - (Pre - retrofit\ value) \quad (2)$$

Percent reductions from pre-retrofit consumption was calculated as shown in Equation 3.

$$\%\ Reduction\ = \frac{Reduction\ in\ metric}{Pre-retrofit\ value} \quad (3)$$

Additionally, intensities (EUI, GHGI and WUI) were determined for each building through Equation 4.

$$Intensity\ = \frac{Yearly\ consumption}{Building\ GFA} \quad (4)$$

Note that building GFA was provided by TCHC and accounts for all above-grade interior space.

3.2.2 Category 2 Projects

Category 2 projects include 2 buildings; Buildings 10 and 11. These building retrofits saw ECMs completed in succession over a period of approximately four to five years. Category 2 retrofits include over-cladding as an energy conservation measure (ECM).

Pre-retrofit utility data for all buildings was based on 2015 energy and water utility information provided by TCHC.

Post-retrofit data for both buildings was taken from 2020 utility bills. The year 2020 was used as it was the first full year where each building's ECMs were completed.

Summarized yearly pre- and post-retrofit electricity, natural gas, and water consumption data is found in Appendix A.

Raw utility data was used for Category 2 projects and therefore was not weather normalized.

Yearly reductions in utilities, percent reductions from pre-retrofit consumption, and EUI, GHGI and WUI were calculated as described in Section 3.2.1, Equations 2, 3, and 4.

3.3 Cost Benefit Analysis

A cost-benefit analysis was conducted by determining the cost intensity (CAD/m^2) of each retrofit, determining the EUI, GHGI, and resulting cost savings, and calculating a simple payback. The Table 9 in Section 7.0 shows the cost-benefit of the energy savings (electricity and natural gas) only, as water consumption was likely inflated due to the COVID-19 pandemic, skewing the results.

The "total cost intensity of the retrofit ECMs" is the incurred retrofit cost per square metre of gross floor area and is calculated as shown in Equation 5.

$$Total\ cost\ intensity\ of\ retrofit\ ECMs = \sum \frac{Incurred\ individual\ retrofit\ cost}{GFA} \quad (5)$$

Equation 6 describes how "energy cost savings" was calculated. It pertains to the cost savings (from electricity and natural gas only) compared to 2020 consumption, which was weather normalized for Category 1 only. The pre-retrofit values were taken from the 2014-2016 weather normalized average for Category 1 and from 2015 utility data for Category 2. A negative value for the "energy cost savings" indicates a reduction in spending.

$$Energy\ cost\ savings = 2020\ energy\ utility\ costs - baseline\ energy\ utility\ costs \quad (6)$$

3.4 Project Delivery Interviews

Structured interviews were conducted with TCHC employees to better understand the project delivery process. Participants included 2-3 members from each of the 4 teams involved in the retrofits: Design and Engineering (D&E), Construction and Preservation (C&P), Smart Buildings and Energy Management (SBEM), and Capital Engagement and Conservation Program (CECP). A description of each team's responsibility can be found in Section 9.0 of this report.

The interviews were conducted in 4 one-hour calls (for each team) over one week. The interview questionnaire was provided to interviewees ahead of time. The aim of the interviews was to gather subjective information highlighting successes and failures from those who have worked closely on the projects.

The analysis was driven by the initial research questions and the goal of the interviews: to understand the project delivery process, its challenges, and lessons learned. Similar responses were noted, particularly where statements or sentiments were repeated multiple times.

4.0 Building and ECM Retrofit Summary

Eleven TCHC buildings were retrofitted using various ECMs. The goal of the retrofits was to decrease energy consumption and improve building efficiency. The energy efficiency retrofits fall under two funding categories: Category 1 and Category 2. Category 1 retrofits were completed concurrently over the course of approximately 1 year. Category 2 retrofits were staggered over a 4–5-year period and included over cladding. A summary of implemented ECMs is found in Section 4.2.

4.1 Building Summaries

Category 1 and 2 building size, typology, age, and occupancy are summarized in Table 2. All buildings are located in Toronto.

Table 2: Building summaries

Building ID	Year Built	Building Type	Occupant Type	Gross Floor Area (m^2)	No. Units	No. storeys
Category 1 Projects						
1	1969	High-rise	Mixed/family	14,399	166	11
2	1972	High-rise	Mixed/family	34,850	374	24
3	1969	High-rise	Mixed/family	21,645	213	13
4	1970	High-rise	Mixed/family	19,306	238	19
5	1972	High-rise	Mixed/family	36,002	419	20
6	1972	High-rise	Mixed/family	19,243	238	14
7	1962	High-rise	Mixed/family	18,621	225	19
8	1967	High-rise	Mixed/family	20,435	221	10
9	1969	High-rise	Mixed/family	15,498	189	14
Category 2 Projects						
10	1960	Mid-rise	Seniors	10,922	200	6, 5
11	1971	High-rise	Mixed/family	22,633	278	24

Category 1 and 2 building occupancies are shown in Table 3. Building occupancy was calculated using Equation 1, described in Section 3.1.

Table 3: Building occupancy rates

Building Number	Total Units	Total Occupancy
Category 1 Buildings		
1	166	637
2	374	1497
3	213	856
4	238	882
5	419	1411
6	238	1003
7	255	840
8	221	853
9	189	683
Category 2 Buildings		
10	200	600
11	278	975

4.2 Energy Conservation Measures

In both Category 1 and Category 2 projects, various ECMs were applied to reach energy conservation goals.

Table 4 outlines the ECMs and implementation date for each building. Dates are described quarterly using “Q1”, “Q2”, “Q3”, and “Q4”. Where dates were undisclosed, an “X” was used to mark that the measure was completed. Note that Buildings 1-9 fall under Category 1 and Buildings 10 and 11 are Category 2.

Descriptions of ECMs are as follows:

<u>Lighting:</u>

- Lighting retrofit
    - LED lights in common areas

<u>Mechanical Systems:</u>

- Air Conditioning (AC) program
    - Option to upgrade existing window ACs to floor-mounted models
- Makeup air unit (MUA) upgrade
    - MUA units replaced with ERV units
    - Variable speed drives (VSD) installed
- Garage ventilation
    - Monitoring and control added

Water Systems:

- Water conservation
    - Replaced toilets, showerheads, aerators
- Plumbing fixture upgrade
- Heating and domestic hot water (DHW) upgrade
    - Radiators flushed
    - Control valves installed
    - Boilers and pumps replaced
- Booster pump
    - Retrofit with VSDs

Building Systems:

- Suite metering
    - Data to be used for tenant engagement programs, not billing
- Thermostat installation (in-suite)
- Building automation system (BAS) upgrade

Building Envelope:

- Cladding
    - Complete over-cladding, partial application of exterior insulation and finish systems (EIFS), or localized repairs
- Roof replacement
- Window retrofit
    - Double glazed

Table 4: ECM summary and completion dates

		Building Number										
	Retrofit/ECM description	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Lighting	Lighting retrofit	2018 (Q3)	2018 (Q4)	2018 (Q3)	2018 (Q3)	2018 (Q3)	2018 (Q3)	2018 (Q4)	2018 (Q4)	2018 (Q3)	2016 (Q2) (Exterior, common area)	2018 (Q4) (Parking garage, common area)
Mechanical	AC program	2019 (Q2)	2019 (Q2)	2019 (Q2)	2019 (Q2)	2019 (Q2)	2019 (Q2)	2019 (Q2)	2019 (Q2)	2019 (Q2)		
	MUA upgrade	2018 (Q4)	2018 (Q3)	2018 (Q4)	2018 (Q4)	2018 (Q4)	2018 (Q4)		2018 (Q3)	2018 (Q4)	2018 (Q3)	2018 (Q3)
	Garage ventilation	2018 (Q4)	2019 (Q4)	2018 (Q4)	2018 (Q4)	2018 (Q4)	2018 (Q4)			2018 (Q4)		
Water	Water conservation	2017 (Q4)	2017 (Q4)	2017 (Q4)	2017 (Q4)	2017 (Q4)	2017 (Q4)	2017 (Q4)	2017 (Q4)	2017 (Q4)		
	Plumbing fixture upgrade										2019 (Q1)	2019 (Q1)
	Heating and DHW upgrade		2018 (Q4)	2018 (Q4)	2018 (Q4)	2018 (Q4)		2018 (Q4)	2018 (Q4)			
	Booster pump	2018 (Q3)	2018 (Q3)	2019 (Q2)	2018 (Q4)	2018 (Q4)	2018 (Q3)	2018 (Q3)	2018 (Q3)	2018 (Q3)		
Systems	Suite metering	2018 (Q2)	2018 (Q4)	2018 (Q2)	2018 (Q2)	2018 (Q2)	2018 (Q2)	2018 (Q4)	2018 (Q4)	2018 (Q2)	2019 (Q4)	2019 (Q4)
	Thermostat installation										2019 (Q4)	2019 (Q4)
	BAS upgrade	2018 (Q4)		2018 (Q4)	2018 (Q4)	2018 (Q4)	2018 (Q4)			2018 (Q4)		
Envelope	Cladding						X (Localized repairs)	X (Partial application of EIFS)	X (Localized repairs)		2018 (Q3)	2021 (Q1)
	Roof replacement										2020 (Q4)	
	Window retrofit	2018 (Q4)	2019 (Q2)	2019 (Q3)	2019 (Q3)	2019 (Q3)	2018 (Q4)	2019 (Q2)	2019 (Q2)	2018 (Q4)	2018 (Q3)	2021 (Q1)

5.0 Category 1 Project Results

Yearly pre- and post-retrofit energy consumption, water consumption, and GHG emissions were determined for all Category 1 projects (Buildings 1-9). Pre-retrofit data was developed using weather normalized 2015-2016 utility consumption data. Post-retrofit data was collected from weather normalized 2020 utility data.

5.1 Energy Consumption

For each building, the energy and GHG reduction from ECMs are summarized in Table 5. A negative value indicates a decrease in consumption (savings).

Table 5: Category 1 energy consumption and GHG reductions from ECMs

Building No.	Reduction in Electricity Consumption (kWh/year)	Reduction in Natural Gas Consumption (ekWh/year)	EUI (ekWh/m²/year)	GHGI ($MTCO_2e/m^2/year$)
1	-35,206 (-3%)	-2,160,798 (-40%)	-153 (-32%)	-0.028 (-38%)
2	141,563 (5%)	-1,379,045 (-17%)	-36 (-11%)	-0.007 (-16%)
3	2,166 (0%)	-1,286,880 (-23%)	-59 (-18%)	-0.011 (-22%)
4	-130,255 (-7%)	-23,346 (0%)	-8 (-2%)	-0.0004 (-1%)
5	-248,275 (-7%)	74,913 (1%)	-5 (-2%)	0.0002 (1%)
6	-4,560 (-0%)	-686,119 (-13%)	-36 (-10%)	-0.007 (-12%)
7	-181,292 (-12%)	-570,206 (-13%)	-40 (-12%)	-0.006 (-13%)
8	177,922 (11%)	-1,876,971 (-32%)	-83 (-23%)	-0.017 (-30%)
9	129,274 (10%)	-1,691,568 (-33%)	-101 (-24%)	-0.020 (-32%)
Total	**-148,663 (-1%)**	**-9,600,020 (-19%)**	**-**	**-**
Average	**-**	**-**	**-58 (-16%)**	**-0.011 (-20%)**

Overall EUI was decreased for all buildings. The greatest energy savings were shown during the winter months (months that require space heating) where natural gas use is the highest. Buildings that reduced winter natural gas consumption (Buildings 1, 2, 3, 6, 7, 8, 9) showed the largest reductions in EUI and GHGI.

Building 4 decreased natural gas consumption by less than 0.5%. Building 5 increased natural gas consumption by 1% due to a small increase in energy use in April and May. Buildings 4 and 5 both decreased electricity consumption by 7% and overall EUI by 2%. Both buildings underwent the same ECMs as the other Category 1 buildings. Additionally, the ECMs were carried out over the same period (primarily 2018). The minimal changes in natural gas consumption may be due to increased time spent at home caused by the COVID-19 pandemic. Additionally, occupant and building operator behaviour may be the cause of increased natural gas consumption at Buildings 4 and 5.

Electrification of building systems caused increases in electricity consumption in some buildings (Buildings 2, 3, 8, 9), but large reductions in natural gas consumption. This results in a reduction in GHGI.

Overall, Category 1 buildings reduce EUI by 16%, or an average of 58 ekWh/m^2/year. GHGI is reduced by 20% or an average of 0.011 MTCO2e/m^2/year compared to pre-retrofit levels.

5.2 Water Consumption

Yearly water consumption was analyzed for each building as shown in Table 6. Note that a negative value indicates a decrease in consumption (savings).

Table 6: Category 1 water consumption reductions from ECMs

Building No.	Reduction in Water Consumption (m^3/year)	Reduction in WUI (m^3/person/year)	Percent Reduction (%)
1	-1,164	-2	-3%
2	-7,129	-5	-7%
3	3,356	4	6%
4	-1,255	-8	-2%
5	-4,195	-5	-5%
6	32,223	32	56%
7	8,331	10	18%
8	25,836	30	54%
9	9,247	14	27%
Total	**65,250**	**-**	**-**
Average	**-**	**8**	**14%**

Overall, WUI increased by 14% or an average of 8 m^3/person/year. It should be noted that 2020 water consumption may have been influenced by COVID-19, as occupants were likely spending more time at home than a typical year. This may be a cause of increased water consumption. Another possible cause is water leakage from toilet fixtures. A water leakage audit is recommended to verify this.

For the projects that do decrease water consumption (Buildings 1, 2, 4, 5), the reduction is minimal (2% to 7% reduction compared to pre-retrofit consumption levels).

6.0 Category 2 Projects

Yearly pre- and post-retrofit energy consumption, water consumption, and GHG emissions were determined for all Category 2 projects (Buildings 10,11). Pre-retrofit data was taken from 2015 utility data. Post-retrofit data was collected from 2020 utility data. It should be noted that utility data was not weather normalized for Category 2 projects.

6.1 Energy Consumption

For each building, the energy and GHG reduction from ECMs are summarized in Table 7. A negative value indicates a decrease in consumption (savings).

Table 7: Category 2 energy consumption and GHG reductions from ECMs

Building No.	Reduction in Electricity Consumption (kWh/year)	Reduction in Natural Gas Consumption (ekWh/year)	Reduction in EUI (ekWh/m²/year)	Reduction in GHGI ($MTCO_2e/m^2$/year)
10	9,022 (1%)	-1,390,798 (-41%)	-126 (-32%)	-0.02 (-39%)
11	120,320 (6%)	-1,731,128 (-28%)	-72 (-20%)	-0.01 (-26%)
Total	**129,342 (4%)**	**-3,121,926 (-33%)**	**-**	**-**
Average	**-**	**-**	**-99 (-26%)**	**-0.02 (-31%)**

Both Building 10 and 11 experienced reductions in EUI due to ECM retrofits. The greatest energy reduction is attributed to reductions in winter natural gas consumption. This leads to reductions in EUI and GHGI. The reduction in space heating is likely due to increased insulation (roof replacement and over-cladding) and thermostat installation. Thermostat installation allows for personal control of room temperature. Occupants are more likely to experience thermal comfort and less likely to open windows when heating or cooling is active. Additionally, electrification of building systems at both buildings caused increases in electricity consumption but reduces natural gas consumption.

Overall, Category 2 buildings reduce total EUI by 26%, or 99 ekWh/m^2/year. GHGI is reduced by 31% or 0.02 MTCO2e/m^2/year.

6.2 Water Consumption

Yearly water consumption was analyzed for each building as shown in Table 8.

Table 8: Category 2 water consumption reductions from ECMs

Building No.	Reduction in Water Consumption (m^3/year)	Reduction in WUI (m^3/person/year)	Percent Reduction (%)
10	-29,394	-0.13	-55%
11	-8,009	-0.02	-13%
Total	**-37,403**	**-**	**-**
Average	**-**	**-0.08**	**-37%**

Overall, Category 2 projects decreased WUI by 37%, an average of 0.08 m^3/person/year. Even with the potential of increased consumption in 2020 due to the pandemic, these reductions are significant and likely due to the plumbing fixture upgrades ECM. This ECM was unique to Category 2 buildings.

7.0 Cost-Benefit Analysis

A cost-benefit analysis was completed by determining the cost intensity of each retrofit, EUI, GHGI, resulting cost savings, and calculating a simple payback. Formulas for these calculations are shown in Section 3.3. The analysis uses weather normalized utility data for Category 1 projects, and raw utility data for Category 2 projects, as described in Section 3.2.

Table 9 shows the cost-benefit of the energy savings (electricity and natural gas) only. Note that a negative value indicates a cost reduction. The energy savings for Category 1 buildings $283,930 and $66,210 for Category 2. Water consumption was not included in the analysis because of the likelihood of inflated consumption values due to COVID-19.

Table 9: Cost-benefit of energy savings for all projects

Building Number	GFA (m^2)	Total Cost Intensity of Retrofit ECMs (CAD/m^2)	Electricity Savings (%)	Natural Gas Savings (%)	Energy Cost Savings (CAD)	Payback (Years)
Category 1						
1	14,399	$146	-32%	-38%	- $64,163	33
2	34,848	$254	-11%	-16%	- $16,837	526
3	21,645	$216	-18%	-22%	- $34,812	134
4	19,305	$216	-2%	-1%	- $19,785	211
5	36,001	$254	-2%	-1%	- $34,451	266
6	19,242	$173	-10%	-12%	- $19,401	172
7	18,620	$205	-12%	-13%	- $42,216	91
8	20,434	$313	-23%	-30%	- $25,085	255
9	15,498	$146	-24%	-32%	- $27,175	83
Avg C1	22,221	$214	0%	-19%	- $31,547	-
Total C1	**-**	**-**	**-**	**-**	**- $283,926**	**130**
Category 2						
10	10,922	$355	-32%	-39%	- $36,641	106
11	22,633	$462	-20%	-26%	- $29,571	353
Avg C2	16,777	$408	-26%	-33%	- $33,106	-
Total C2	**-**	**-**	**-**	**-**	**- $66,213**	**175**

While the simple payback period is lengthy, the programs resulted in significant utility cost savings for TCHC overall. Also note that some ECMs were implemented to improve the facility condition, as building components reached end of life. Simple payback is not a useful metric for key decision making on ECMs to be implemented for this reason. ECMs should be selected on a building-by-building basis and must consider the facility condition along with a cost benefit analysis.

Additionally, these numbers can be considered conservative as it is expected that energy and water consumption will decrease as occupants return to “normal patterns” after COVID-19. Energy and water consumption rates should continue to be monitored to ensure this is the case.

Other benefits of the retrofits include reduced environmental impact (reduction in GHGI) due to electrification of mechanical services, and the qualitative benefits to both tenants and TCHC as described in Section 9.5.

8.0 ECM Recommendations

ECMs were reviewed and recommendations were made based on the cost savings and consumption reductions discussed in Sections 5.0 to 7.0. Note that Category 2 projects reduced EUI and GHGI more than Category 1 projects overall, however, the cost intensity of these projects were also greater than Category 1 projects. Additionally, Category 2 project consumption data was not weather normalized and may not indicate typical year-to-year savings.

As these projects are in a heating-dominant climate (Toronto, Ontario), reducing space heating from natural gas was emphasized. Typically, it was found that the largest reductions in natural gas occurred in the winter, where space heating is required. These space heating reductions resulted in decreases in building GHG emissions and reductions in EUI.

While most Category 1 projects had very similar ECMs, the actual EUI and GHGI savings varied. Compared to the baseline, total savings from ECM retrofits varied from 2% to 34% for EUI savings and 38% savings to 1% increase for GHGI. The majority of ECMs were completed over the year 2018 for all projects. A potential reason for differences in consumption could be occupant behaviour and building operation. Increased education of occupants and building managers may provide further savings.

Building envelope ECMs (holistic over-cladding, roof replacement, window retrofits) are likely a significant factor in EUI and GHGI reductions as Category 2 projects showed larger EUI reductions than Category 1 projects. Improvements to the building envelope increase the insulative performance of the building, therefore requiring less overall heating and cooling. Building envelope ECMs have a lengthy payback but become cost-effective when these components reach end of life and warrant replacement anyway. Additionally, mechanical equipment upgrades with higher efficiencies use less energy to heat, cool, and provide ventilation to the building. Electrification of these systems contributes to reduced GHG emissions.

Installation of thermostats is an ECM used in Category 2 projects only. This ECM allows occupants to set room temperature based on personal comfort. Occupants are less likely to open windows when heating or cooling is active and are more likely to experience thermal comfort. This ECM should continue to be monitored to quantify impact over time.

Reductions in WUI were more significant in Category 2 projects. Some Category 1 buildings (Buildings 1, 2, 4, and 5) experienced minor decreases in WUI (2% to 7%). Building 10 experienced a reduction in WUI of 55% and Building 11's WUI decreased by 13%. Category 2 projects used the plumbing fixture upgrades ECM while Category 1 projects did not.

ECM savings were likely impacted by the COVID-19 pandemic. Occupants likely spent more time at home than a typical year. It is expected that energy and water consumption levels were higher in 2020 than a typical year. Continued monitoring of performance is imperative to determining long-term effects of ECMs.

9.0 Project Delivery

Structured interviews with TCHC staff were conducted to gain a better understanding of project delivery process, challenges encountered, and lessons learned. All groups involved in the design and implementation of the projects were interviewed. These TCHC groups and their roles are:

1) **Design and Engineering (D&E)**: Procurement of consultants and contractor; Management of design phase of project and consultant(s).
2) **Construction and Preservation (C&P)**: Management of construction and contractor(s).
3) **Smart Buildings and Energy Management (SBEM)**: Monitor and report on utility (natural gas, electricity, water) consumption across the portfolio and implement various utility reduction and renewable energy programs.
4) **Capital Engagement and Conservation Program (CECP)**: Tenant engagement and consultation before, during, and after implementation of capital projects and programs.

9.1 Project Delivery Process

The project delivery process includes design, construction, commissioning, and post-retrofit measurement and verification. The following sections describe the conclusions and recommendations from the interviews.

9.1.1 Design

The D&E team are responsible for scoping the project and retaining design consultants. The team also manages the entire design process and leads tenant consultations along with CECP to inform tenants of the upcoming capital work and collect tenant feedback on the proposed design, materials, and color finishes.

The C&P and SBEM teams are also important stakeholders in the design process. The project requirements are developed in consultation with these teams and then shared with design consultants to develop the design basis and move along the design process. The C&P team have a crucial during the design phase in evaluating the consultant's contract documents before issuing the construction tender.

9.1.2 Construction

The D&E team ensures that the design intent is adhered to. After this, the C&P team is primarily responsible for construction management. The CECP team is involved for the duration of the project, informing the tenants about the construction schedule, phasing, and project impact on tenant lives. The tenant engagement carried out by CECP is discussed in Section 9.2.

The project delivery method and the contract structure differed for Category 1 and Category 2 projects. Category 1 projects retained a construction manager using a CCDC-5b contract while Category 2 projects retained a general contractor using a CCDC-2 contract. Each project delivery method has its own advantages and disadvantages. Some considerations are listed below for reference.

CCDC2 is ideal in the following circumstances (Emanuelli, n.d.):

- Where the construction project is relatively simple;
- Where there would be little innovation advantage gained in design improvements by including the builder in the design discussions;
- Where there is a relatively small risk of dispute between the designer and builder, or related cost overruns or delays, that could otherwise be mitigated by involving the builder in the design discussions; and
- Where time permits the project design to be completed prior to tendering the construction contract and commencing construction.

Basically, the Stipulated Price Contract (CCDC 2 – 2008) model is the traditional default construction industry standard format for typical design-bid-build tendering and contracting processes.

CCDC 5b approach is ideal under the following circumstances (Emanuelli, n.d.):

- Where due to timing factors the owner is unable to finish project designs and obtain accurate stipulated sum pricing prior to the commencement of work;
- Where there would be an innovation advantage gained in design improvements by including the builder in the design discussions in the role of construction manager;
- Where due to project complexities there is a greater risk of dispute between the designer and builder, as well as related cost overruns or delays that could be mitigated by involving the builder as contract manager in the design discussions;
- Where the owner can establish a reasonable maximum ceiling price to protect against cost overruns; and
- Where the owner is not prepared to assume the additional risk and contract administration burden associated with directly managing the trades and would prefer to shift those contractual obligations to a more traditional approach, where the construction manager assumes a role like the general contractor and directly contracts with the trades.

Procurement and legal advice are always recommended when selecting an appropriate contract structure as circumstances may vary from project to project. In all cases, pre-qualifying vendors and/or adopting a qualifications-based selection as part of the procurement process is paramount for project success.

9.1.3 Commissioning and Post-Retrofit Measurement and Verification

Commissioning agents were involved in Category 2 projects earlier than in Category 1 projects. This allowed for more involvement in remote system monitoring via automation. It was found that extended post-retrofit measurement and verification (M&V) is a benefit; the D&E team recommends 3 years post-construction and that this policy be introduced from the initiation of the project to get the testing started early. Ongoing trend-logging and analysis through the project phases and after construction allows for fine-tuning of the building systems and for any necessary repairs or tweaks to be found within the warranty period.

9.2 Tenant Engagement Process

Tenants are engaged in the retrofit process from pre-construction through to completion. Two TCHC teams focused on engagement and conservation manage this. Firstly, tenants are invited to a preconstruction meeting where they are asked for input on colours and common area aesthetics.

An opening survey provides an idea of what issues exist in the building. Then, tenants receive a 60-day notice of construction, informing them of the work that is to be done. Following this, a tenant information session is held so tenants are aware of what they can do to minimize interferences with the construction. If an information session cannot be held notices are posted to each door including the necessary instructions, and contact information for a TCHC staff member, should tenants have questions. Information packages, flyers, and surveys are provided in building lobbies at several phases before and during construction. Tenants are given a minimum of 24 hours' notice when entry into units is required. When the updates are completed, a close-out survey is conducted, which helps to catch any deficiencies in the work. TCHC found that the typical response rate for opening or closing surveys is 40%, however with door-to-door outreach the response rate is about 70%.

Another key part of tenant engagement is education. As building envelopes are being improved and units are being fitted with new equipment (i.e., thermostats), tenants should be informed in best practices for both thermal comfort and energy conservation. TCHC has developed an expanded training program to educate tenants on how to use their thermostats, how to set them, when to open windows and when not to, etc. This information has come in varied forms including flyers, lobby postings, fridge magnets, and instructional videos.

Throughout the entire tenant engagement process, language barriers and disabilities are also considered. Informational media is translated into multiple languages and those with disabilities are recognized and accommodated. It is a priority to TCHC that tenants are kept well informed throughout the retrofit process.

9.3 Challenges

The implementation of retrofit upgrades while buildings are occupied poses some unique challenges. For in-unit work, tenants must be informed 24 hours in advance, however they still may not be willing or able to vacate; tenants may also not clear out spaces where work is to be done. Ultimately, tenants cannot be forced out of their homes, so clear communication is key here.

Similarly, the work may require more than one day to complete. Phasing of work must be well-planned, considering the safety and living conditions of the tenant between work shifts. Certain work may not be possible or may have to be postponed to the off-season, and off-seasons vary depending on the system. For example, the off-season for a boiler would be in the summer months when heating is not required. Envelope work generally occurs from spring to fall, as weather permits such construction work to take place and issues with transportation of materials is minimal.

Timelines present another challenge in these projects as trades are tightly scheduled back-to-back. One delay can affect the entire project schedule. COVID-19 increased the number of delays due to supply chain issues, government lockdowns, etc. Typically, TCHC aims to limit the number of distinct entries into units, however the pandemic made this more difficult as well. In the past, there may have been multiple contractors in one unit at a time, where possible, to complete the work more quickly. With these projects, however, the number of workers entering units at a time had to be limited. The pandemic also affected the ability to efficiently interact with tenants and in collecting feedback after project completion. Tenant feedback is a crucial part of the process as it can highlight deficiencies that may have otherwise gone unnoticed.

9.4 Key Learnings

Key lessons learned include:

1) Choose a project delivery method at the project inception stage by seeking procurement and legal advice per organizational structure.
   - *Design-bid-build* is a traditional method of project delivery. Seek procurement, legal advice, and undertake a risk assessment before selecting an appropriate contract structure.
   - *Integrated project delivery* (IPD) is another upcoming construction project delivery method that seeks efficiency and involvement of all parties (design consultants and contractors) through all phases of design and construction.
   - Building information management (BIM) can help with efficiency in project delivery and is worthwhile to consider, especially in the IPD method.
2) Include post-completion monitoring in the commissioning scope (i.e., 3 years).
   - Helps catch deficiencies and tweak systems.
   - Undertaking monitoring after tendering is found to be more challenging.
   - Start data collection early in the process.
3) Early establishment of delivery teams and drawing approvals is an important benefit.
4) Consider space layout when decommissioning and replacing equipment in mechanical rooms (example: boilers in heating season); including eliminating service gaps if possible.
5) Effective communication and coordination are crucial to both project delivery and tenant engagement; contractors, managers, TCHC staff, superintendents, and of course tenants all must be well-informed through the entire process.
   - Consider tenants' level of technical understanding and language barriers.

9.5 Benefits

Aside from measurable benefits associated with cost savings and decreased energy and water consumption, qualitative benefits both to tenants and TCHC were identified:

- Occupant comfort is improved, as the retrofits address thermal comfort and air quality in the units.
- Effective tenant engagement results in smoother, more successful implementation, as well as a better experience for the tenants.
- Tenants appreciate the upgrades completed as they improve the building that they live in.
- Cost savings will generate potential reinvestment in further upgrades in the future.

10.0 Conclusions and Next Steps

Category 2 projects resulted in greater energy and water savings on average. The additional energy savings for Category 2 projects is likely due to the building envelope ECMs. These ECMs include over-cladding on Buildings 10 and 11, and roof replacement for Building 10. When compared to pre-retrofit consumption levels, Building 10 experienced the greatest reductions in EUI and GHGI. Additionally, Buildings 10 and 11 experienced the greatest WUI reduction from plumbing fixture upgrades (compared to pre-retrofit levels). Note that Building 10 and 11 also have the highest cost intensity for retrofit and that utility data for these buildings was not weather normalized.

Of the Category 1 buildings, Building 1 experienced the largest reduction in EUI and GHGI. Buildings 1 and 9 were found to be the most cost effective, both with the highest EUI and GHGI reductions and the lowest payback periods.

As all projects are in a heating dominant climate (Toronto, Ontario), reducing heating from natural gas was emphasized as an important step in reducing EUI and GHGI. In all buildings that experiences reductions in natural gas, the largest reductions occurred in the winter, where space heating is required. Buildings that reduced winter natural gas consumption (Buildings 1, 2, 3, 6, 7, 8, 9, 10, 11) showed the largest reductions in EUI and GHGI.

The most effective ECMs in terms of reductions to EUI and GHGI were building envelope ECMs (holistic over-cladding, roof replacement, window retrofits). These measures were unique to Category 2 projects. Some Category 1 projects included localized cladding repairs however did not undergo major envelope restoration. Additionally, mechanical equipment upgrades with higher efficiencies use less energy to heat, cool, and provide ventilation to the building. Electrification of these systems contributed to the reduced GHG emissions. Category 2 projects installed a programmable thermostat which allows for occupants to set room temperature based on personal comfort. With personal controls, occupants are more likely to experience thermal comfort and therefore less likely to open windows when heating or cooling is active. Continued monitoring of ECM results is imperative to determining long-term effects of ECMs.

Water consumption reductions were primarily realized by Category 2 projects by the plumbing fixture upgrades ECM that was unique to Category 2. This ECM is likely the most impactful to actual water savings.

ECM savings were likely impacted by the COVID-19 pandemic. Occupants likely spent more time at home than a typical year. It is expected that energy and water consumption levels were higher in 2020 than a typical year. Continued monitoring of performance is imperative to determining long-term effects of ECMs.

The cost-benefit analysis revealed lengthy simple payback periods, however, the programs resulted in significant utility cost savings for TCHC overall. Some ECMs were implemented to improve the facility condition, as building components reached end of life, therefore, simple payback is not a useful metric for key decision making on ECMs to be implemented for this reason. ECMs should be selected on a building-by-building basis and must consider the facility condition along with a cost benefit analysis. Additionally, the cost-benefit analysis can be considered conservative as it is expected that energy and water consumption will decrease as occupants return to "normal patterns" after COVID-19. Energy and water consumption rates should continue to be monitored to ensure this is the case.

A review of the project delivery process revealed actions that could result in additional insights:

- Tenant consultation and feedback is crucial. While recognizing the challenges posed by the COVID-19 pandemic, it would have been beneficial to have the opportunity to either interview tenants directly or have access to the tenant closeout surveys. Further work should be completed using tenant closeout surveys to determine the tenants experience during the retrofits and their satisfaction with the results.
- Post-retrofit studies typically include a comparison to as modelled or expected energy savings. Since no modelling of expected energy savings was completed, this research was limited to comparisons of pre- and post- retrofit utility data. Energy modelling of implemented ECM's would allow comparison to expected energy consumption. Knowing expected energy consumption can be useful in determining whether the building is performing as intended and prioritizing building participants.
- Benchmarking against other MURBs in Ontario and in Canada to determine how TCHC buildings compare to other buildings of the same typology, both within and outside of the social housing sector is recommended.
- TCHC should continue monitoring the buildings to ensure they are performing as intended.

11.0 References

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Appendix A – Pre- and Post-Retrofit Data

Table A1 – Category 1 Pre-Retrofit Utility Energy Data Summary (July 2015-June 2016)

Building No.	Pre-Retrofit Electricity Consumption (kWh/year)	Pre-Retrofit Natural Gas Consumption (ekWh/year) [m³/year]	Pre-Retrofit EUI (ekWh/m²/year)	Pre-Retrofit GHGI ($MTCO_2e/m^2$/year)
1	1,333,299	5,448,249 [527,420]	471	0.07
2	2,787,078	8,057,193 [779,980]	311	0.04
3	1,689,929	5,486,046 [531,079]	332	0.05
4	1,864,100	4,829,781 [467,549]	347	0.05
5	3,331,909	5,773,530 [558,909]	253	0.03
6	1,723,656	5,364,855 [519,347]	368	0.05
7	1,557,357	4,522,298 [437,783]	327	0.05
8	1,676,024	5,843,939 [565,725]	368	0.05
9	1,356,353	5,075,046 [491,292]	415	0.06

Table A2 – Category 2 Pre-Retrofit Utility Energy Data Summary (2015)

Building No.	Pre-Retrofit Electricity Consumption (kWh/year)	Pre-Retrofit Natural Gas Consumption (ekWh/year) [m³/year]	Pre-Retrofit EUI (ekWh/m²/year)	Pre-Retrofit GHGI ($MTCO_2e/m^2$/year)
10	919,176	326,592 [326,592]	393	0.06
11	1,975,599	596,470 [428,888]	360	0.05

Table A3 – Category 1 Weather Normalized Post-Retrofit Utility Energy Data Summary (2020)

Building No.	Post-Retrofit Electricity Consumption (kWh/year)	Post-Retrofit Natural Gas Consumption (ekWh/year) [m^3/year]	Post-Retrofit EUI (ekWh/m^2/year)	Post-Retrofit GHGI ($MTCO_2e/m^2$/year)
1	1,298,093	3,287,450 [318,243]	318	0.04
2	2,928,641	6,678,149 [646,481]	276	0.04
3	1,692,095	4,199,166 [406,502]	272	0.04
4	1,733,845	4,806,435 [465,289]	339	0.05
5	3,083,634	5,848,443 [566,161]	248	0.03
6	1,719,096	4,678,736 [452,927]	332	0.05
7	1,376,065	3,952,093 [382,584]	286	0.04
8	1,853,946	3,966,968 [384,024]	285	0.04
9	1,485,627	3,383,478 [327,539]	314	0.04

Table A4 – Category 2 Post-Retrofit Utility Energy Data Summary (2020)

Building No.	Post-Retrofit Electricity Consumption (kWh/year)	Post-Retrofit Natural Gas Consumption (ekWh/year) [m^3/year]	Post-Retrofit EUI (ekWh/m^2/year)	Post-Retrofit GHGI ($MTCO_2e/m^2$/year)
10	928,199	1,982,894 [191,955]	267	0.04
11	2,095,919	4,430,409 [428,888]	288	0.04

Table A5 – Category 1 Utility Water Data Summary (Pre-Retrofit Data: 2015-2016, Post-Retrofit Data: 2020)

Building No.	Pre-Retrofit Water Consumption (m^3/year)	Pre-Retrofit WUI (m^3/person/year)	Post-Retrofit Water Consumption (m^3/year)	Post-Retrofit WUI (m^3/person/year)
1	36,894	58	35,730	56
2	103,176	69	96,047	64
3	58,914	69	62,270	73
4	64,272	73	63,017	71
5	84,768	60	80,573	57
6	57,240	57	89,463	89
7	47,121	56	55,452	66
8	48,018	56	73,854	87
9	34,368	50	43,615	64

Table A6 – Category 2 Utility Water Data Summary (Pre-Retrofit Data: 2015, Post-Retrofit Data: 2020)

Building No.	Pre-Retrofit Water Consumption (m^3/year)	Pre-Retrofit WUI (m^3/person/year)	Post-Retrofit Water Consumption (m^3/year)	Post-Retrofit WUI (m^3/person/year)
10	53,374	0.24	23,980	0.11
11	62,408	0.18	54,399	0.15

Appendix B – Definitions

AC: Air conditioning / air conditioner

BUR: Built-up roofing [system]

Category 1: Projects where ECMs were completed together over approximately 1 year.

Category 2: Projects where ECMs were completed staggered over approximately 4-5 years and ECMs include over-cladding.

CO_2e: Carbon dioxide equivalent; Measurement comparing emissions from various greenhouse gases based on their global-warming potential (GWP).

DHW: Domestic hot water

ECM: Energy conservation measure; multiple ECMs were used to complete the energy retrofits

ERV: Energy recovery ventilator

EUI: Energy use intensity; measurement of energy use per GFA, typically (kWh/m^2). EUI encompasses total energy use (electricity and natural gas).

GFA: Gross floor area; all above-grade interior space

GHG: Greenhouse gas

LED: Light-emitting diode

MT: Metric tonne

MUA: Makeup air [unit]

MURB: Multi-unit residential building

SBC: Sustainable Buildings Canada

TCHC: Toronto Community Housing Corporation

VFD: Variable flow drive

VSD: Variable speed drive

WUI: Water use intensity; measurement of water use per person (m^3/person).