A Pilot Study Regarding the Use of Food Waste Grinders in a Multi-Unit Residential Building

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

This study evaluated the impact of food waste grinders (FWGs) in multi-unit residential buildings (MURBs) that also had access to green bins (GBs) on solid waste and wastewater generation. A 15-month technical sampling program and two user experience surveys were conducted at a 32-unit MURB to gather information on potable water demand, wastewater and solid waste properties and user perceptions of factors that influence GB and FWG use. Data gathered during a four-month control period without access to FWGs was compared to that from an 11-month study period where access to FWGs was provided to assess the impact of the devices on the aforementioned areas of focus.

There was no statistically significant change in the per unit potable water demand when access to FWGs were provided. FWG use did not result in any sewer-use bylaw exceedances although the fats oils and grease (FOG) content of the wastewater increased significantly suggesting that challenges associated with FOG during wastewater conveyance may be worsened by widespread FWG implementation. The mass loading of fixed dissolved solids (+9 g/unit/day, +16.2%, $p = 0.01$), and FOG (+4 g/unit/day, 45.1%, $p = 0.01$) to the sewer increased significantly with FWG use while all other wastewater analytes did not change significantly. The variability in most wastewater responses (nutrients, solids, FOG) as indicated by their standard deviation increased significantly. The impacts measured in this study were less than the reported impacts of literature, which was attributed to the FWGs being implemented alongside green bins. The results suggest that widespread FWG use may increase the discharge of fixed dissolved solids in wastewater treatment plant effluents. Further, the impact of increased FOG loadings on sewer systems and wastewater treatment plant operations may need to be considered.

The amount of unavoidable food waste disposed of in the green bin decreased (-79 g/unit/day, -19%, $p = 0.02$) following FWG implementation, however, the amount of organics in the mixed waste stream (fugitive organics) was not affected by FWG access. The results suggest that FWGs were employed for materials that were disposed of in green bins prior to FWG access in this building. The results indicate that FWG access may not reduce the presence of fugitive organics in the mixed waste stream when implemented in this setting.

Survey respondents indicated using both FWGs and GBs, with respondents preferring one or both technologies. Most respondents reported using the FWG devices primarily for fruits, vegetables, and plate scrapings while some respondents reported use of FWGs for FOG and dairy products despite these categories not being FWG targets as explained in educational materials provided to residents. When the survey responses on food waste generation and FWG use were combined with wastewater generation data; multiple lines of evidence suggest that wastewater treatment plants may experience more variable aeration requirements and sludge production with widescale FWG implementation. This study was the first evaluation to focus specifically on aspects of FWG implementation in a MURB population that also had access to GBs.

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Table of Contents

List of Figures

List of Tables

List of Acronyms

BOD_5	=	Biochemical Oxygen Demand
CV	=	Coefficient of Variation
FDS	=	Fixed Dissolved Solids
FOG	=	Fats, oils and grease
avFOG	=	Animal and Vegetable Fats Oils and Grease
mFOG	=	Mineral Fats Oils and Grease
FS	=	Fixed Solids
FSS	=	Fixed Suspended Solids
FW	=	Food Waste
FWG	=	Food Waste Grinder (or Garburator or Food Waste Disposer or Garbage Grinder)
g	=	Grams
GB	=	Green bin
kg	=	Kilograms
L	=	Litres
mg	=	Milligrams
MP	=	Market Penetration
MURB	=	Multi-Unit Residential Building
NH_3	=	Ammonia
NH_4	=	Ammonium
NO_2	=	Nitrite
NO_3	=	Nitrate
OW	=	Organic Waste
OWAT	=	Ontario Waste Auditor Training
REB	=	Research Ethics Board
sBOD	=	Soluble Biochemical Oxygen Demand
SSO	=	Source Separated Organics
TDS	=	Total Dissolved Solids
TKN	=	Total Kjeldahl Nitrogen
TP	=	Total Phosphorous
TS	=	Total Solids
TSS	=	Total Suspended Solids
VDS	=	Volatile Dissolved Solids
VS	=	Volatile Solids
VSS	=	Volatile Suspended Solids
WA	=	Waste Audit (index used for referencing waste audit events)
WW	=	Wastewater (index used for referencing wastewater sampling events)
WWTP	=	Wastewater Treatment Plant, Water Resource and Recovery Facility

Chapter 1: Introduction

The need to manage food waste is one of the largest driving forces in the policies and operations of municipal solid waste collection (Diggelman & Ham, 2003); and it is the largest mass fraction of the residential sector's solid waste produced in Canada (ECCC, 2020). Through marketing and public notices, an increasing number of municipalities in Ontario have been trying to reduce the amount of food waste that is sent to landfills (Ontario, 2018). Food waste within landfills can cause and/or amplify challenges associated with leachate generation and landfill gas/greenhouse gas generation (Rosenwinkel & Wendler, 2001). The scale of issues that are caused by the landfill disposal of food wastes has inspired a large amount of research into methods and technologies that divert food waste from landfills. These methods include engineering technology solutions such as composting or anaerobic digestion; policy changes such as a reduction in the collection frequency of mixed waste, incentives to use green bins/home composters, and recently, setting quantifiable greenhouse gas emission and waste generation targets for the future (Ontario, 2018). Notably, many of these solutions rely on or involve the use of green bins and therefore miss or underserve a large and growing population that lives in multi-unit residential buildings (MURBs), also known as low, medium, and high-rise apartment buildings.

Residents of single-family residences often have access to a green bin and household composting that can divert food waste from the landfill waste stream. Residents of MURBs face challenges with food waste disposal as many MURBs do not provide access to green bin programs and household composting is usually not available in such a setting. As an example, in Ottawa, only 15% of apartment buildings were reported to have had access to a green bin program in 2015, five years after a city-wide green bin program was implemented (Pearson, 2015). This was attributed to building managers directly managing the organic waste collection and have not historically prioritized green bins (Pearson, 2015).

Many MURB dwellers are not involved in the collection or storage of their waste, which means that policy changes that affect collection frequency or green bin implementation are out of their control (Ordonez, et al., 2015). Hence, much of the MURB population disposes of food and organic wastes in the mixed waste stream. Furthermore, operators of buildings that do provide green bins can face behavioural and operational barriers that limit acceptance and use. For example, in some cases, food waste cannot be disposed of easily in garbage chutes and requires the user to carry organic wastes to a general collection point. These common collection points can result in an increased risk of pests and must be managed carefully. If it is assumed that an individual will take the path of least resistance in waste disposal, there is the potential for much of the organic food waste that is generated by the MURB population to enter landfills. As the population of MURB dwellers in Canada increases (Statistics Canada, 2017), food waste management solutions targeted at MURBs will become more vital to ensuring sustainable waste practices and achieving waste management objectives.

Food waste grinders (FWGs) are in-sink devices that can be installed in MURB units that do not rely on the solid waste collection system (i.e., green bins). They directly dispose of food waste to the wastewater stream, thereby relieving the need for a sorted organic waste collection system (storage and subsequent street pick up). However, concerns about potential impacts to the wastewater collection system and the additional organic loading that this would provide to wastewater treatment plants (CWWA, 2019), have limited the adoption and use of this technology. The potential for solid waste diversion with FWGs has not been quantified in Ontario and current food waste policies within Ontario do not consider food waste diverted by a FWG as recovered or diverted from landfills (Ontario, 2018), and thus municipalities are not motivated to explore the implementation of such a technology at this time. This restriction may be due to the concerns previously mentioned and it is clear that more information is needed to evaluate if this policy restriction on FWGs implemented in this setting is merited.

The objective of this study was to quantify the impacts of FWGs implementation in MURBs that also have access to green bins within Ontario, based on a pilot-scale study. This work will explore the impacts to common wastewater characteristics (concentrations and loadings of solids, nutrients, and FOG), potable water consumption, solid waste diversion and the resident's reported experience with green bins and FWG devices. FWG research within Ontario is limited and a detailed assessment of these issues will support improved decision-making about the widespread implementation of FWGs in MURBs.

Chapter 2: Background and Literature Review

A literature review was conducted on all aspects of FWG impacts within the scope of the current study to inform methodologies and provide results to compare the study results and findings to. The literature regarding FWGs in MURBs was found to be modest, and this study aims to address research gaps identified through this literature review. Literature was gathered from peer-reviewed journal-library databases (University of Waterloo Library + OMNI Libraries) employing the keywords listed in Appendix A and the references within found articles. Papers with relevant data to the study were reviewed in full and data was extracted and summarized in this report. When all recent publications had been reviewed and a range of data collected, summary evaluations and observations of literature were made and are described in this section. For quantifiable metrics, average estimates of FWG impact were calculated to inform expected values for comparison with the current study's streams of data collection.

Non-peer-reviewed reports that were directly sponsored by food waste grinder suppliers were not included in this review. However; non-peer reviewed reports that were sponsored by individual municipalities and independent research groups were included. Approximately 32 papers were reviewed that contained data deemed to be relevant to the study which were extracted and presented in this section. In total, 47 papers were reviewed with information relevant to the study. Sources were categorized by the overall methodology as "experimental" meaning direct measurements were taken from either a pilot program or lab experiment or "theoretical" meaning that a desktop study/review was employed.

The following sections address literature describing impacts that may be caused by the implementation of food waste grinders in MURBs in a variety of settings, and background information regarding FWGs. The review was categorized in terms of the legal standing of FWGs in Ontario and impacts on wastewater systems, potable water consumption, solid waste diversion, and resident attitudes regarding disposal. The results of this literature review were used to ensure that the methods employed in the current study align with industry standards and were also used as points of comparison with the results generated in this study.

2.1 Food Waste Grinder Background

Food waste grinders [also called garburators, food waste disposers, and garbage grinders] are in-sink units that grind food/organic waste into particles for it to ultimately enter the greywater/wastewater stream. Despite widespread belief, FWG units do not have spinning blades such as a blender and instead use a spinning disk that uses centripetal forces to grind the food waste against a sharp grate that grinds the waste into particles to a smaller size. Water is washed through the system while grinding to provide carrier water that transports the ground food and organic particles to the sewer/collection system.

FWGs have been historically employed in Canada but in low numbers (CWWA, 2019). Many municipalities in Ontario have banned or discouraged their use (Table 1) due to concerns about increased pollutant loading to wastewater treatment plants, increased water usage, potential damage to the collection (sewer) system, and lack of motivation from the provincial government (CWWA, 2019). The Canadian Council of Ministers of the Environment has also suggested that by default, all municipalities ban the installation and use of FWGs in sewer-use bylaws (CCME, 2009). Ontario has targeted a 50% reduction or resource recovery from food waste generated in MURBs by 2025, but has specified that "the direct discharge of food waste into a municipal sewer by food waste disposers or other grinder devices" is not considered recovery (Ontario, 2018). The lack of FWG use in many municipalities may also be attributed to the availability of green bin programs that make FWGs redundant in some households (Weidner, 2018). Overall, it is clear that FWG use in Ontario is currently low, and that many municipalities do not currently permit FWG discharge to sewer systems.

Table 1. Regulations Addressing Food Waste Grinders in Ontario (as of July 2021)

Jurisdiction	FWG Policy Description	Relevant Policy Citation
City of Toronto	Industrial, Commercial, or Institutional Allowed with Effluent Restriction, **Residential Prohibited**	Toronto Municipal Code Chapter 681-10E
City of Ottawa	**Prohibited**	Sewer Use Bylaw No. 2003-514 Section 17
Region of Peel	No Restriction, No Encouragement, or Discouragement	N/A
Region of York	No Restriction, Discouraged	Staff communication
Region of Durham	No Restriction, Discouraged	Staff communication
Region of Waterloo	No Restriction, Discouraged	Statement by Kathleen Barsoum, Regional Waste Co-ordinator
City of London	No Restriction, No Encouragement, or Discouragement	Attempted Prohibition: City of London Waste Discharge Bylaw - WM-16 - Amendment 10004 (Not Passed)
City of Kingston	**Prohibited**	City of Kingston Bylaw No. 2008-192 (Part 12)
City of Guelph	**Prohibited**	City of Guelph Sewer Use Bylaw 1996-15202 Section 2. -(1)(d)(i)

2.1.1 FWG Market Penetration

Market penetration (MP), or the percentage of people that have access to a FWG which contributes to a wastewater collection system can be expected to affect the wastewater and associated solid waste quantity and quality. In the literature review, the assumed MP in each study was reviewed to facilitate a comparison of the current study's results with the literature. Some studies did not use MP and instead used "penetration factor" or PF such as in Moñino, et al. (2017), which was considered synonymous with MP in this study. The majority of studies reported MPs of 100 % and some studies adjusted their results to match expected 100 % MP rates. There are advantages to reporting impacts at 100 % MP and reporting on a per capita basis as it allows for municipalities to calculate the expected impact based on market penetration on loading to the wastewater treatment plants. As an example, NYC-D.E.P. (1997), recommended that FWGs be "legalized" in New York City but also warned that very high market penetration rates would result in negative impacts on wastewater treatment. It was suggested that the market penetration rate be closely monitored to support future policy development (NYC-D.E.P., 1997), which indicates the importance of this qualifying metric. In summary, the market penetration value was found to be specific to individual study goals, and evaluating FWG impacts at 100 % market penetration will allow the current study's wastewater measurements to be comparable with the majority of literature.

2.2 Wastewater Characteristics

2.2.1 Wastewater Characterization Methodologies

Studies that directly measured FWG impacted wastewater were reviewed to understand the methodologies employed and support the development of the methodologies in the current study. Though less abundant than laboratory-scale experiments, pilot projects that evaluated FWG impacts on wastewater have been conducted in the United States, Europe, and Asia. The New York City Department of Environmental Protection conducted one of the largest FWG pilot programs in MURBs within three neighbourhoods of New York City (NYC-D.E.P., 1997). Within each studied neighbourhood, a nearby control population of a similar demographic was sampled, however, the details of the sampling program such as measurement resolution and methodology were not provided (NYC-D.E.P., 1997). Battistoni, et al. (2007), evaluated FWG impacts in small-decentralized towns in Italy and sampled wastewater directly from the WWTP influent twice a week with "daily averaged samples", after monitoring the same community before FWGs were implemented. It is expected that FWGs add an additional source of variability in wastewater loadings and the methodologies recorded in the literature suggest that studies measuring the wastewater impacts of FWGs must account for and design for a considerable amount of variability. The available literature shows that the use of control populations and daily averaged samples such as composites are common and should be used in the current study.

2.2.2 Wastewater Characteristics

It was deemed important to understand the change in wastewater characteristics that might result from FWG use. A prior literature review (Iacovidou, et al., 2012), summarized per capita wastewater loading increases (TSS, BOD, COD, TKN, P, and FOG), and thus the current review employed a similar format (Table 2).

Table 2. Wastewater Characteristics Impacts of FWGs

	TSS		BOD		COD		N		P		FOG		Type of Analysis	M.P. (%)	Region
Source	g/cap/day	%	g/cap/day	%	g/cap/day	%	g/cap/day	%	g/cap/day	%	g/cap/day	%			
Zan, et al. (2019)	-	67	-	-	-	37	-	9	-	-	-	-	Experimental, Laboratory		Hong Kong
Stantec Consulting Ltd. (2017)	-	0.3	-	0.3	-	-	-	-	-	0.1	-	-	Weighted Theoretical Loadings	1	Alberta, Canada
	-	15	-	15	-	-	-	-	-	6	-	-	Weighted Theoretical Loadings	50	Alberta, Canada
	-	30	-	30	-	-	-	-	-	11	-	-	Weighted Theoretical Loadings	100	Alberta, Canada
Thomas (2011)	14.1	18	16.5	28	35.8	24	-	-	-	-	-	-	Experimental, Laboratory "Low" FW Loadings	100	United Kingdom
	31	39	35.1	59	71.9	48	-	-	-	-	-	-	Experimental, Laboratory "High" FW Loadings	100	United Kingdom
Evans, et al. (2010)	-	-	-	8	-	31	-	0.2	-	-2.8	-	-	Experimental, Pilot "Early" Implementation	50	Surahammar, Sweden
	-	-	-	-31	-	18	-	-5.8	-	-26.1	-	-	Experimental, Pilot "Late" Implementation	50	Surahammar, Sweden
Battistoni, et al. (2007)	11	30	-	-	55	44	2	19	-	-	-	-	Experimental, Pilot	67	Macerata, Italy
Marashlian & El-Fadel (2005)	-	1.9-7.1	-	17-62	-	-	-	-	-	-	-	-	Experimental, Laboratory	25-75	Greater Beirut Area, Lebanon
Bolzonella, et al. (2003)	50	-	-	-	75	-	2.5	-	0.25	-	-	-	Experimental, Laboratory	100	Italy
Diggelman & Ham (2003)	-	7.9	-	7.5	-	-	-	1.4	-	1.2	-	-	Theoretical, Literature and Analysis	-	United States
Metcalf & Eddy (2003)	20	22.2	20	25	30	15.8	1.3	10	0.3	9.4	4	13.3	Experimental	25	United States
Galil & Shpiner (2001)	7-34	-	10-31	-	-	-	-	-	-	-	-	-	Experimental, Laboratory	-	Israel
Rosenwinkel & Wendler (2001)	28-40	40-60	6-15	10-25	18-36	15-30	1.5	5-10	0.13-0.25	7-14	-	-	Experimental, Laboratory and Literature	100	Germany

Percent increases represent the percent change in wastewater loadings between non-FWG impacted wastewater and FWG impacted wastewater reported in or calculated from literature.

Table 2. Wastewater Characteristics Impacts of FWGs (Continued)

	TSS		BOD		COD		N		P		FOG		Type of Analysis	M.P. (%)	Region
Source	g/cap/ day	%	g/cap/ day	%	g/cap/ day	%	g/cap/ day	%	g/cap/ day	%	g/cap /day	%			
NYC-D.E.P. (1997)	21.6	-	23.6	-	37.6	-	4.5	-	0.45	-	-	-	Experimental, Pilot	100	New York City-Queens, United States
	177	-	77.2	-	165.5	-	8.5	-	1.2	-	-	-	Experimental, Pilot	100	New York City-Brooklyn, United States
	20.9	-	42.2	-	54	-	5.8	-	0.54	-	-	-	Experimental, Pilot	100	New York City-Manhattan, United States
De Koning & van der Graaf (1996)	48	-	52	-	76	-	1.6	-	-	-	-	-	Theoretical	-	The Netherlands
Magagni (1996)	20.8-90.6	-	10.4-36	-	-	-	0.6-2	-	0.1	-	-	-	Experimental	-	Padova, Italy
Jones (1994)	-	-	-	16.5	-	-	-	3	-	4.6	-	-	Experimental	-	Australia
Nilsson & Hallin (1990)	34	48	31	48	88	-	10.2	12	3.1	-	-	-	Experimental	-	Sweden

Percent increases represent the percent change in wastewater loadings between non-FWG impacted wastewater and FWG impacted wastewater reported in or calculated from literature.

The range of values reported for the wastewater characteristics was considered to be important as it impacts the ability to make statistically significant comparisons. Table 2 shows that there is a considerable range in expected values for many of the wastewater loadings associated with FWGs. This range in values could be a result of several influences, such as differences in sampling techniques between studies, and differences associated with a diet that impacts waste quantities and composition. The food waste disposal technologies employed have also often not been reported, and it is anticipated that this might also impact the loadings. The wide range of reported values for wastewater impacts in literature suggests that sampling must account for wastewater variability and that statistical approaches will be required to identify significant changes in average loadings and concentrations.

The presence of suspended solids in wastewater will ultimately contribute to biosolids generation in WWTPs and hence are of interest when considering FWG implementation. Intuitively, the solids content of FWG impacted wastewater is expected to increase as the grinders primarily convert solid organic waste into organic waste particles. From Table 2, it can be seen that there is a large range in TSS loadings resulting from FWG use. Excluding the NYC-Brooklyn data, the literature indicates an increase in TSS of 7 - 91 g/cap/day, with a mean increase of approximately 34 g/cap/day. Metcalf & Eddy (2003) indicates that non-FWG impacted wastewater has loadings of 60-150 g/cap/day with a typical value of 90 g/cap/day. Hence, an increase of 34 g/cap/day would correspond to a 22-56 % increase in suspended solids loadings. Under these conditions, it might be expected that wastewater treatment plants may need additional solids processing abilities if wide-scale FWG implementation were considered. It is clear that the solid loading rate may increase substantially as a result of large-scale FWG implementation.

The impact of FWG implementation on biochemical oxygen demand and chemical oxygen demand concentrations was reviewed as the energy demand associated with the removal of these parameters at WWTPs can be significant. FWGs introduce biological material into the wastewater, and like TSS, intuitively would increase as a result of FWG contributions. As shown in Table 2, the range of BOD and COD increases is large, with reported increases of 6-52 g/cap/day and 18-106 g/cap/day respectively (neglecting the results of the NYC study on Brooklyn, which reportedly was influenced by a nearby sinkhole (NYC-D.E.P., 1997)). These results show that a measurable increase in oxygen demand can be expected within this study although the extent of the increase is uncertain.

Nitrogen and phosphorous loadings were assessed as they are typically addressed in the treatment objectives of wastewater treatment plants and the addition of food waste can be expected to increase these loadings to WWTPs. Food waste predominantly is made up of organic material that contains nitrogen and phosphorus (Götze, et al., 2016); carbon, nitrogen, and phosphorus have been reported to contribute 47.9 %, 3.0 %, and 0.52 % of food waste total solids respectively (Götze, et al., 2016). It can therefore be expected that the addition of food waste solids will increase nitrogen more than phosphorus and that there should be an increase in both of these nutrient loadings. The literature presented in Table 2 shows that nitrogen loadings increased by 0.6-12 g/cap/day with an average of 4.4 g/cap/day. Phosphorus increased between 0.1-3.1 g/cap/day, however, the larger increases were dominated by a few studies and the average increase of phosphorus was 0.8 g/cap/day. These nutrient loadings are important to understand for their impact on WWTPs. However; there is evidence in the literature that suggests that the increased carbon in the food waste and minimal loadings of nutrients like nitrogen and phosphorus can increase the removal efficiency of carbon consuming nutrient removal processes (Kim, et al., 2015). It was noted that most literature did not provide speciated loadings, such as organic versus ammonia nitrogen or orthophosphate and total phosphorus, and hence this study aims to expand this understanding to fully predict FWG impacts on wastewater systems.

The impacts that FWGs have on the FOG content of wastewater within sewers is an important aspect of FWG implementation and thus was reviewed for this study. As shown in Table 2, the majority of studies reviewed did not consider or report FOG. The importance of this parameter to municipalities operating sewer systems and its lack of research is a gap that this study addresses.

2.3 Potable Water Consumption

The methods employed to determine potable water use associated with FWGs were reviewed to assist with identifying a strategy for the current study. Several studies have explored the water demand of FWGs by either measuring the water demand of households with FWGs and comparing it to local water usage or previous measurements (NYC-D.E.P., 1997) or by measuring water use in a lab setting with assumed levels of FWG use. Based upon the approach reported in the literature it was concluded that potable water metering techniques synonymous with water billing metering should be employed to evaluate the impact of FWG implementation on water use.

The increase in potable water demand associated with FWG use was reviewed to provide a range of comparable values for this study. FWGs use potable water as a carrier to flush particles from the grinding plate. Other food waste disposal methods such as green bins do not require water other than during cleaning, and thus household water use is expected to increase following FWG implementation and is often cited as a reason for not permitting large-scale implementation of FWGs (McKenzie, 2012). The per capita increases in potable water use due to FWG introduction are presented in Table 3.

Table 3. Potable Water Consumption of Food Waste Grinders in Recent Literature

Source	Water Demand Increase due to FWG use (L/cap/day)	Water Demand Increase due to FWG use (%)	Region	Type of Analysis
Stantec Consulting Ltd. (2017)	4	-	Alberta, Canada	Theoretical
McKenzie (2012)	2.6 L/day	0.7-3.0	Vancouver, Canada	Theoretical, Literature
Butwell, et al. (2010)	7.38 L/day	-	United Kingdom	Theoretical
Evans, et al. (2010)	-	(-0.6)-10.4	Surahammar, Sweden	Experimental, Pilot
Marashlian & El-Fadel (2005)	-	0.72-2.35	Greater Beirut Area, Lebanon	Experimental, Laboratory
Bolzonella, Pavan, Battistoni, & Cecchi (2003)	1-1.9	0.4-0.8	Italy	Theoretical
Diggelman & Ham (2003)	1.0	-	United States	Theoretical
Metcalf & Eddy (2003)	4-8 L/day	-	United States	Experimental
Galil & Shpiner (2001)	0.8-6.6	0.3-3	Haifa, Israel	Experimental
Rosenwinkel & Wendler (2001)	4.5	3.5	Germany	Experimental, Laboratory and Literature
Wainberg, et al. (2000)	2.95	-	Sydney, Australia	Experimental, Pilot
NYC-D.E.P. (1997)	3.78	-	New York City, United States	Experimental, Pilot

From Table 3, it can be observed that the increase in water consumption due to FWG use has been found to be small when compared to daily average water use and is consistent with that reported by the literature reported by Iacovidou, et. al. (2012). One study, (Evans, et. al., 2010), reported an initially high increase in potable water demand (10%), however, later in the study the water consumption was found to decrease below pre-FWG levels. It would appear that FWGs do not likely increase potable water consumption significantly.

2.4 Solid Waste Diversion with FWGs

Literature regarding solid waste diversion was reviewed as it is one of the primary motivations for implementing FWGs in MURBs. This section reviews studies that evaluated the impact of food waste grinder implementation on solid waste generation and characteristics.

The methodologies employed to quantify solid waste diversion by FWGs were reviewed (Table 4) to assist with designing the methods to be applied in the current study. The most common form of solid waste quantification is through waste audits, which involves the collection and separation of wastes by category with subsequent weighing. Yang, et. al. (2010), measured FWG impact within a community in Japan's mixed waste generation for a period of 20 months; seven months before implementation and 13 months after implementation (Yang, et. al., 2010). They employed waste audits to categorize waste composition while also measuring the mass and number of bags collected from the community twice a week. Other studies have evaluated waste characteristics through the collection of individual food wastes and extending the results to the population as described by Thomas (2011). Another study took the existing conditions from a study community and applied different expected effects of food waste grinders to infer waste generation effects in a desktop review (Marashlian & El-Fadel, 2005). The methodology found in practical studies consistently employs a control vs. study period methodology with one population when evaluating the impact of FWGs on solid waste diversion.

Table 4. Food Waste Grinder Impacts on Solid Waste Generation

	Market Penetration (%)	Mass Reduction (%)	Mass Reduction (kg/cap/year)	Water Content (%)	Organic Loading Captured (g OW/cap/ day)	Type of Analysis	Region
Yang, et. al. 2010	97	54.3	22*	>50	111	Experimental, Pilot	Tojo District, Japan
Yang, et. al. 2010	90	31	51*		126	Experimental, Pilot	K District, Japan
Marashlian & El-Fadel 2005	25-75	12-43	-	-	-	Theoretical	Greater Beirut Area, Lebanon
Galil & Shpiner 2001	60	7	-	4.5-13.3	-	Theoretical	Israel

*Calculated from published results

The reduction in mass of the mixed waste stream was reviewed to establish the range of results that might be expected in the current study. The reduction in mass of mixed waste collection is of interest as food waste grinders divert only organic wastes to the wastewater stream, and thus any reduction in the mixed waste stream as a result of FWG implementation can be attributed to organics diversion. The results show that these reductions were between 7-54 %, depending on the market penetration of the FWG devices. Normalizing the waste generation per capita, a reduction of 22-51 kg/cap/year was described by Yang, et. al. (2010). Organic waste is heavy due to the high moisture content and contributes much of the mass of the mixed waste stream and implementation of FWGs in the absence of green bins is expected to divert a larger mass fraction of organic waste than if FWGs are provided to households that already have green bin system access. The results of this review show that populations without alternative organic diversion strategies will use FWGs to manage food waste. There is however a lack of information on the extent to which food waste grinders will be employed when alternative disposal methods such as green bins are available and additionally the effect of the MURB setting is poorly understood regarding solid waste impacts.

2.5 User Attitudes Towards FWGs

The attitudes of residents towards food waste disposal were of interest as their perceptions may impact their tendency to use FWGs. In this regard papers that reported individuals' experiences with food waste handling were reviewed as their methodologies might be employed in the current study. The majority of organic diversion strategies that are not FWG based (i.e., green bins) depend on source separation. Hence, the prevalence of green bins has resulted in a majority of such studies having this focus. It was hypothesized that these results could apply to the current study as the motivations of an individual to divert their organic waste could be expected to be similar regardless of the technology diverting the waste.

The methodologies for evaluating attitudes towards food waste diversion were reviewed to identify industry standards in this regard. The most common method of determining food waste management practices involves surveying at the household level. Municipal-scale results have been reported by van der Werf & Cant (2007) and smaller-scale surveys have been reported by Ordonez, et al. (2015). The latter study investigated waste sorting behaviour in a Swedish MURB through waste audits, a household-level survey, and field observations. Despite a lack of reports on household-scale waste disposal practices, there has been considerable research investigating the generation of household food waste. This data collection has usually involved household-level surveys (Neff, et al., 2015). Some studies (Evans, 2011) conducted household interviews and observed waste disposal to record and evaluate food waste practices. Regarding the scope and objectives of this study, it was determined that surveying would most accurately evaluate the user perspective regarding FWGs.

The attitudes of individuals actively diverting their organic waste were reviewed to understand the experiences of waste diversion and personal motivations regarding organic waste disposal. The literature indicates that a majority of people want to dispose of their waste properly (Neff, et al., 2015; Ordonez, et al., 2015; Quested, et al., 2013; Evans, 2011). Furthermore, Canada (2013), reported that in 2011, approximately 61 % of Canadians "participated in some form of composting activity." However; it was unclear whether this referred to occasional composting of food waste when available in public spaces such as malls or participation in municipal green bin programs at the household level. The literature indicates that individuals are motivated to dispose of their organic waste correctly, with the majority of people participating in some level of diversion practice. In the context of MURBs, a building's waste disposal is often managed by minimizing costs may act as a barrier to organic waste diversion. Therefore, it is hypothesized that technologies that avoid the requirement for building managers to provide another stream of solid waste disposal, such as FWGs, may increase the level of diversion observed in MURBs.

Barriers to organic waste disposal experienced by individuals were investigated to understand areas in that FWG implementation could be most beneficial. Ordonez, et al. (2015), found that the majority of survey respondents wanted to dispose of organic waste properly and were hindered by either a lack of space in available organic waste disposal points or ambiguity regarding waste sorting methods and requirements. They also concluded that the perspective of the waste generator is important when developing waste management policies and that by ignoring these perspectives, the management practices will “fail to adequately address waste sorting problems,” (Ordonez, et al., 2015). The results of this review suggest that FWG focused organics diversion systems may reduce barriers to organics diversion, as FWGs do not require storage space for the waste by removing it from the household upon disposal. The presence of FWGs may however contribute to ambiguity in diversion messaging as some food wastes, such as fats oils and grease, large bones, or wastes that do not fit within the device that are not disposable with FWGs. The possible benefits or barriers experienced by MURB residents with FWGs and green bins are however not well understood and an area that this research aims to address.

Chapter 3: Methodology

This chapter describes in detail the methodologies employed in the current study. In brief, the study included a detailed assessment of potable water consumption, wastewater, and solid waste impacts as well as resident attitudes associated with FWG implementation in a MURB. A portion of the study involved surveying individuals in the MURB and was subject to a research ethics board review (REB File #41967). The descriptions of the study participants and study building have been left purposely vague as to meet research ethics board requirements of anonymity; however, important details that would be required for the replication of this study elsewhere have been included.

3.1 Study Design and Overview

To achieve the various study objectives, this project measured the impacts of FWG implementation at 100% MP in a MURB in Ontario, Canada, that had access to green bins and held 32 units which housed approximately 44-54 inhabitants. The data collection was split into two distinct phases that consisted of a control period, where residents did not have access to FWG devices; and a study period, where residents were provided with FWG devices. Throughout the project, the residents always had access to green bins. This design allowed for the direct comparison of potable water consumption, wastewater characteristics, solid waste characteristics, and user attitudes towards the FWG devices using a single population as both the control and study population. The data collection for the project spanned 15 months, beginning in January 2021, and concluding in March 2022. The control period lasted four months between January 2021 and April 2021. The duration of the study period was designed to account for the anticipated variability in measured parameters and thus had a duration of approximately 11 months between May 2021 and March 2022. The methodologies employed for data collection remained identical throughout the control and study periods.

Table 5 shows the timelines of each data collection activity and the frequency that sampling was conducted. The subsequent sections within this chapter detail the methodology employed to address the study objectives. In addition to the sampling described subsequently, two variability assessments were conducted in the first two weeks of the control and study periods to obtain a preliminary assessment of parameter variability and confirm the frequency of sampling employed in the regular sampling program. Figure 1 shows the timing of the various activities that were conducted in the study.

Table 5. Data Collection Overview

Data Collection Activity	Sampling Description	Control Period Sampling Events	Study Period Sampling Events	Frequency of Sampling
Potable Water Consumption	Continuous building influent potable water metering	Continuous	Continuous	1 Reading/5 minutes, 16 months of monitoring
Wastewater	Daily flow-weighted composite	3 (19 Individual Composites) *	11 (51 Individual Composites) *	Saturday, Sunday, Monday, Tuesday daily composites once per month, ~15 months
Solid Waste Audits	Solid waste audit with volatile solids determination	2	4	~1 Audit/3 Months
User Surveys	Household-level survey distributed to each unit	1	1	1 Survey per Control/Study Period

*7 additional composites collected during variability assessments

Item	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21	Jan-22	Feb-22	Mar-22
Control Period	Only Access to Green Bins														
Study Period					Access to both Green bins and FWGs										
Potable Water	Continous Monitoring														
Wastewater		Var*-Control	WW-1	WW-2, WW-3	Var*-Study	WW-4	WW-5	WW-6	WW-7	WW-8, WW-9	WW-10		WW-11	WW-12	WW-13, WW-14
Solid Waste		WA-1	WA-2			WA-3				WA-4				WA-5	WA-6
User Surveys		Survey 1												Survey 2	

*Variability assessment (2 weeks, daily sampling)

Figure 1. Sampling Schedule Gantt Chart

3.2 Study Building Selection and Control-Study Period Methodology

The building selected for this study was a 32-unit multi-unit residential building located in southern Ontario. The building was selected by the research sponsor based on a multi-criteria analysis. The building was primarily populated by residents above the age of 65; however, two units had residents with ages between 18 and 25 years. The units in the building had an average household size of 1.5-1.6 people per unit, leading to a total population of approximately 44-54 individuals which fluctuated to a slight extent throughout the project. All units had one kitchen area with a single sink basin that was fitted with the FWG unit (commercially available FWG units) (Figure 2).

Figure 2. FWG Sink and Sink Arrangement in Standard Study Building Unit

The impacts of FWG implementation were assessed by comparing the results obtained during the control and study periods. The control period had a duration of four months and during this time the FWG units were not active. During this period, the FWG units were installed in the residents' sinks, however, they were not powered and could not be activated. To prevent irregularly disposed food waste from entering and being held in the FWG device while inactive, all units were provided with a specially fitted sink-strainer that would ensure particles that would be retained on standard non-FWG sinks would not influence control period measurements. The FWGs were then activated for the study period which had a duration of approximately 11 months. This study design resulted in the same population for both periods which removed any biases associated with differences between control and study populations. To commence the study period, the building's manager activated all FWG units during a routine unit inspection where residents were also provided with instructions regarding proper care and use of the FWG devices.

3.3 Tenant Education Methodology

The education and communication materials that residents receive can directly affect their preferential use and opinions of the devices. To ensure that the operation of the study had minimal effect on these perceptions, the study team minimized advertisement or encouragement of the use of either FWG devices or green bins throughout the study. FWGs were activated by the building manager of the study period on May 3rd, 2021, marking the transition between the control and study periods. While activating the

FWG devices the building manager provided the residents with instructions on the proper and safe operation of the devices using training material provided by the FWG device manufacturer.

In addition to the training provided by the building manager, a list of FWG eligible products was provided to each resident in a brochure and on a fridge magnet during device activation. The list of items deemed acceptable for FWG use was developed by the partner municipality and based on existing sewer use bylaws (Table 6). Copies of materials provided to the residents for education purposes are included in Appendix D.

Table 6 Examples of Waste Disposal Eligibility

Green Bin Eligible Examples	FWG Eligible Examples
• Birdseed • Butter, margarine, grease, and lard • Cake, cookies, and candy • Coffee grounds • Coffee filters and tea bags • Dairy products • Diapers • Eggs and shells • Fruits and vegetables (raw or cooked) • Fur and hair • Herbs and spices • Houseplants • Incontinence products • Kraft paper (non-waxed) • Meat, fish, and seafood (including bones) • Microwavable popcorn bags • Muffin wrappers • Newspaper (soiled) • Nuts and shells • Paper flour and sugar bags • Paper towels, napkins, and tissues • Pasta, bread, cereals, rice, and grains • Pet bedding • Pet food • Pet waste (including cat litter) • Sanitary products • Sauces and soups • Soiled paper cartons, paper plates, and cardboard • Shredded paper (small amounts)	• Cake, cookies, and candy • Coffee grounds • Eggs and shells • Fruits and vegetables (raw or cooked) • Herbs and spices • Meat, fish, and seafood (including bones) • Nuts and shells

3.4 Technical Sampling Methodology

This study explored a wide range of FWG impacts including wastewater quality, potable water consumption, and solid waste disposition. Figure 3 shows the sampling points employed for the technical study. Sampling point 1 consisted of an in-line flow meter that measured the flow of potable water into the building. Sampling point 2 was a backwater flume within the wastewater outfall manhole. At sampling point 2, two autosamplers were employed to collect flow-weighted composite samples for wastewater characterization. Sampling point 3 involved the collection of the three solid waste streams for subsequent auditing. In the following sections, the details of the methodologies are described.

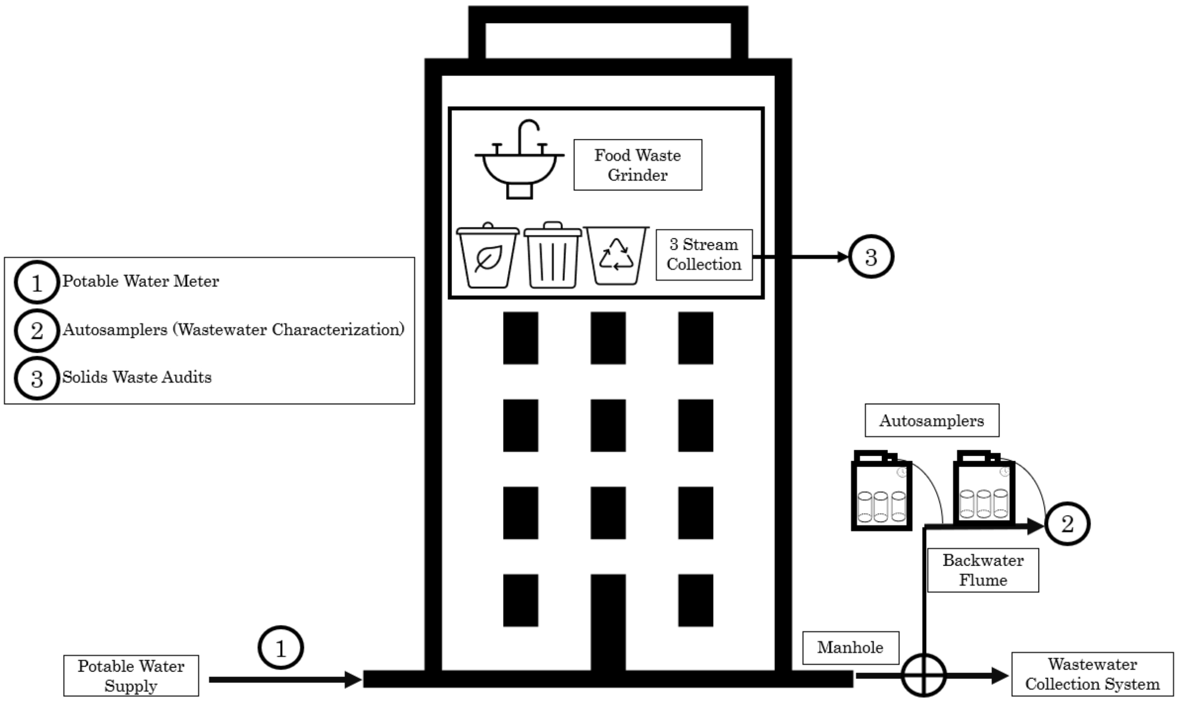

Figure 3. Sampling Point Diagram

3.4.1 Potable Water Consumption Monitoring Methodology

The flow of potable water into the building was measured at the building's connection to the water main so that the impact of FWG implementation on potable water consumption could be assessed. A clamp-on pipe monitor was installed (Endress Hauser Prosonic 91W clamp-on transit time) on the connection to measure all potable water entering the building throughout the study. This device measured flow through the pipe at a five-minute resolution and the values were converted to a daily volume of potable water consumption through trapezoidal integration. This device's accuracy was evaluated by comparing per unit potable water consumption to industry standards.

Throughout the project, the number of units inhabited fluctuated between 29 and 32 units, and hence water consumption was normalized by the number of occupied units. To compare the control period and study period potable water consumption, the normalized potable water consumption values were generated for each period. These two populations of potable water consumption were then compared statistically to assess whether the impacts of FWG implementation were significant.

3.4.2 Wastewater Characterization Methodology

During the first two weeks of the control and study periods, variability assessments were conducted to ensure that the sampling plan methodology would be able to accurately compare the periods. The first week of each variability assessment involved the collection of samples hourly for measurement of total solids concentrations to generate a daily total solid loading profile and quantify hourly variability over seven days. The second week of each variability assessment involved the collection of daily flow weighted composite samples to quantify day-to-day variability over seven days. These composite samples were analyzed for all parameters included in the long-term sampling plan and were sampled using the same sampling protocol. These daily composites were subsequently included in the population of wastewater characterization data gathered in the long-term sampling plan.

The wastewater composition leaving the building was characterized with a long-term monthly sampling plan that was developed to facilitate an assessment of the impact of FWG implementation on wastewater properties. The methodology employed was informed by the literature review as well as the variability assessments and flow measurements that were conducted before the monthly sampling program began. Due to the observed daily and hourly effects observed in the hourly variability assessments, it was concluded that flow-weighted composites would be required to accurately characterize the wastewater. Furthermore, it was anticipated that weekends may present different wastewater characteristics and food waste management (such as large Sunday dinners), and therefore both weekdays and weekends were sampled using the autosamplers. Addressing the above, it was determined that four sampling days per month would be employed for the duration of the project to characterize the wastewater while accounting for weekend/weekday effects, FWG effects, and seasonal variability. The days chosen for sampling were Monday, Tuesday, Saturday, and Sunday. Each sampling day resulted in one composite sample that was generated from 24 x 1 L samples that were collected hourly. Sampling days were scheduled to avoid the impacts of holidays/cultural events such as Christmas and Thanksgiving on wastewater quality.

The control period had three monthly sampling events of four days each, and with the seven-variability assessment daily composites, a total of 19 control period composite samples were generated. It was anticipated that the variability of the wastewater composition might increase post-FWG implementation which was confirmed during the variability assessments. Hence, more study period samples were required to identify statistically significant effects of FWG use on wastewater loadings. Therefore, in addition to the seven-study period variability assessment daily composite samples, a total of 11 monthly study period wastewater sampling events were conducted leading to a total of 51 study period samples. This sampling methodology allowed for occasional sampling failure due to blockages within the autosampler sampling tubes or errors in the scheduling of the autosamplers to still generate sufficient samples to allow for statistical comparisons.

Flow weighted composites were manually created by the sampling technician using the hourly volumes displayed in Figure 4 that were derived from an analysis of the daily potable water consumption over a two-week period after 100% occupancy had been reached. The technician acquired the 24 x 1 L sample bottles from an individual autosampler and, after shaking the sample, measured the appropriate volume for the sample using a 1 L graduated cylinder. The composite was prepared in a bucket from which individual sample containers were filled to a total volume of 4 L to facilitate sample bottle volume requirements. Approximately once every three sampling events, a triplicate analysis was conducted for each parameter to allow for the determination of analytical accuracy. These triplicate samples required additional composite volume due to the additional sample bottles, and thus the triplicate composites were made to 10 L before bottling for individual analytes. The samples were subsequently sent for laboratory analysis at the regional analytical lab (ISO/IEC 17025:2017 accredited). The buckets used to create the composites were rinsed with clean water between composites. The detailed sampling protocol used by technicians during the project is presented in Appendix B.

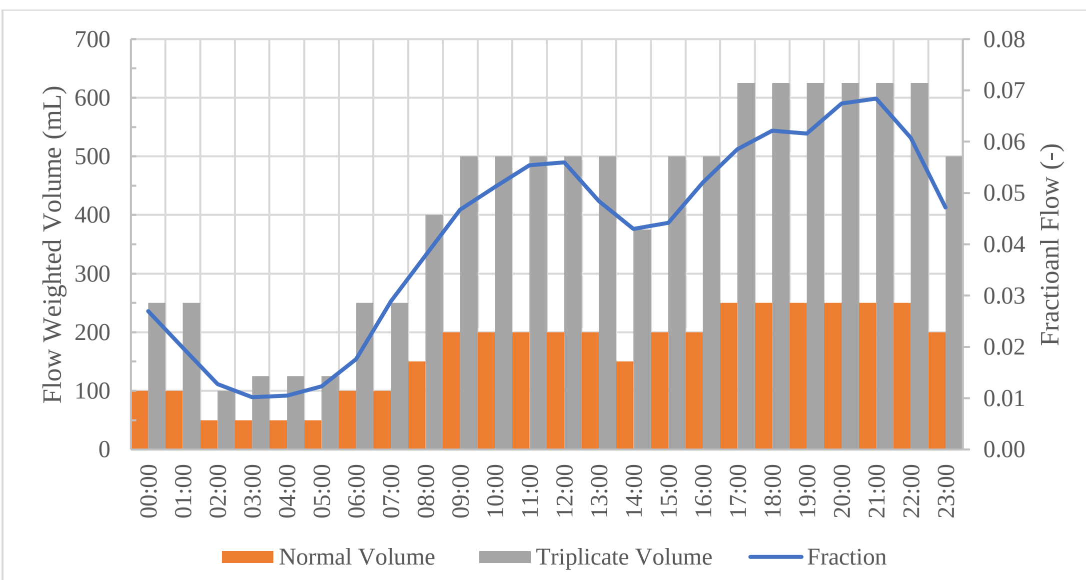

Figure 4. Flow Weighted Composite Composure

Two autosamplers were employed for sampling and were placed within fridges to ensure that the wastewater samples would be stable before being collected (Figure 5). The scheduling of the composite sample collection enabled efficient pick-up and redeployment of autosamplers while still sampling for 24 hours. Autosamplers were scheduled to collect samples from 10 am to 9 am the following day with the two autosamplers being able to sample two days in a row before sample collection. For example, a Saturday and Sunday sampling event was scheduled to start sampling at 10 am Saturday until 9 am Sunday, where the second autosampler then continued sampling from 10 am Sunday to 9 am the following Monday.

Figure 5. Auto Sampler Deployment in Fridge

The samples generated from the composite samples were analyzed for selected wastewater quality parameters that were determined through the literature review and by the recommendation of industry stakeholders (Table 7). The parameters were deemed relevant for determining the impacts of FWGs on both WWTPs and collection systems. To enhance the determination of impacts on collection systems, a sieve analysis was conducted to measure the amount of particles retained on a standard ASTM E11 quarter inch sieve. Particles from FWGs are reported to be between 0.59 – 4.76 +/- 0.34-0.62mm, which all were found to not negatively affect sewer flow except for eggshells (Legge, et al., 2021). Particles that are retained by a quarter-inch (6.35 mm) screen are classified as “course” in the Ontario design guidelines for sewage works, which are recommended to be screened from wastewater to protect pumps and other wastewater treatment equipment (Ontario, 2019). If FWGs introduce particles of this size, it would represent negative sewer conveyance and wastewater treatment outcomes.

Table 7. Wastewater Parameters Analyzed

Parameter Category	Acronym	Individual Analytes	Reference Method*
Solids	TS	Total Solids	SM 2540D
	VS	Volatile Solids	SM 2540E
	FS	Fixed Solids	SM 2540E
	TDS	Total Dissolved Solids	Calculated (TS-TSS)
	VDS	Volatile Dissolved Solids	Calculated (VS-VSS)
	FDS	Fixed Dissolved Solids	Calculated (FS – FSS)
	TSS	Total Suspended Solids	SM 2540D
	VSS	Volatile Suspended Solids	SM 2540E
	FSS	Fixed Suspended Solids	SM 2540E
Nutrients	TKN	Total Kjeldahl Nitrogen	SM 4500NORGD
	NH_3-N	Ammonia Nitrogen	SKALAR SM 4500-NH3-G
	NH_4-N	Ammonium Nitrogen	SKALAR SM 4500-NH3-G
	NO_3-N	Nitrate Nitrogen	SKALAR SM 4500-NO3-H
	NO_2-N	Nitrite Nitrogen	SKALAR SM 4500-NO2-B
	TP	Total Phosphorous	SKALAR SM 4500-P H
	PO_4	Phosphate Phosphorous	SKALAR SM 4500-P F
Biochemical Oxygen Demands	BOD5	5 Day Biochemical Oxygen Demand	SM 5210B
	sBOD5	Soluble 5 Day Biochemical Oxygen Demand	SM 5210B
Fats, Oils, and Grease (FOG)	FOG	Total Fats Oils and Grease	SM 5520B/SM5520G
	mFOG	Mineral Fats Oils and Grease	SM 5520F
	avFOG	Animal/Vegetable Fats Oils and Grease	SM 5520F
Other Analytes		Conductivity	Modified SM 2510
		Sieve Analysis	Appendix B

*Methods employed at an ISO/IEC 17025:2017 accredited laboratory

Wastewater parameters were measured as concentration of the given analyte in the daily composite. Monitoring and analysis was conducted for both concentrations and loadings, to determine FWG impacts on wastewater conveyance and treatment capacity respectively. Because loadings are a per-unit normalization, minor fluctuations in the study building population would be accounted for in loadings analysis but not necessarily concentration analysis. Loadings were calculated using Equation 1.

$$Loading\ \left(\frac{g}{unit \times day}\right) = Concentration \left(\frac{mg}{L}\right) \times Daily\ Water\ Consumption \left(\frac{L}{unit \times day}\right) \times \frac{1g}{1000mg} \quad \text{Equation 1}$$

3.4.3 Solid Waste Audit Methodology

One of the primary motivations for the implementation of the FWG devices is the diversion of organic waste from landfills. To characterize the impact of FWGs on organic solid waste diversion, six waste audits were conducted at the study building. Two waste audits were conducted during the control period to establish baseline green bin use and the pre-FWG level of fugitive organics within the mixed waste stream. An additional 4 waste audits were conducted throughout the study period, including two waste audits at approximately the same time of year as that employed in the control period, as described in Table 8.

Table 8. Solid Waste Audit Schedule

Waste Audit Number and Period	Date	Season
1 – Control	February 24, 2021	Winter
2 – Control	March 31, 2021	Spring
3 – Study	June 23, 2021	Summer
4 – Study	October 20, 2021	Fall
5 – Study	February 23, 2022	Winter
6 – Study	March 30, 2022	Spring

In each audit, all waste generated in the building was characterized thereby avoiding errors associated with the generation of subsamples. Each audit occurred on the Wednesday of the collection week, leading to a seven-day collection period for blue bin recycling and the green bin and an eight-day collection period for the mixed waste stream, as the mixed waste was not collected on the normal collection schedule of Tuesday during the waste audit weeks. All waste generated was transported to a waste sorting facility, where the total masses of each stream were measured by trucking mass delta. The wastes were then sorted manually, as shown in Figure 6.

Figure 6. Manual Sorting of Waste During Waste Audit #1

Each waste audit fractionated and weighed 112 individual categories of waste (Appendix C) for each stream (green bin, blue bin, mixed waste). All waste auditors were trained under, and applied the methodologies described within, the Ontario Waste Auditor Training (OWAT) standards. After fractionation, each fractionated waste sub-category was weighed using a briefcase scale, as shown in Figure 7. After all streams were weighted, a total mass audited was recorded and compared to the total mass collected to ensure that at least 95% of the mass collected was measured in the audited categories to designate a successful waste audit.

Figure 7. Waste Audit Weighing During Waste Audit #1

In addition to the typical waste audit categories, the volatile solids of the organic content found in each stream was also measured to facilitate a fate of volatile solids analysis for the building. For each audit, the total waste stream was fractionated into all categories measured during waste audits and measured. After all fractions had been measured, all organic waste categories (non-food organics and food waste) from each stream (green bin, blue bin, mixed waste) were combined into collection stream-specific bins. Per stream, this organic waste was homogenized by shred/grinding with a Muffin Monster 1-SHRED industrial grinder. Each stream's organic waste fraction was passed through the shredder thrice to ensure complete homogenization of waste. After shredding, three samples of the homogenized organic waste per stream were sent to the regional lab for volatile solids and moisture analysis (Figure 8). In the case that insufficient organic mass was collected for an individual stream, the amount collected would be recorded but a volatile solids sample would not be submitted.

Figure 8. Homogenized Green Bin Organics During Waste Audit #1

3.5 Tenant Surveying and Advertisement Methodology

The residents' waste disposal attitudes were assessed with two surveys that were conducted throughout the project to determine the impacts of FWGs on waste disposal attitudes. The results of the survey were employed to evaluate any changes in attitudes that might develop after the implementation of FWG devices. The first survey was conducted in the control period after the residents had lived in the building with de-activated FWGs for approximately four months; the second survey was conducted in the study period after approximately 11 months of FWG access. The surveys were conducted in a manner approved by a Research Ethics Board (REB) at the University of Waterloo, which included precautions to ensure reasonable anonymity was maintained in the results of this study and that identification information was collected for the sole purpose of providing compensation. The REB approval protocol for this study is "#41967 - Impact Study of Food Waste Grinders in Multi-Residential Settings".

For each survey, each unit received a unit-addressed envelope that contained a letter from the study team and paper copies of the questionnaire in both English and simplified Chinese (Appendix E). Several posters were displayed in the building by the building manager in general spaces and garbage disposal rooms. The English versions of posters, letters, and information shared with residents in association with the surveys are presented in Appendix D. Residents were able to complete surveys by either completing the paper survey and returning it in pre-stamped envelopes or over the phone in a follow-up phone call. In survey 1, residents were able to complete the survey online, however, due to lack of online participation, this was not made available in survey 2. The phone calls occurred two weeks after the paper surveys were provided to residents and allowed the residents to ask questions related to the study. Phone calls were conducted between 2:00 and 5:00 pm and a phone call script is provided in Appendix D. The online survey was emailed to each unit's primary email collected by the building manager. Residents were provided with a $25 gift card to the closest grocery store to the building for each survey they completed for a total of $50 compensation for a unit that completed both surveys.

The surveys (Appendix E) asked a variety of questions related to waste disposal. The questions were categorized by food waste, soiled paper products, and other organic wastes to observe differences in waste disposal based on the type of organic waste being disposed of. In each category, residents were asked parallel questions regarding the frequency of which they generate the waste, if the waste generation changes by season, and by which disposal technology they primarily used for the disposal. The design of the two surveys (conducted in the control and study period respectively), was such that a direct comparison between questions regarding the three categories of organic waste could be made without explicitly asking questions regarding waste disposal preference. In survey 1, there were questions specific to green bins that polled factors that discourage the resident from using the green bin, and also how often the resident empties their green bin. In survey 2, in addition to all questions in survey 1, questions specific to FWGs were asked. These questions included determining if the residents felt comfortable using the devices and if they understood the instructions provided. The surveys also queried how often the resident used their FWG, what types of organic waste they disposed of in the grinder and what considerations they had in deciding to use the FWG in comparison to the green bin.

3.6 Statistical Tests Employed

Several statistical tests were used to evaluate the data collected through the various study activities (Table 9). In discussions hereinafter, the term "statistically significant" was used to identify comparisons that were calculated to have p-values less than the identified alpha value in Table 9. P-values were also provided within the text where significant levels were identified. Significance values for each comparison were determined based on the accuracy of collection methods for the data collection activity.

Table 9. List of Statistical Tests Employed and Significance Level

Data Comparison Category	Compared Populations or Metrics	Statistical Test Employed (Montgomery, 2013)	Significance Evaluated (α)
Variability Assessments	ANOVA: TSS Daily variability and hourly variability effects	Two Factor ANOVA	0.05
	Average of control and study period variability assessments wastewater loadings	Right-Tailed T-Test*	0.05
	Standard deviation (variance) of control and study period variability assessments wastewater loadings	Right-Tailed F-Test	0.05
Potable Water Consumption (L/unit/day)	Average of control and study periods total daily consumption	Two-Tailed T-Test*	0.05
	Standard Deviation (variance) of control and study periods total daily consumption	Right-Tailed F-Test	0.05
Wastewater Concentrations (mg/L)/Loadings (g/unit/day)	Average of control and study periods concentration/loading per analyte	Right-Tailed T-Test*	0.05
	Standard Deviation (variance) of control and study periods concentrations/loadings per analyte	Right-Tailed F-Test	0.05
	Average of weekend and weekday concentrations/loadings per analyte	Two-Tailed T-Test*	0.05
	Average of control and study period weekend and weekday concentrations/loadings (where weekend effects were significant)	Bonferroni Multiple Mean Comparison Test	$\alpha = 0.05$ $\alpha' = 0.025$
Solid Waste Generation (g/unit/day)	Average of control and study periods solid waste generation per stream, per analyte or group of categorical analytes	Left-Tailed T-Test*	0.10
Volatile Solids Generation (g VS/unit/day)	Volatile solids generation per stream (blue bin, mixed waste, green bin, wastewater, total)	Two-Tailed T-Test*	0.05

*Welsh's t-test as described in Montgomery (2013).

Chapter 4: Results and Discussion

4.1 Study Building Demographics and Characteristics

The study building, located in Ontario, was monitored with respect to population and demographics throughout the study to accurately normalize technical sampling results and account for these differences numerically (Table 10). Informed by both survey responses querying basic demographic information such as household density and age, as well as communications with the building manager, the demographics did not change substantially between the control and study period. The total units occupied remained at 29 throughout the control period, whereas the study period occupancy fluctuated between 30 and 32 units occupied, with the average number of units occupied displayed in Table 10. Due to uncertainty in the number of occupants residing in each unit it was deemed most appropriate to report normalized waste generation on a per-unit basis.

Table 10. Comparison of Building Demographics Between Control and Study Periods

Item	Control Period (January 2021 – April 2022)	Study Period (May 2022 – March 2022)
Average Household (Unit) Density	1.5 persons/unit	1.7 persons/unit
Average Units Occupied	29.0 units	31.4 units
Total Population Estimate	44 persons	54 persons
Reported Age of Residents*	>65	>65

*Two units were occupied by youths (16-26)

The households consisted of a mix of single and double occupancy, with no unit housing more than two individuals. The average household density in the municipality was approximately 3.1 persons/dwelling unit, and the average MURB household density was 1.9 persons/unit (personal communication with municipal staff, Sept. 23, 2021), indicating that the study building had a slightly lower household density than average for its location. The study building was primarily populated by residents over the age of 65, with one unit being occupied by people between the ages of 55 and 64 and two units occupied by people between the ages of 16 and 24. These characteristics are described to qualify this study with future possible studies in other locations using other study buildings and to describe how technical results were normalized for back-calculation should it be required. These demographics are also employed in the normalization of certain analytes in the technical sampling program.

4.2 Technical Sampling Results

This section presents and discusses the results of the potable water consumption monitoring, wastewater characterization, and solid waste audits. An integrated volatile solids mass balance analysis that integrated the results of the three separate activities was also conducted to provide an additional assessment of data quality.

4.2.1 Potable Water Consumption

Potable water consumption was measured for 68 days within the control period and 333 days in the study period. Due to small changes in building occupancy throughout the study, potable water consumption was normalized on the basis of the number of units that were occupied. The potable water consumption data, when expressed on a daily basis, are summarized in a box and whisker plot (Figure 9) and tabulated results are presented in Appendix F.

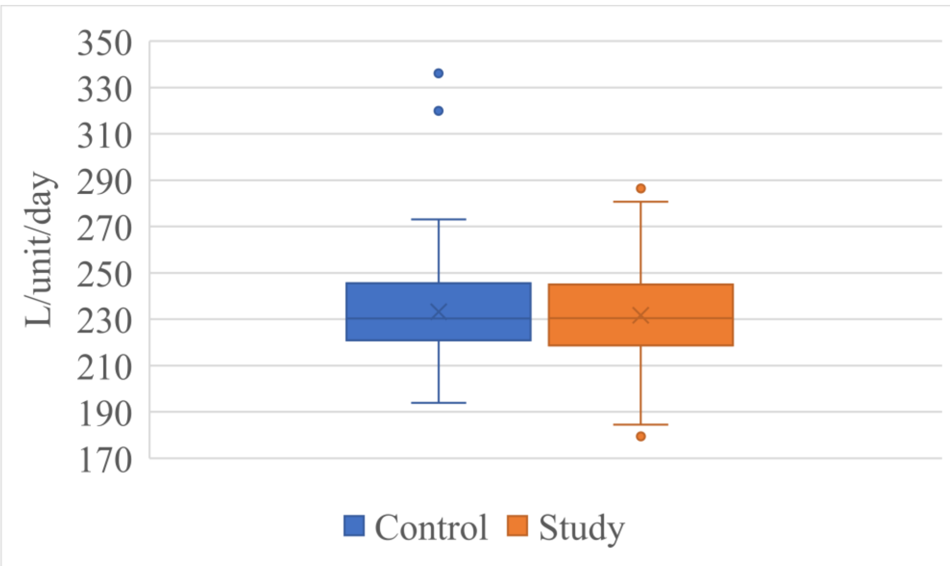

Figure 9. Potable Water Consumption Results

The results indicate that there was no significant change ($p = 0.49$) in potable water consumption per unit following the implementation of FWGs in the study building. The average potable water consumption over the two periods was 233 L/unit/day, which was within the range of reported values for potable water consumption for a building of this population density (225-490 L/unit/day, (Metcalf & Eddy, 2003)). The results suggest that the use of FWGs in combination with green bins did not significantly increase potable water consumption relative to the period when only green bins were available. If FWGs were responsible for an increase in potable water consumption, that increase could not be distinguished from background variability in the potable water consumption of the building.

The temporal consumption of potable water was monitored to understand the daily trends of this consumption following the FWG introduction (Figure 10). Differences between 65-minute averages of the control period and study period were very small in comparison to the variability observed in the potable water consumption. Due to this variability and low differences, no significant change was identified for the temporal consumption of potable water following FWG implementation, which was consistent with the conclusions drawn from bulk consumption of potable water in the study building.

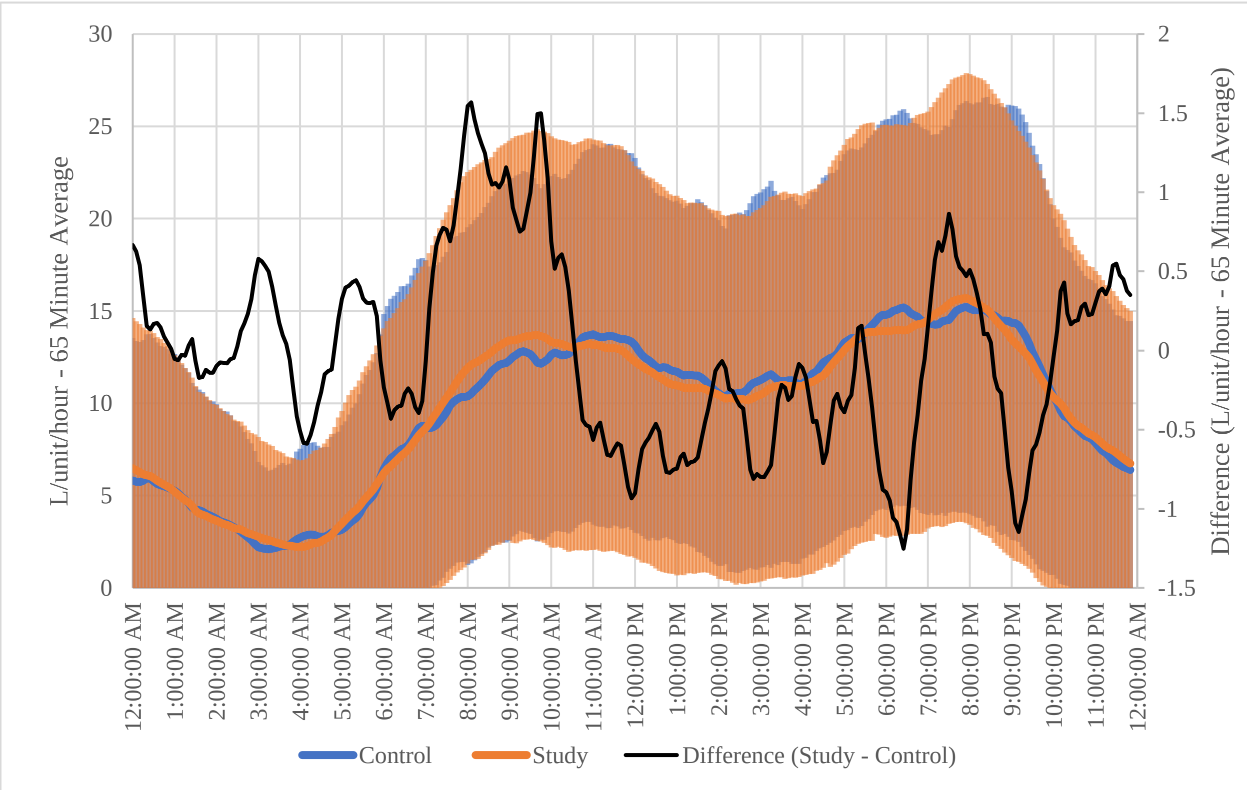

Figure 10. Temporal Trend of Potable Water Consumption, 65 Minute Average +/- 1 Standard Deviation

The potable water consumption was employed to calculate loadings of wastewater constituents to the sewer throughout the study. In this regard average total daily potable water consumption values of 6,763 +/- 691 L/day and 7,319 +/- 629 L/day were estimated for the control and study periods respectively. The change in average total water consumption was attributed to minor occupancy differences between the two periods.

4.2.2 Wastewater Characterization Results

Wastewater properties were analyzed throughout the study to determine the impact that implementing FWGs at a 100% MP would have on wastewater quality produced by the study building. Changes in wastewater quality may have impacts on conveyance and treatment systems which are considerations for municipalities and building managers when considering the implementation and use of FWGs. During the study, variability in wastewater composition was characterized to develop an adequate sampling strategy and to determine the initial wastewater characteristics of the study building. The concentrations of wastewater constituents were measured and benchmarked against typical municipal wastewaters to inform future studies of the conditions present at the study building. The concentrations of common wastewater constituents were compared between the control and study period to assess whether FWG implementation might impact conveyance system operation in support of future municipal decisions. Finally, loadings were evaluated to determine the possible impacts of FWGs on wastewater treatment and sludge production. Together, this study aimed to quantify and describe the impact of FWGs on wastewater characteristics and make connections to possible impacts on wastewater infrastructure.

4.2.2.1 Variability Assessments

During the initial stages of the control and study periods, variability assessments were conducted to assist with developing the long-term sampling strategy that would characterize wastewater from the building. Hourly assessments of total solids, that involved taking individual hourly grab samples for a period of 168 consecutive hours were conducted in this regard (Figure 11). Descriptive statistics of the results from the two periods were initially examined to determine whether FWG implementation impacted the bulk data characteristics. The average total solids concentrations in the control and study periods were 646 +/- 313 mg/L and 674 +/- 361 mg/L respectively and it was concluded that the average values did not change significantly ($p = 0.30$). However, the variability of the TS concentrations was found to increase significantly ($p = 0.03$), as evidenced by a 5.3% increase in the CV. The increase in TS variability suggested that other analytes may also become more variable following FWG implementation, and hence more samples were collected in the study period as compared to that of the control period to improve the characterization of variability.

To determine an appropriate method of wastewater sampling for the building, an ANOVA analysis was completed on the total solids profiles from the variability assessments to determine the impact of day-to-day variation and hour-to-hour variation of TS concentrations. In the control period, hour-to-hour variation was determined to be significant ($p < 0.01$), whereas day-to-day variation was not ($p = 0.53$). In the study period, hour-to-hour variation was determined to be insignificant ($p = 0.09$), however, day-to-day variation was significant ($p < 0.01$). To account for the hour-to-hour variability observed in the control period, flow-weighted composites were subsequently employed to improve the estimates of analyte loadings from the building. Though hour-to-hour variation was not found to be significant in the study period flow-weighted composites were employed in both periods to maintain consistency in approach. The observation of significant day-to-day variability in the study period suggested an irregular impact of FWGs on TS concentrations. The long-term sampling design included sampling on multiple days per month in both periods to establish a measure of day-to-day variability throughout the study.

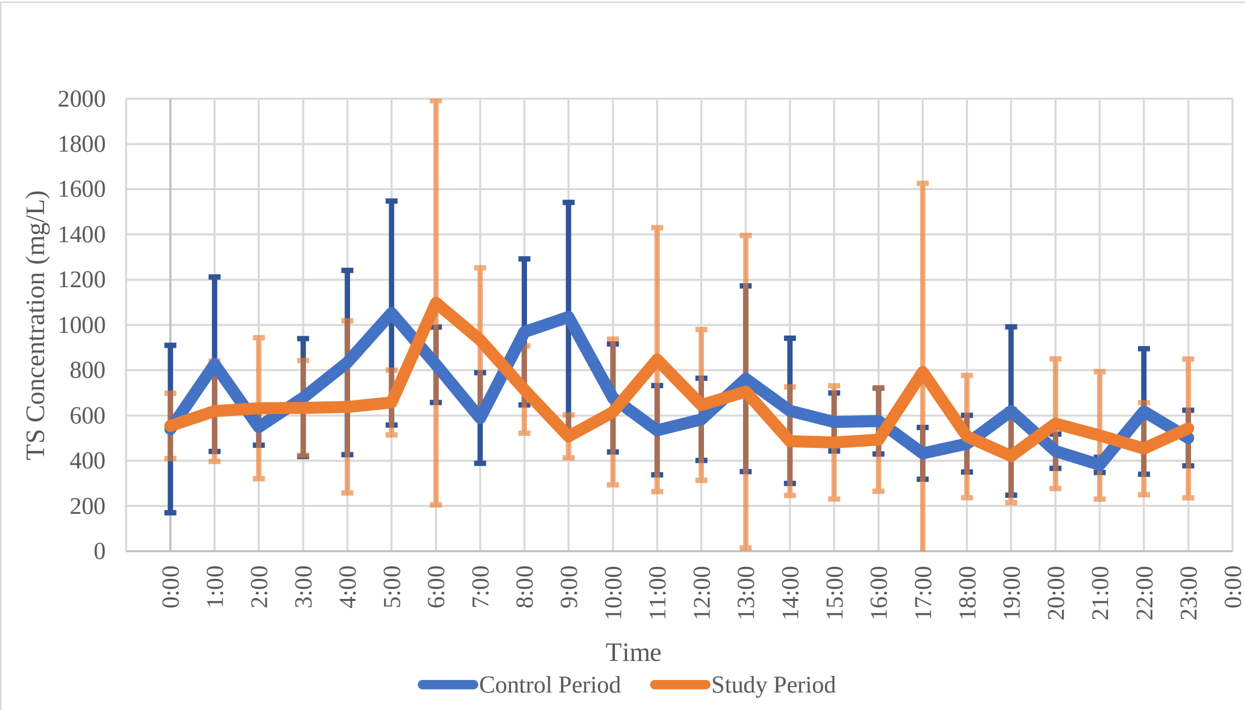

Figure 11. Daily Total Solids Profile of Control and Study Period Variability Assessments

The day-to-day variability of flow-weighted composites was assessed with respect to the full list of analytes to assist with developing the long-term sampling plan and to provide insight into the level of uncertainty that could be expected from the long-term sampling program. As shown in Table 11, the CV of most analytes was greater than 10% in both the control and study periods, indicating that day-to-day variability was above this level regardless of FWG presence. Analytes with high CVs (CV > 30%), were FSS, BOD_5, and FOG, which indicated that high levels of variability were present in a range of species. Though insufficient data was available for statistical comparisons, most analytes showed an increase in average concentration during weekends when compared to weekdays in both periods. This data suggested that sampling on multiple days which included weekend and weekdays would enhance the quality of data such that the impacts of FWG implementation on wastewater analytes could be discerned. Hence, the sampling plan included two weekend samples and two weekday samples to block any weekend effects from wastewater characterization following FWG implementation.

Table 11. Comparison of Analyte Concentrations in Control and Study Period Daily Variability Assessments

Category	Analyte	Control Period (n=7)		Study Period (n=7)	
		Average (mg/L)	C.V. (%)	Average (mg/L)	C.V. (%)
Solids	TS	640	11.4	633	9.7
	VS	391	17.9	342	15.8
	FS	249	8.2	291	8.0
	TDS	452	9.2	479	9.6
	VDS	212	18.0	193	22.0
	FDS	240	9.9	286	8.1
	TSS	188	22.5	154	22.5
	VSS	179	23.9	150	23.6
	FSS	9	45.4	6	57.4
Nutrients	TKN	85	15.7	69	12.9
	(NH3+NH4)-N	59	16.1	40	10.5
	(NO3+NO2)-N	N/A	N/A	N/A	N/A
	NO3-N	N/A	N/A	N/A	N/A
	NO2-N	N/A	N/A	N/A	N/A
	TP	7	17.3	7	11.5
	PO4	5	16.8	4	13.9
Biochemical Oxygen Demands	BOD5	325	37.1	279	23.3
	sBOD	153	44.2	179	27.5
Fats, Oils and Grease	FOG Total	33	70.6	34	37.8
	FOG Mineral	N/A	N/A	N/A	N/A
	FOG Animal/Veg	29	72.4	32	44.5
Other	Conductivity (µs/cm)	1019	11.9	862	4.2

The day-to-day variability of the full list of analytes in the flow-weighted composites was compared between the control and study period to assist with developing the long-term sampling plan and to gain preliminary insight into the levels of uncertainty that could be expected in the full study. All solids analytes had insignificant changes in variability, except for FSS, which increased by 33% in the study period, possibly due to the low magnitude of this analyte. The CV of most nutrient analyses and biochemical oxygen demand were also found to be similar in both periods. FOG showed the largest decrease in CV in the variability assessments, with a reduction in CV of about 28% in the study period. The day-to-day variability assessment comparison indicated that there was not a consistent change in variability amongst the analytes and thus the same sampling protocol was employed in both periods.

4.2.2.2 Wastewater Benchmarking to Typical Wastewater Concentrations

It was recognized that the building under study had a population with a somewhat narrow demographic distribution and hence the properties of the wastewater during the control period were examined to assess whether its composition was representative of typical municipal wastewater as reported by Metcalf & Eddy (2014). To benchmark the wastewater with typical wastewater analyte values, the average concentrations of the control period samples (pre-FWG installation) were examined (Table 12).

Table 12. Comparison of Control Period Wastewater Properties with Typical Municipal Wastewaters

Category	Wastewater Analyte	Average Concentration mg/L (Standard Deviation)	Metcalf & Eddy (2014)* (mg/L)
Solids	TS	615 (69)	537-1612
	TDS	433 (34)	374-1121
	VDS	191 (24)	150-449
	FDS	243 (21)	224-672
	TSS	181 (35)	130-389
	VSS	171 (34)	101-304
	FSS	11 (5)	29-86
Nutrients	TKN	79 (14)	23-69
	(NH_3+NH_4)-N	51 (15)	14-41
	$(NO_3 + NO_2)$-N	<0.4	0
	TP	7.3 (1.3)	3.7-11.0
	PO_4	4.2 (1.2)	1.6-4.7
	BOD_5	301 (84)	133-400
FOG	FOG (Total)	33 (19)	51-153

*The range displayed is low - high strength wastewater concentrations reported in Metcalf & Eddy (2014)

FWGs were anticipated to add food waste particles to the wastewater stream and thus the solids were examined before FWG implementation to establish baseline properties and benchmark the building's solids profile with that of typical municipal wastewater. In general, most solids analytes were in the range of low to medium strength wastewater values reported by Metcalf & Eddy (2014). Fixed suspended solids concentrations were on average found to be somewhat lower than typical municipal wastewater. The lower values might be attributed to the primarily residential nature of the wastewater whereas more general municipal wastewaters typically have other inputs that can have higher fixed solids concentrations. The lower concentrations of fixed suspended solids were not expected to impact the findings of the current study. Overall, the solids content of the non-FWG impacted wastewater at the study building was comparable to medium strength typical municipal wastewater (Metcalf & Eddy, 2014).

FWGs divert food waste which is known to contain nutrients and organic matter and therefore the concentrations of common nutrients and BOD_5 were characterized and benchmarked against typical wastewater ranges. Both TKN and ammonia nitrogen concentrations were found to be marginally above the range of expected concentrations for these analytes in typical municipal wastewater. Nitrite and nitrate were not detected in the building's wastewater which was consistent with common municipal wastewater. The concentrations of total phosphorous, orthophosphate, and BOD_5 were found to be comparable to that of high-strength municipal wastewater. The use of water-efficient appliances and lack of dilution from other non-residential sources likely led to the wastewater from the study building matching high-strength wastewater. With other nutrients such as phosphorous and BOD_5 also matching typical high-strength wastewater, the wastewater from the study building could be considered a high-nutrient strength typical wastewater (Metcalf & Eddy, 2014).

The concentrations of FOG were examined throughout the study and benchmarked against typical wastewater as the presence of FOG in wastewater can have impacts on the wastewater conveyance system and the headworks operations at wastewater treatment plants. FOG concentrations were found to be considerably lower than that of typical wastewater (Metcalf & Eddy, 2014). This low FOG presence was attributed to the residential nature of the study building and a lack of commercial inputs such as restaurants.

4.2.2.3 Impact of FWG Implementation on Analyte Concentrations in Wastewater

The wastewater was characterized using flow-weighted daily composites, and thus the concentrations discussed in this section represent the daily average wastewater values. The concentrations of the analytes in the wastewater were initially compared between weekend and weekday samples to determine if the time of week affected analyte concentrations and hence would need to be considered when evaluating the impact of FWG implementation on wastewater properties. When the control and study period data were combined TSS, VSS and FSS were found to be significantly higher in weekend samples as compared to the weekday samples ($p < 0.01$, $p < 0.01$, $p = 0.03$ respectively). For the analytes that did not show evidence of a weekend effect, the control and study period data were subsequently compared against each other without including weekend effect considerations. For TSS, VSS and FSS data, the Bonferroni multiple mean comparison test (α' of 0.025) was employed to separately compare weekday and weekend concentrations in the control and study periods. This analysis revealed no statistical differences between the control and study period weekday samples and the control and study period weekend samples ($p > 0.25$, $p > 0.38$ respectively). Based on these sub comparisons of data, it was concluded that while suspended solids species concentrations were elevated on the weekend, the implementation of FWGs did not significantly increase the content of suspended solids.

FWGs were anticipated to increase the amount of particulate in wastewater, as the FWGs grind portions of food waste into particles which are then flushed to the conveyance system. It was also hypothesized that FWG use might increase the concentrations of FOG and dissolved species such as salts due to the grinding of high-water content foods such as vegetables and fruits. The changes in concentrations with FWG use were considered as they may negatively impact the conveyance of wastewater. For example, if very high concentrations of suspended solids were present in the wastewater, sewer pipes might become clogged. To evaluate these impacts, the concentrations of the previously described wastewater analytes were compared between the control and study periods and additionally against the local sewer use bylaw maximum acceptable concentrations (MAC) (Table 13).

Table 13. Average Concentrations of Wastewater Analytes and Sewer-Use Bylaw MAC

Category	Analyte	Control Period	Study Period	Significance	Local Sewer Use Bylaw MAC
		Average (mg/L) (St. Dev)	Average (mg/L) (St. Dev)	p_{ave}|p_{var}	mg/L
Solids	TS	615 (69)	692 (199)	0.01 | 0.00	Not Defined (N.D.)
	VS	362 (59)	398 (179)	0.11 | 0.00	N.D.
	FS	253 (25)	293 (33)	0.00 | 0.12	N.D.
	TDS	434 (49)	497 (125)	0.00 | 0.00	N.D.
	VDS	191 (36)	214 (111)	0.10 | 0.00	N.D.
	FDS	243 (25)	282 (30)	0.00 | 0.24	N.D.
	TSS	181 (35)	195 (100)	0.21 | 0.00	350
	VSS	171 (34)	184 (94)	0.21 | 0.00	N.D.
	FSS	11 (4)	11 (8)	0.39 | 0.01	N.D.
Nutrients	TKN	79 (14)	72 (23)	0.94 | 0.02	100
	(NH3+NH4)-N	51 (16)	42 (13)	0.99 | 0.83	N.D.
	(NO3+NO2)-N	<0.4	<0.4	N/A	N.D.
	NO3-N	<0.4	<0.4	N/A	N.D.
	NO2-N	<0.015	<0.015	N/A	N.D.
	TP	7 (1)	7 (2)	0.80 | 0.01	10
	PO4	4 (1)	4 (2)	0.78 | 0.11	N.D.
Biochemical Oxygen Demand	BOD5	301 (85)	300 (167)	0.52 | 0.00	300
	sBOD	164 (51)	174 (101)	0.30 | 0.00	N.D.
Fats, Oils and Grease	FOG Total	34 (19)	49 (29)	0.01 | 0.03	N.D.
	FOG Mineral	<5	<5	N/A	15
	FOG Animal/Veg	32 (19)	48 (28)	0.01 | 0.03	150

The variability (standard deviation and CV) of the analytes was assessed as it was anticipated that FWG use might be episodic in nature. As shown in Table 13, the variability of many analytes (TS, VS, TDS, VDS, TSS, VSS, FSS, TKN, TP, BOD_5 $sBOD_5$, FOG), increased significantly following the introduction of FWGs. The increases in concentration variability affects the ability to identify statistically significant results and may have masked small increases in analyte concentrations; thereby affecting conclusions regarding FWG use impact. The increases in variability suggest that factors of safety employed when designing the capacity of treatment at WWTPs may need to be increased to account for greater uncertainty in analytes loadings.

It was anticipated that the majority of material leaving the FWGs would be particulate in nature, which was measured in terms of total and suspended solids. TS and FS concentrations increased significantly following FWG implementation ($p = 0.01$, $p <0.01$ respectively), however, the concentrations of the suspended solids species did not change significantly as discussed. The dissolved solids increased similarly to the total solids ($p < 0.01$), indicating that the increase in total solids species was primarily in the form of dissolved solids. These results show that the FWGs produced primarily soluble components rather than suspended solids which was originally hypothesized. The organic fraction of municipal solid waste is known to have a high-water content (64-69% (Pagliaccia, et al., 2019)), and fruits and vegetables are known to have an even higher water content (88.5-92.5% (Edwiges, et al., 2018)). The results suggest that FWG use discharged substantial amounts of dissolved solids that were present in the water associated with the food waste.

The solids concentrations were further assessed to evaluate whether the FWG implementation might impact upon wastewater conveyance. The TSS concentrations were compared against the sewer bylaw MAC values (Table 13) and found to be consistently lower than the allowable values throughout the study. Additionally, no large particulates were retained on a quarter-inch sieve throughout the study, suggesting that FWGs do not add large particles that might impact flow. The results suggest that FWG implementation would have negligible impacts on wastewater conveyance due to suspended solids loading.

Limits for nutrients in wastewater are defined in sewer-use bylaws to protect wastewater treatment plants from receiving exceptionally high loads of specific nutrients and to ensure that odour controls in sewer systems are not overwhelmed. Table 13 shows that the ammonia concentration decreased by approximately 19% ($p = 0.01$) after FWG implementation, while TKN concentrations did not change. TKN concentrations were below the sewer use bylaw MAC throughout the study. Phosphorous and orthophosphate concentrations did not change significantly following FWG implementation and TP was below the regulated limit in both periods. With the increase in TS and TDS, it was anticipated that dissolved nutrient concentrations would also have increased. However, the results suggest that the observed increase in dissolved solids was due to non-nutrient dissolved constituents such as salts. Regarding wastewater conveyance, the implementation of FWGs did not produce nitrogen or phosphorous concentrations that would be expected to affect collection systems.

The BOD_5 concentrations were compared against the MAC for BOD_5 to evaluate the potential for exceedances due to FWG implementation. As shown in Table 13, the average BOD_5 concentration was approximately equivalent to the MAC value in both periods. Additionally, the average BOD_5 concentration did not change between the control and study periods, suggesting that FWGs had little effect on this analyte's concentration in wastewater. In summary, the average BOD_5 concentration in wastewater was not found to increase at a significant level and was near the MAC value throughout the data collection period.

The amount of TDS that increased following FWG implementation was compared with soluble BOD_5 to determine the extent to which the additional TDS were biodegradable. The ratio of $sBOD_5$/VDS did not change at a significant level and was approximately 0.81-0.85 mg $sBOD_5$/mg VDS. The $sBOD_5$/TDS ratio also remained unchanged following FWGs, with a value of 0.35 – 0.38 mg $sBOD_5$/mg TDS. Soluble biochemical oxygen demand concentrations did not increase significantly although this conclusion may have been affected by the large variability observed in sBOD concentrations compared to that of TDS ($CV_{sBOD5(Study)}$ = 58%, $CV_{TDS(Study)}$ = 25%). These results suggest that the observed increase in TDS was due to the presence of inorganic salts or dissolved minerals that do not contribute to biochemical oxygen demand. The TDS increase did not appear to be associated with dissolved biodegradable materials as $sBOD_5$ was not found to change following FWG use.

FOG is increasingly being scrutinized as a wastewater component as it can mix with particulates, including particulates from FWG operation, and form blockages (Mattsson, et al., 2015). The animal/vegetable FOG concentrations were found to increase by approximately 15 mg/L (45%, $p < 0.01$) in the current study. This increase occurred despite the distribution of educational materials to residents instructing them not to dispose of FOG items via the FWGs. Assuming that the education materials were heeded, the results suggest that the increase in FOG concentrations might be attributed to the disposal of general food waste instead of improper use of FWGs. Though the increase in FOG concentrations following FWGs was substantial, the FOG concentrations were consistently below sewer use bylaw limits. While the FOG concentrations were below sewer-use limits, increases in FOG concentrations have implications for contributing to blockages and removal requirements at the receiving WWTP and should be considered in decisions regarding FWG implementation.

4.2.2.4 Impacts to Wastewater Loadings

In this study, the wastewater loadings were estimated as the mass flow of a given analyte entering the wastewater system, normalized by the number of contributing units. Hence, the loadings accounted for the population fluctuations in the study building. Changes in loadings with FWG implementation would need to be accommodated at the wastewater treatment plant receiving the discharges and the wastewater treatment effects discussed in this section are based on the results of this study's monitoring program which corresponds to a 100% MP of FWGs while residents also have access to green bins. This section addresses the loading impacts observed at the building over the course of the project and connects these loading impacts with expected impacts to a receiving WWTP.

Wastewater loadings were calculated using flow-weighted daily composites normalized by the number of units occupied and average water consumption and thus represent the average daily loadings of analytes measured. Wastewater loadings were assessed for weekend/weekday effects to determine if sub-fractionation of the sample populations would be necessary to determine FWG impacts. Similarly to the concentration evaluation, TSS and VSS were found to have significantly higher weekend loadings when compared to weekdays ($p < 0.01$, $p < 0.01$ respectively). All other analyte loadings were not found to have a significant difference between weekday and weekend samples and thus could be compared between the control and study period populations directly. TSS and VSS were futher evaluated employing the Bonferroni multiple mean comparison test (α' of 0.025) to evaluate TSS and VSS loadings separately between weekday and weekend loadings in the control and study periods. The results of this analysis found that TSS and VSS loadings were higher on weekends when compared to weekdays, and that the implementation of FWGs in this setting did not significantly increase the TSS or VSS loadings.

The average total solids loadings produced by the study building and the associated variability were assessed as FWGs were found to increase the dissolved solids concentrations from the study building (Figure 12). The average TS loading increased by 17.7 g/unit/day (12.3%, $p = 0.01$), and the standard deviation in TS loading also increased by 30 g/unit/day (188%, $p < 0.01$) with FWG implementation. The average TSS loading did however not change indicating that the increase in total solids loading was primarily in the form of dissolved solids (TDS), which increased by 14.6 g/unit/day (15%, $p < 0.01$). The standard deviation of TSS and TDS also increased significantly by 15 g/unit/day (183%, $p < 0.01$) and 18 g/unit/day (154%, $p < 0.01$) respectively. The increase in TSS and TDS variability suggests that WWTPs must account for additional uncertainty regarding TSS removal requirements and TDS treatment capacity. Furthermore, with TDS increasing significantly WWTPs can expect a larger loading of dissolved species such as salts and nutrients, and the characteristics of these dissolved loadings are explored further in this section.

Volatile solids loading represents the organic species in wastewater that impact biological processes and were analyzed due to the expected high volatile solids content of food waste (Figure 12). The VS, VDS and VSS loadings were all found to not increase at a significant level, however, the standard deviations of these loadings all increased at a significant level (28 g/unit/day (204%) $p < 0.01$, 18 g/unit/day (212%) $p < 0.01$, 14 g/unit/day (174%) $p < 0.01$ respectively). The VSS/TSS ratio and VS/TS ratios were not found to change following FWG implementation indicating a similar volatile solids content in FWG impacted wastewater. The large increases in variability may have contributed to the inability to discern any impacts of FWG use on these responses. The increases in variability of loadings suggest that higher factors of safety may be required in the design and operation of biological treatment processes. Furthermore, the increase in volatile solids variability may increase biosolids generation variability and, as such, increased safety factors may also need to be considered for these systems.

Fixed solids loadings were monitored due to their importance for WWTP sludge production and the capacity for FWGs to increase these analytes (Figure 12). FS and FDS were both found to increase significantly (each by 9 g/unit/day, $p < 0.01$) with FSS not increasing significantly. These results are consistent with the previous discussion that found FWGs primarily increased the loadings of dissolved species rather than the originally anticipated suspended solids loading. Only the standard deviation of FDS increased at a significant level (1 g/unit/day (17%), $p < 0.01$), however, this variability increase was small in magnitude. The fixed solid loading results suggest that the increase in TDS previously discussed was primarily FDS instead of VDS, which was not found to increase significantly. Increases in FDS loadings indicate that discharges from WWTPs receiving FWG impacted wastewater may experience larger amounts of dissolved species that may not be removed during standard WWTP treatment operations (Metcalf & Eddy, 2003).

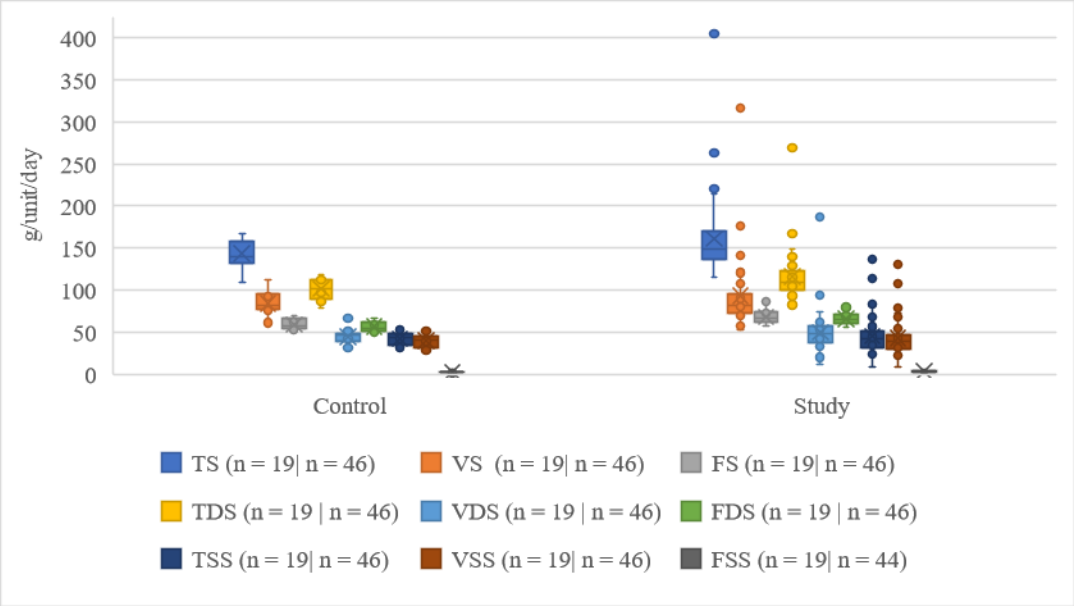

Figure 12. Comparison of Solids (Total, Dissolved and Suspended) Loadings between Control and Study Periods

The biochemical oxygen demand loading of wastewater is a measure of the loading of biodegradable organic matter and was examined to determine whether FWG implementation could substantially impact on factors like oxygen demand and sludge generation in biological treatment processes (Figure 13). BOD_5 and soluble BOD_5 loadings did not increase significantly following FWG implementation in the study. However, the standard deviation of both these loadings did increase (19 g/unit/day (96%) $p < 0.01$, 12 g/unit/day (97%) $p < 0.01$ respectively), showing that FWGs may affect these analytes episodically leading to more wastewater variability. The sBOD/BOD ratio did not change during the study period when compared to the control period, however, the BOD/VS ratio decreased marginally from 0.83 to 0.75. This change suggests that the volatile solids content in FWG impacted wastewater was less BOD_5 dense than non-FWG impacted wastewater. An increase in the variability of BOD_5 loading would translate into an increase in variability in aeration requirements following FWG use, though on average these results do not suggest a significant increase in total aeration requirements. Prior studies indicated that a somewhat high BOD_5 increase should be expected following FWG implementation (Iacovidou, et al., 2012), however, in the current study BOD was minimally affected by the FWGs. The low BOD_5 increase could indicate a low FWG use, or that the materials disposed of in the FWG were less BOD_5 dense in the settings previously reported. The increase in BOD_5 and $sBOD_5$ variability was consistent with the increase in TDS and VDS loading variability previously discussed, indicating that WWTPs receiving FWG impacted wastewater may need to address increased variability in aeration requirements, sludge production, and disposal.

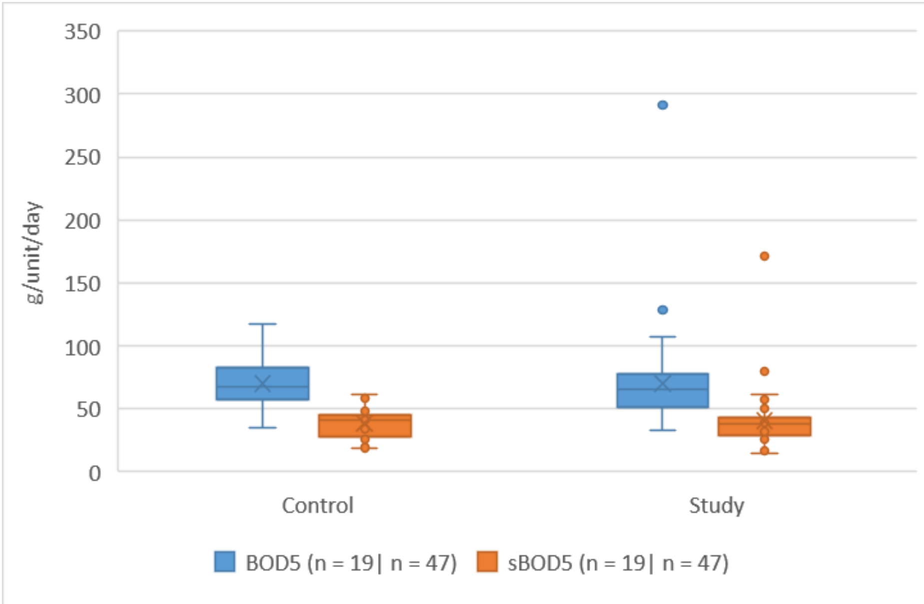

Figure 13. Comparison of BOD_5 and $sBOD_5$ Loadings between Control and Study Periods

Food waste can be expected to contain nitrogenous components, and due to nitrogen's importance in wastewater treatment due to its high oxygen demand, the loading of nitrogen-containing nutrients was examined (Figure 14). Nitrogen species loadings did not change significantly following FWG implementation, however, the standard deviation of TKN loadings was found to increase (2 g/unit/day (56%) $p = 0.02$). Nitrate and nitrite loadings remained at non-detectable levels in almost all samples, indicating no addition in these analytes following FWG use. The NH_4/TKN ratio did not change at a significant level following FWG implementation and was between 0.60 and 0.64. The consistent loading in both phases suggests that the FWGs have a relatively low impact on nitrogen species in wastewater, which was consistent with prior studies that found low-negligible increases following FWG implementation (Iacovidou, et al., 2012). The consistent nitrogen loadings suggest that proteinaceous materials were not being disposed of in the FWG and suggests that disposal of carbohydrates and lipids from fruits and vegetables may have been dominant. The increase in variability of nitrogen species would correspond to an increase in variable aeration requirements for nitrification. Overall, FWG implementation did not increase the loading of nitrogen-containing nutrients, however, occasional spikes in these loadings may need to be addressed in WWTP operation.

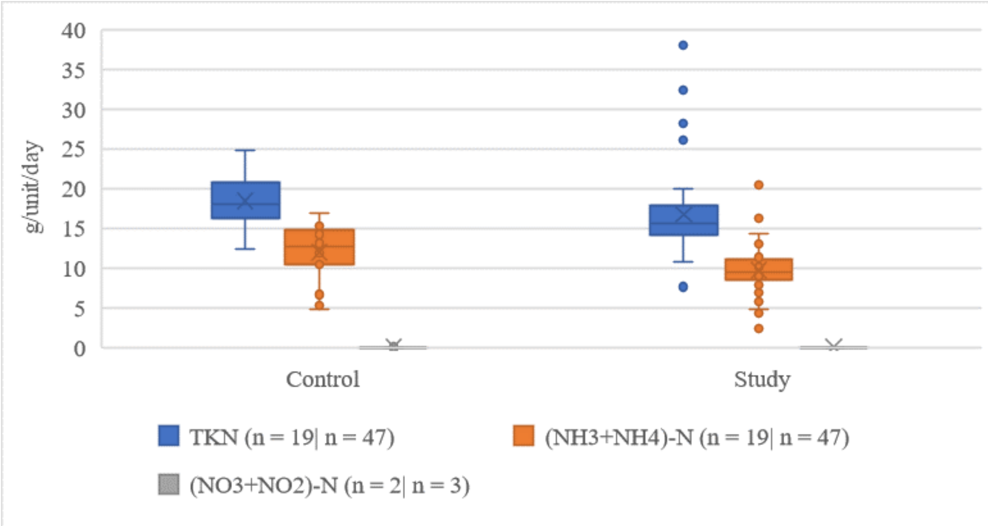

Figure 14. Comparison of Nitrogen Analyte Loadings between Control and Study Period

Phosphorous components were also of interest as wastewater treatment typically needs to achieve very high removals of this element (Figure 15). Both total phosphorous and orthophosphate loadings were found to not increase significantly with FWG implementation. The standard deviation of total phosphorous did however increase (0.1 g/unit/day (64%), $p = 0.01$), which was consistent with other analytes. The PO_4/TP ratio did not change following FWG implementation, indicating that changes to PO_4 or TP occurred in similar characteristics to the original characterization of wastewater. Phosphorous can be found in dairy, meat, and grains which suggests that residents were not primarily using the FWGs for these foods or at least not in large amounts. Fruits and vegetables are often low in phosphorous content, which was consistent with the findings with respect to nitrogen loadings (Götze, et al., 2016). With no increase in phosphorous loading and a minor increase in variability, the results suggest that WWTPs would not need to change operations in this regard.

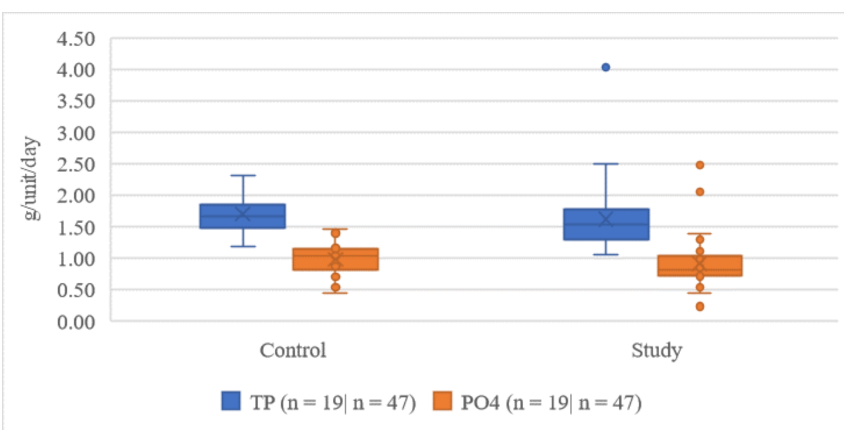

Figure 15. Comparison of Phosphorus Analytes between Control and Study Periods

The presence of FOG in wastewater is of interest as it can present challenges to wastewater conveyance such as blockages and pipe restrictions (Mattsson, 2015). Loadings of total FOG, animal/vegetable FOG, and mineral FOG were examined in this regard. There were negligible concentrations of mineral FOG measured at the study building effluent, and thus only animal/vegetable FOG was found to contribute to the total FOG observed during sampling. FOG loading was found to increase on average by 3.5 g/unit/day (45.1 %, $p = 0.01$) representing close to a doubling in the average FOG loading. The FOG variability also increased significantly by 2 g/unit/day (50%, $p = 0.03$). These results suggest that oils and grease were being disposed of in the FWG despite instructions that were provided to the residents and not disposed of at the same consistency as pre-FWG implementation. While dependant on local sewer conditions, these results suggest that FWG impacted wastewater may contribute to challenges associated with the presence of FOG in wastewaters.

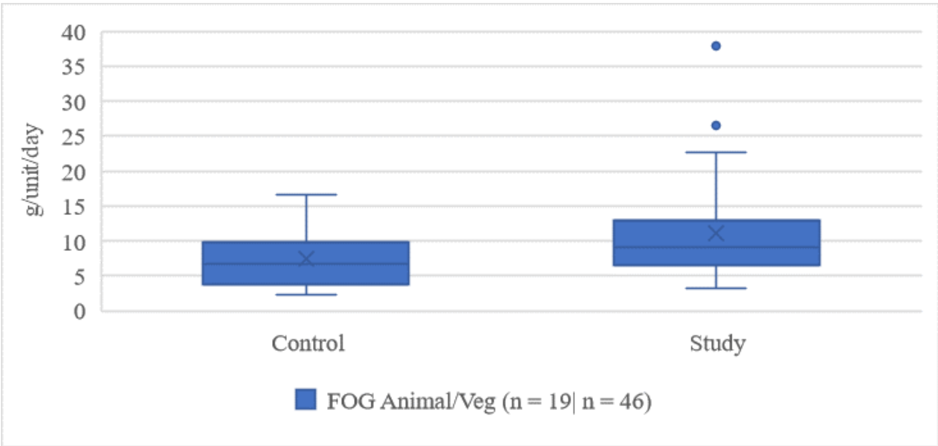

Figure 16. Comparison of FOG Loading between Control and Study Periods

As discussed, many parameters were observed to have significant increases in variability ($p < 0.05$) without significant increases in average loadings. Central limit theorem would suggest that random discharges of food waste to wastewater from FWGs will tend to offset each other when considering average loading. Therefore, a WWTP receiving wastewater that is impacted by many individual discharges of food waste may not necessarily experience the same increase in wastewater variability unless the patterns of discharges were similar amongst dischargers. The patterns of use of a population of FWGs will likely be linked to aspects of food waste generation (seasonality of generation, mutual cultural celebrations producing food waste, weekend effects), and hence may be related in time and therefore could collectively contribute to increased variability in loadings to a receiving WWTP. In this latter scenario, higher factors of safety may be needed in WWTP design to accommodate the increased variability in loadings associated with widespread adoption of FWGs.

4.2.3 Solid Waste Audit Results

A primary motivation for FWG implementation in MURBs is the diversion of organic waste from solid waste streams and ideally from mixed waste streams where organic waste would be disposed of in landfills. Three solid waste disposal streams, blue bins, mixed waste, and green bins were characterized in this study. The control portion of the study characterized solid waste disposition in the MURB when these were the only options while the study period added the option of disposing of food waste to the sewer via the FWGs. Hence, the study design facilitated an assessment of the impact of a 100% MP FWG implementation in a 32-unit MURB that also had access to green bins. To account for minor fluctuations in the number of occupied units throughout the study and differences in collection periods between streams, results were normalized based on the number of occupied units in the building.

The total mass of each stream audited before normalization is displayed in Figure 17. The total mass audited was relatively variable between 150 and 240 kg of waste audited. Due to the manageable total mass of waste generated in the study building, 100% of waste collected during waste audits was audited with no sub-sampling of waste. These results indicate that the building's total generated waste was variable throughout the study and that normalization of data is required to make conclusions.

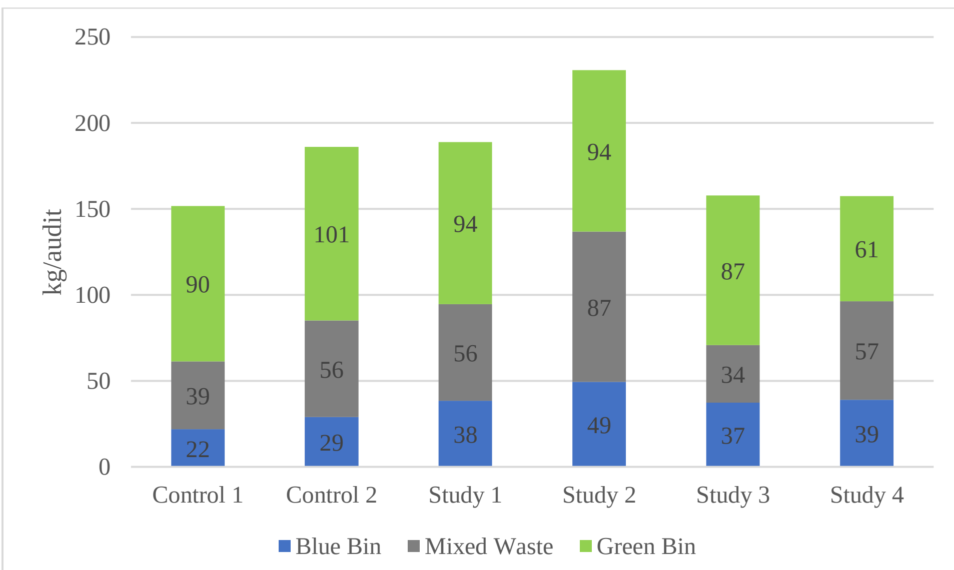

Figure 17. Total Mass of Waste Generated in Each Solid Waste Stream (Wet Weight)

The mass of streams was reviewed against time to infer if any time series or seasonal effects were observable in the data (Figure 18). The results show that there is no consistent time series effect visible within the data, as all streams appear to randomly fluctuate independent of time of year when plotted against time. With no time-series effects observed in the waste audit data, it was determined that a statistical comparison between the control period and study period would adequately evaluate the differences between the two periods.

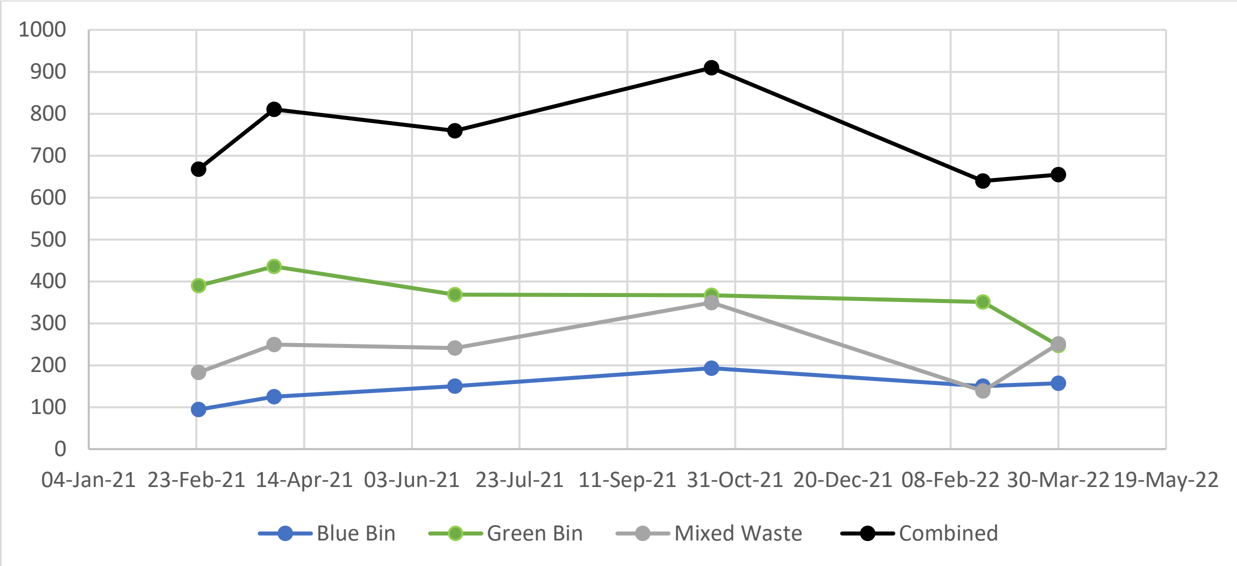

Figure 18. Time Series of Normalized Solid Waste Generation by Stream

Given the narrow demographics of the study building, the total generation of each stream of waste was benchmarked against other waste audit results at the respective study building municipality to ensure waste generation was not significantly abnormal from municipal averages (personal communication with municipal staff, Sept. 23, 2021) (Figure 19). The total waste generation rate for the building was determined to be on the lower range of waste generation rates when compared to regional data for MURBs with green bins. The mixed waste and blue bin waste generation were both lower than regional averages, which could be a product of the building's demographics generally being low-middle income as reported by the building manager which is known to lower solid waste generation rates (Kannangara, et al., 2018). Additionally, the study building unit density was identified to be lower than the average MURB unit in the region, which also could explain this lower mixed waste generation. The green bin solid waste generation was considerably higher in the study building than compared to that of regional MURBs with green bins, indicating that the residents of the study building actively used their green bins at a higher level on average. The study building generated solid waste at the low range of expected generation rates in total, however, green bin use was at the high end of expected generation. From this comparison, it was concluded that this study building is representative of waste generation in the region and there is no evidence that the trends observed at this study building would not be valid for others in the same municipality.

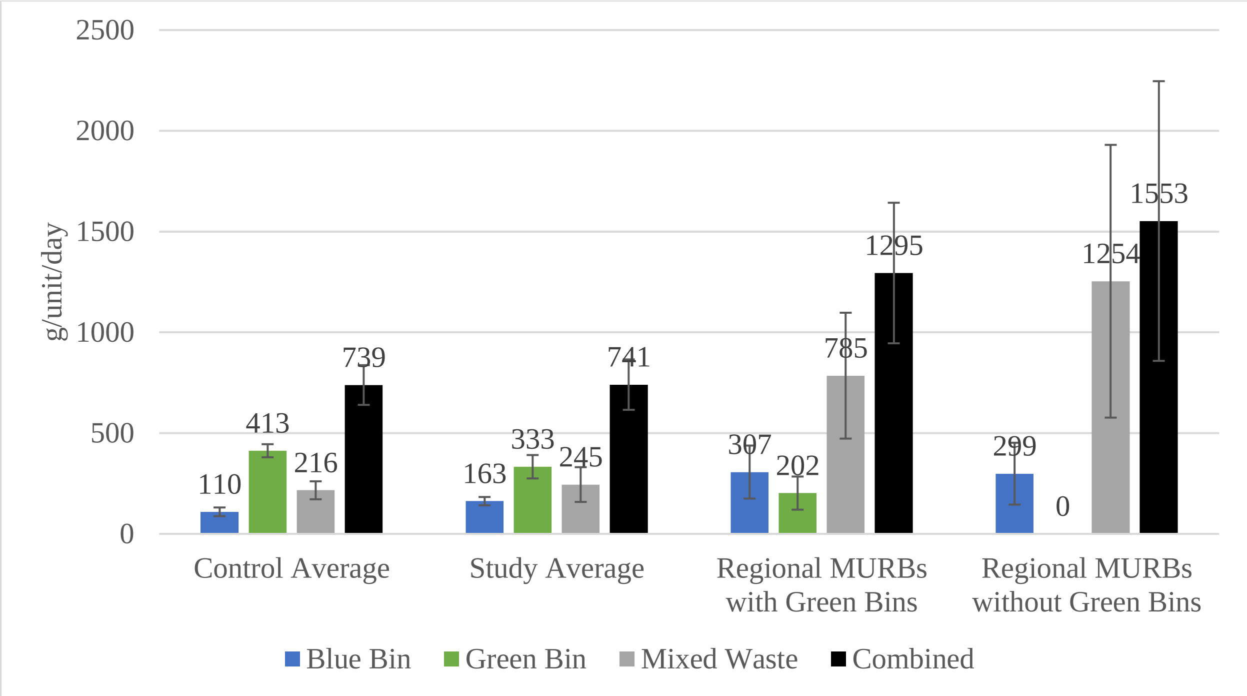

Figure 19. Study Building Bulk Waste Generation Benchmarked to Regional Data

Statistical comparisons were conducted to compare generation of all individual audited categories and several non-target categories such as paper packaging in the blue bin stream and plastics were found to change at significant but small levels. These results were excluded from the discussion as these waste categories were not considered relevant to FWG disposal. Two individual categories were found to decrease at a significant level: "unavoidable food waste" in the green bin stream (75 g/unit/day, 32%, $p = 0.04$) and "avoidable food waste – meat and fish" in the mixed waste stream (2 g/unit/day, 91%, $p = 0.03$). These individual categorical changes show that at a component level, FWGs influenced solid waste generation within the study building.

Total waste generation in the individual and combined streams was compared between the two periods (Figure 11) to infer the impact that FWGs have on bulk waste generation. Despite larger variability observed in the study period, only the green bin stream showed a statistically significant reduction in generation throughout the study of 79 g/unit/day ($p = 0.09$) (Figure 20). Both blue bin and mixed waste generation remained unchanged between the control and study period. Despite the reduction in green bin waste generation, total waste generation (including non-organic wastes) did not change at a significant level. The variability observed in the combined waste stream was such that the lesser generation of green bin waste did not have a significant effect on combined waste generation. In summary, when provided with FWGs, only the green bin solid waste generation decreased at a significant level.

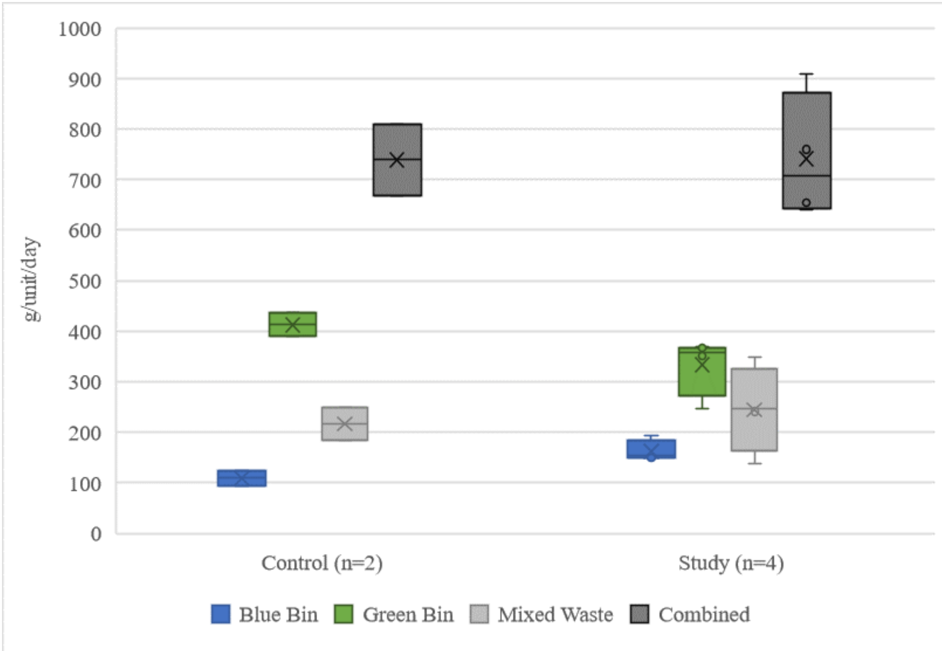

Figure 20. Total Waste Generation by Stream

FWGs are expected to impact the generation of organic waste in solid waste streams and thus this fraction was specifically focused on (Figure 21). Organic waste in this context includes food waste and non-food organic wastes such as used potting soil, pet waste and used paper products. Organic waste generation in the combined, blue bin, and mixed waste streams did not decrease at a significant level between the study periods while green bin organic waste generation decreased by 71 g/unit/day ($p = 0.09$) or by 19%. These results show that the previously described reduction in green bin generation could be attributed to a reduction in organic waste, which was anticipated as contamination levels in the green bin stream remained low throughout the study. Hence, while the amount of organics disposed of in the combined solid waste stream could not be differentiated between the two study periods the results suggest that FWGs were being employed to divert organic waste from the green bin stream.

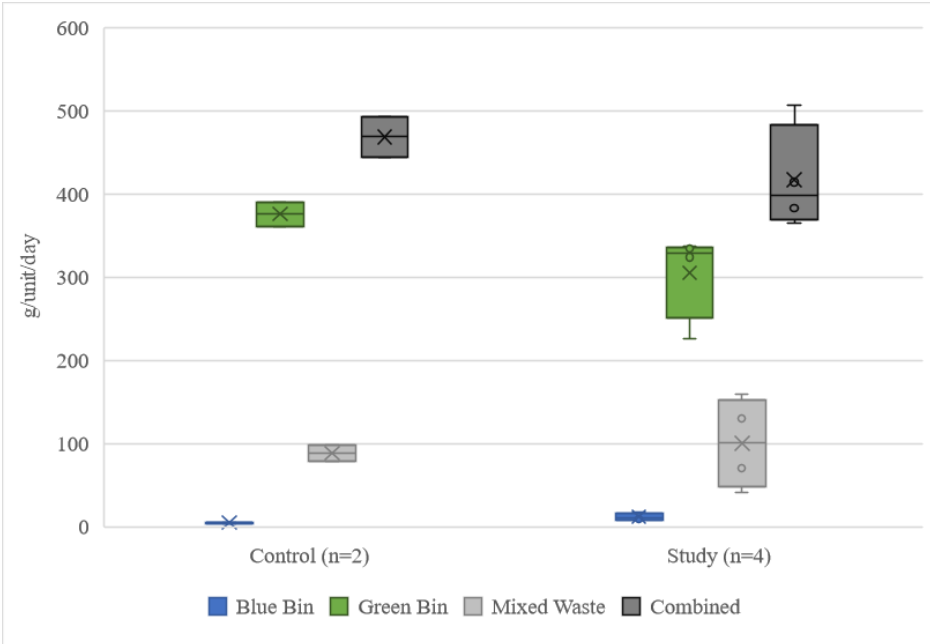

Figure 21. Organic Waste Generation by Stream

Food waste generation is a specific target of FWGs and contributed 78% of organic waste disposed of at the study building throughout the project. Food waste disposition in the blue bin stream was generally negligible, and food waste was predominantly generated in the green bin stream (Figure 22). Food waste generation in the green bin stream decreased by 69 g/unit/day (23%, $p = 0.03$), but did not statistically change in the combined and mixed waste streams. These results suggest that FWGs were primarily used for food waste, which was expected given the educational material they received during the study. Additionally, the food waste that was diverted with the FWGs appeared to be sourced from materials that had been directed to the green bin stream before FWG access. FWG implementation did not appear to impact food waste disposition to the mixed waste stream. These results indicate that fugitive food wastes (disposed of in the blue bin and mixed waste) were not considered for disposition to either the green bin or the FWG. These results suggest that educational materials should be further developed to target food waste that is being disposed of in the mixed waste stream instead of just targeting food waste generally.

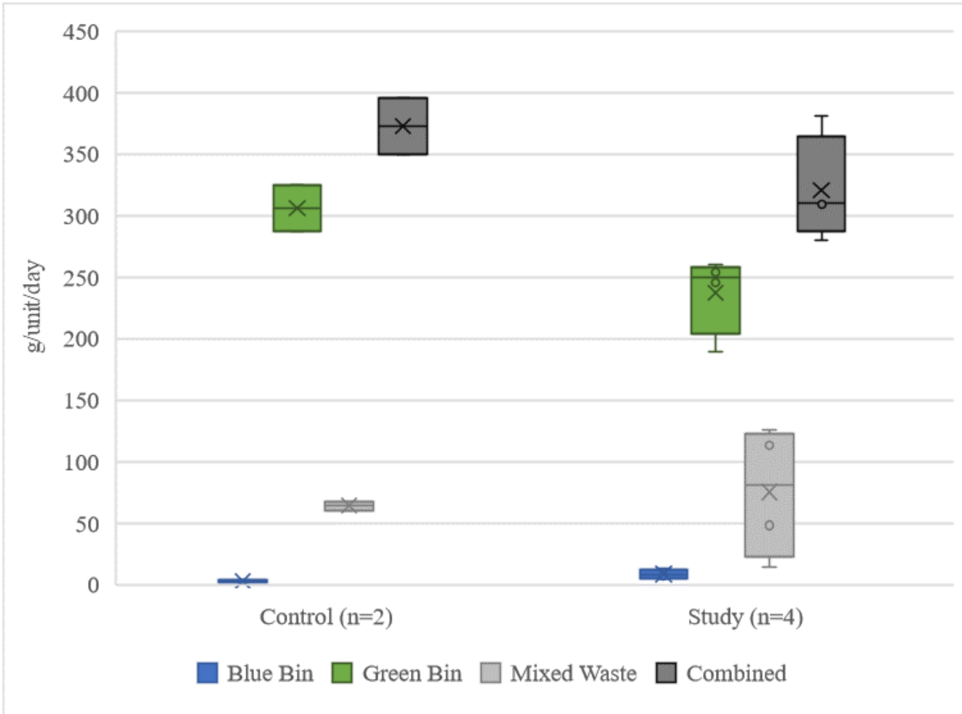

Figure 22. Food Waste Generation by Stream

Two categories of food waste, unavoidable and avoidable, were measured throughout the study to gain a deeper understanding of the food waste being disposed of via FWG. Unavoidable food waste is food that was not expected to be eaten and was generated due to the processing of food; examples of unavoidable food waste include onion peels, banana peels, and bones. Avoidable food waste is food waste that could have been eaten or used but was not and was disposed of; examples of avoidable food waste include bread, banana flesh, and pasta. On average, 64% of the food waste generated in the solid waste streams was unavoidable food waste. Avoidable food waste (Figure 23) was not found to change at a significant level in any of the streams assessed. Unavoidable food waste (Figure 24) decreased in the green bin stream by 75 g/unit/day (32%, $p = 0.02$) after FWG implementation. Approximately 85% of all unavoidable food waste was disposed of in the green bin stream prior to FWG access, and it follows that the total unavoidable food waste generated in solid waste streams decreased by 69 g/unit/day (26%, $p = 0.03$). These results suggest that residents were primarily using their FWGs for unavoidable food waste that was being disposed of in the green bin stream before FWG implementation.

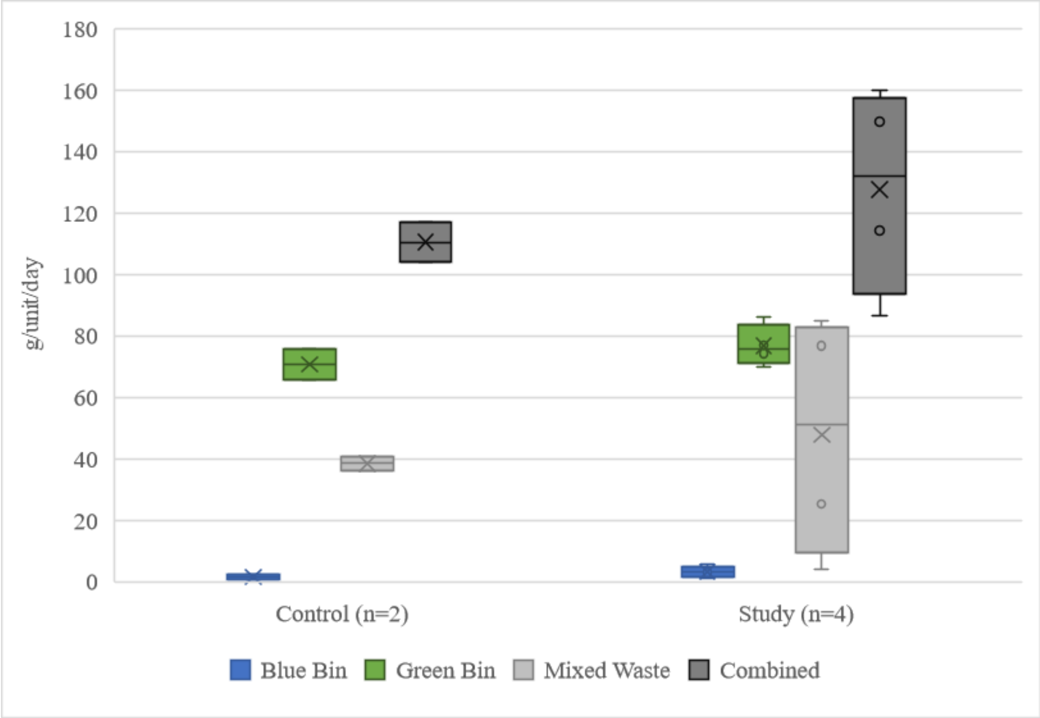

Figure 23. Avoidable Food Waste Generation by Stream

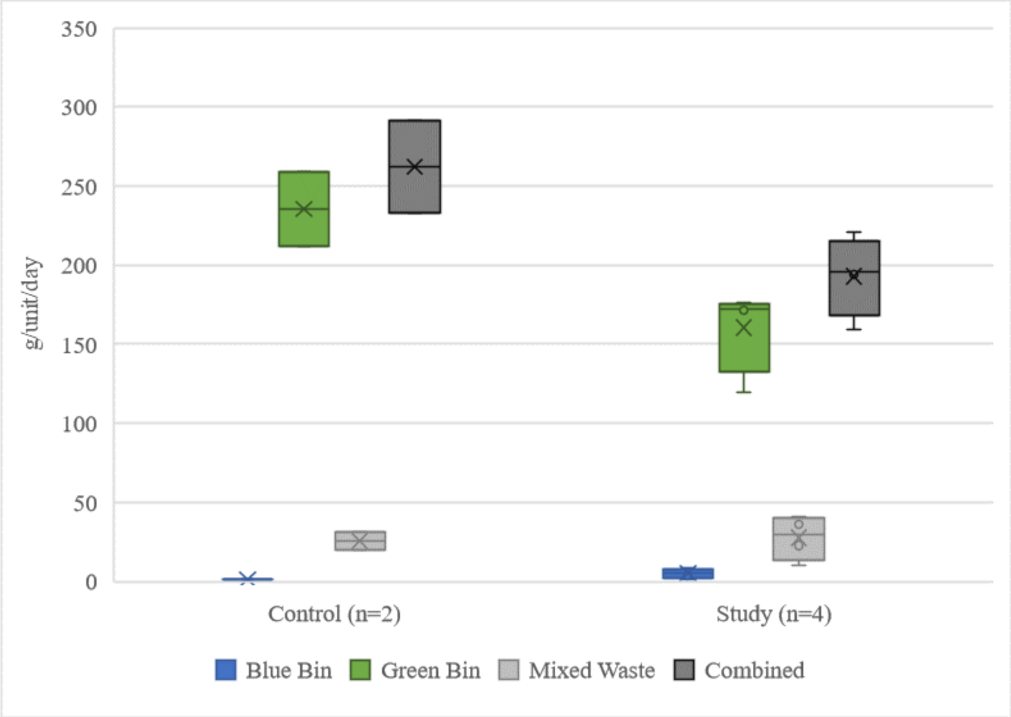

Figure 24. Unavoidable Food Waste Generation by Stream

Non-food waste organics and non-organic waste were also analyzed in this study to infer any possible effects of FWG implementation on these non-target waste streams; visualizations of this data are included in Appendix G. There were no significant changes identified in any of the streams for non-food waste organics and non-organic waste, indicating residents were not using FWGs for non-organic or non-food waste items, which is consistent with the educational materials provided. The results indicate that the provided educational materials (Appendix D) were successful in describing the target wastes for FWG disposal and that residents were receptive to these educational materials.

4.2.4 Volatile Solids Mass Balance Analysis Results

Volatile solids content was analyzed in both the long-term wastewater monitoring program and solid waste audits to gain insight into the quality of data collected through these activities and additionally determine if FWGs impacted volatile solids generation in any specific stream of waste disposal. During each waste audit, the volatile solids content of each organic waste fraction that was separated from each stream was measured. Rates of volatile solids generation in each waste stream were then calculated and compared to the volatile solids loading observed in the wastewater stream for the corresponding period (Figure 25). It was found that the total generation of volatile solids (the summation of blue bin, green bin, mixed waste and wastewater volatile solids) was similar in the control and study periods, with an average total volatile solids generation of 196 +/- 3 g VS/unit/day and 197 +/- 29 g VS/unit/day in the control and study periods respectively. The results demonstrate that total volatile solids generation within the building was not affected by the introduction of FWGs, and thus any observed changes in disposition was attributed to the use of the FWGs.

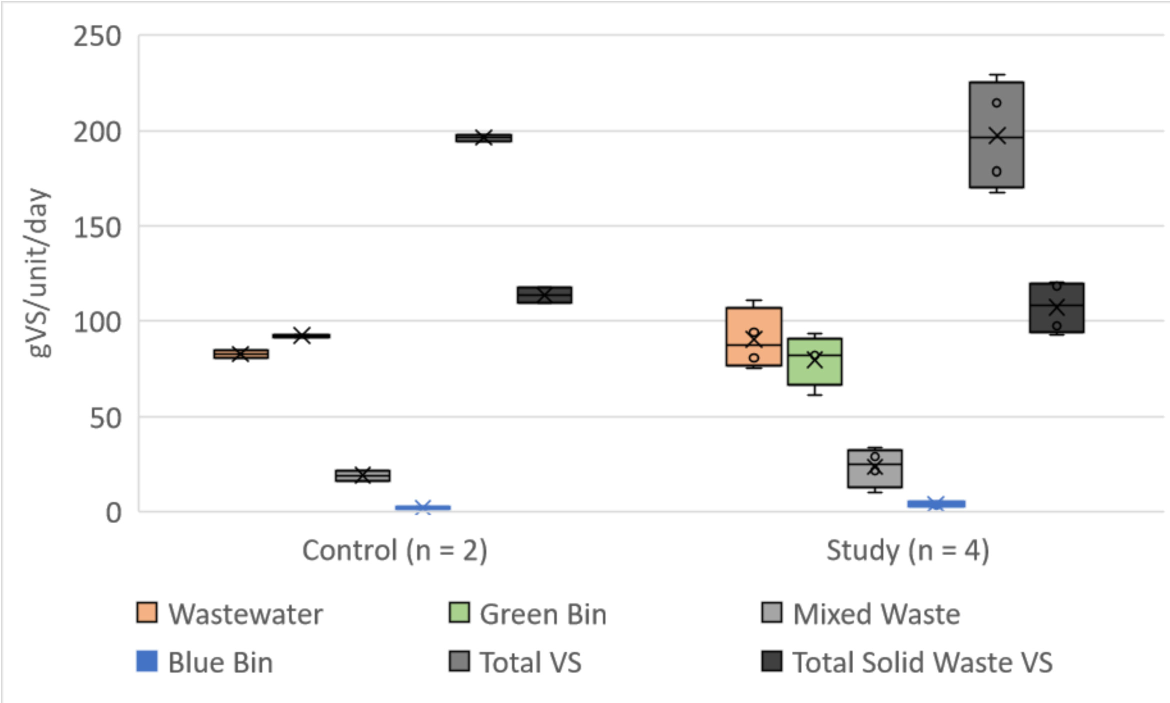

Figure 25. Volatile Solids Generation by Disposal Pathway

The fractionation of volatile solids generation between wastewater and solid waste streams was assessed as it was hypothesized that FWG may influence this fractionation (Figure 25). No statistically significant differences in the average fractionation values or associated variability were observed after activation of the FWGs. Considering the high level of variability observed in the solid waste audits and wastewater characterization; it is possible that the significant changes identified in the more granular responses were masked by the underlying and natural variability in bulk categorical analysis such as volatile solids generation. Furthermore, the number of comparison points in this assessment was limited by the low number of solid waste audit samples, which provided additional challenges in determining statistically significant results. The results suggest that a high level of wastewater characterization and solid waste separation is needed to identify the impacts of FWG utilizations.

4.3 Survey Results

Two surveys were conducted in the study to gain an understanding of the attitudes toward green bins and FWGs, as well as an understanding of residents' perceptions of their waste disposal which can be compared to the results of the technical sampling plan. This section discusses the level of response from the study building for each survey, differences in perceived waste disposal frequency, seasonality, and disposal method, and finally attitudes and use patterns of green bins and FWGs. This section focuses primarily on the comparison between the control period and study period surveys, with detailed individual survey results presented in Appendix H.

The number of respondents in each survey is an important qualifier for comparing the attitudes and waste disposal perceptions of the building's residents. In the control survey, out of 29 occupied units, 19 of them responded to the survey or 66% of occupied units. All control survey respondents completed the paper survey, and as such the online survey option was excluded from the study period survey. During the control period, 18 responses were collected out of 31 occupied units (58% response rate), with 17 paper surveys collected and 1 survey conducted over the phone. These participation rates were deemed acceptable to determine the experiences of the majority of residents within the study building. With similar response rates and similar methods of survey completion, it was assumed that the comparison between the control and study period surveys was not influenced by the response rates, methods of survey reply or survey method.

4.3.1 Perceived Waste Generation Comparison

The perceived frequency of disposal of food waste, used paper products and other organic wastes was queried to gain an understanding of the patterns of generation of these waste components. Food waste, the largest fraction of the organic waste categories queried, was reported to be generated at a similar frequency in the control and study periods (Figure 26). Most residents reported disposing of food waste between once per day and three times per week, indicating that respondents generated food waste often and at consistently throughout the study. These results imply that the implementation of FWGs in the study building did not alter the respondents' perceived frequency of FW generation.

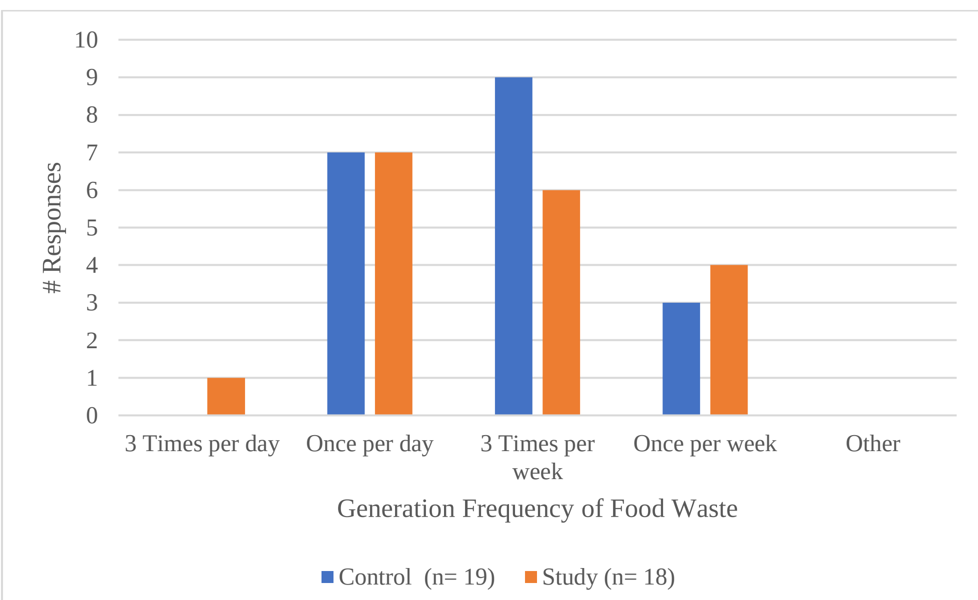

Figure 26. Perceived Food Waste Generation

The frequencies of generation of used paper products and other organic wastes were queried to evaluate whether changes in the generation of wastes that are often co-handled with FW might have influenced the FW generation response. The perceived generation of used paper products increased marginally, with more respondents reporting generating used paper products three times per week in the study periods as compared to once per week reported in the control period. There were no substantial changes in the perceived generation of other organic wastes, with approximately half of the respondents reporting they do not generate them. As the respondents have indicated only modest changes in wastes co-handled with FW, there is no evidence that these categories of organic waste influence the respondents' perception of their FW generation.

The seasonality of the perceived generation of food waste, used paper products, and other organics was queried in both surveys to better understand the residents' perception of their waste generation and gain insight into possible trends in the technical sampling results. In general, most respondents indicated that their waste generation was not seasonal, however, five and two respondents in the control and study survey respectively indicated a seasonal effect and reported that their fruits and vegetable waste increases in the spring and summer due to increased fresh produce consumption. Both used paper products and other organics were reported to not be seasonally affected in both the control and study period surveys. Due to the low reports of perceived seasonality regarding organic waste generation within the building, it was not anticipated that the season of assessment would have an impact on the interpretation of the results of the technical sampling plan.

4.3.2 Perceived Green Bin and FWG Use Patterns and Characteristics

Residents were polled regarding aspects of their FWG education and experience with the FWG devices to ensure that the responses to FWG-related questions came from residents who were educated in using FWGs, felt comfortable using them, and were not experiencing constant external issues related to the device's installation. Specifically, residents were asked if they had received instructions for using the FWGs, if they were comfortable using the FWGs and if in general, they had experienced any issues with the FWGs. A total of 16 out of 17 respondents to these questions reported that they had received instructions of use and were comfortable using the FWG devices, and there were three reports of residents experiencing problems with the devices. Of these reported issues, all were related to the devices shaking during operation and water leaks during the first months of installation, which were reported to be resolved by the building manager early in the study period. It was concluded that the responses to subsequent questions that addressed FWG use were reported by respondents who had received adequate education on the use of the devices and were comfortable using them, and in general, were not experiencing consistent problems with the devices.

The disposal method for food waste was an important aspect of this project and hence the perceived use of FWGs and GBs was queried (Figure 27). Green bins were reported as the preferred method of food waste disposal in the control period survey, with 18 out of 19 respondents stating that they would use the green bin for food waste. After FWG implementation, three respondents indicated they would usually dispose of food waste in the green bin, with seven respondents stating they would usually use the FWG devices, and another six respondents reported using both the green bin and FWG equally. These responses indicate that residents were aware that FWGs is a disposal method for food waste and many respondents use the FWG devices either as a preferred method of food waste disposal or in conjunction with the green bins. Only one respondent reported disposing of food waste in the garbage which was reported in both the control and study periods. Overall, it was concluded that respondents tended to use both green bins and FWGs for food waste disposal.

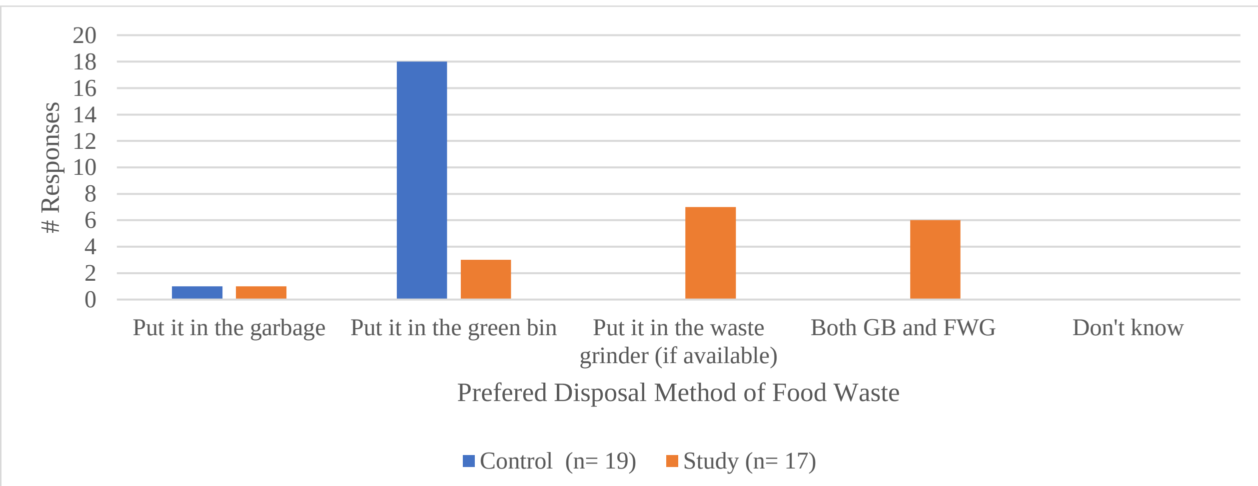

Figure 27. Perceived Food Waste Disposal Methods

The disposal method employed for used paper products and other organic wastes was queried to determine if residents were using either the FWGs or green bins for non-food waste organic categories. Most respondents reported disposing of used paper products in the garbage and green bin in both periods, with one response reporting using the FWG during the study period. Identical results were reported for other organic waste categories, suggesting that residents almost exclusively used the FWGs for food waste and did not dispose of used paper products or other organics (such as pet waste and potting soil) in the FWG devices. All educational materials provided to residents were focused on food waste being disposed of in the FWGs (Appendix D), and furthermore, the name of the devices implies they are intended for food waste disposal. In this regard, it appears the educational materials were successful in identifying to residents the proper use of FWGs. Further, when interpreting the results of the wastewater and solid waste characterization studies, it was anticipated that non-FW materials would not be diverted to wastewater.

Barriers to green bin use were queried to assess whether there were any factors that might have reduced the use of the green bin in the study. During the control period, only three complaints were reported for the green bin, with one complaint of difficulty carrying the green bin to the buildings collection point and two complaints of odours from the green bin. In the study period, seven complaints about the green bins were reported, with two reports of difficulty carrying the green bin to the collection point and five reports of odours from the green bin devices. FWGs are intended to solve both the complaints reported for green bins, as FWGs do not require carrying waste to a specific location in the building other than one's sink and also do not store food waste within the unit, ideally reducing the capacity for foul odours. The increase in complaints about green bins after FWG implementation could be evidence that the respondents were made more aware of their grievances with green bins which, assuming proper use, are not known complaints associated with FWGs.

The frequency of residents emptying their green bins was queried to determine whether access to FWGs affected the number of times resident took their countertop green bin to the building's general collection point (Figure 28). With more responses reporting a green bin emptying frequency of two to three times per week, it was concluded that respondents reported a minor increase in emptying frequency. Given that the solid waste audit data suggests that less waste was generated in the green bin following FWG implementation, it is remarkable that the perceived green bin emptying frequency increased during this same period. This continued green bin emptying frequency could be indicative of emptying the green bin due to temporal reasons such as the generation of odours instead of the bin being full.

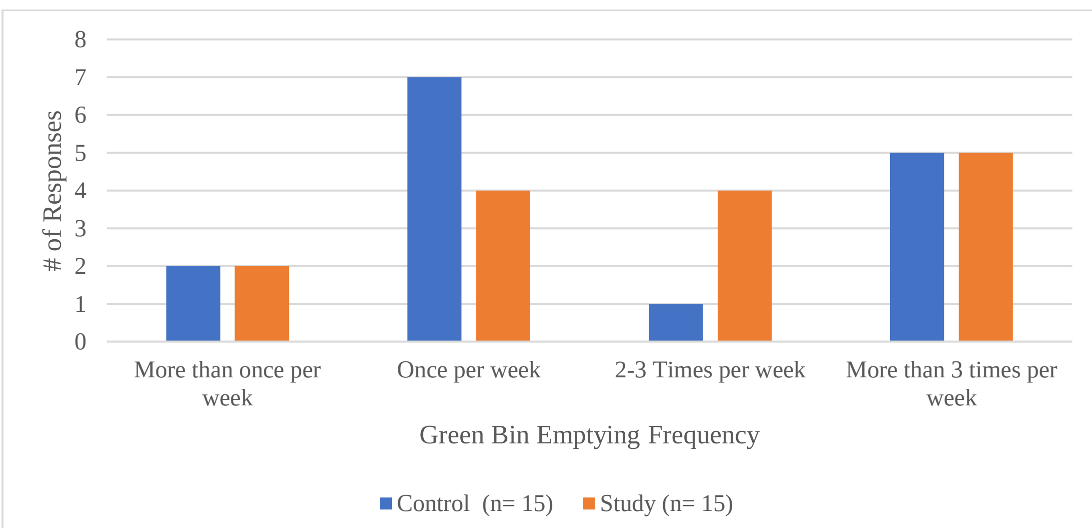

Figure 28. Perceived Green Bin Emptying Frequency

The frequency of FWG use was questioned in the study period survey to compare with the perceived frequency of food waste generation (Figure 29). The reported frequency of FWG use was comparable to the reported generation frequency of food waste, as can be seen in Figure 29. Most respondents reported using their FWG between three times per day and once per day, with some reporting only using the devices three times per week. These responses also indicate that residents do not perceive their food waste generation as equal to their FWG use, indicating that food waste may be generated at a higher frequency than reported. It would also follow that resident use their FWGs often during this food waste generation, with most respondents using their FWGs at least once per day.

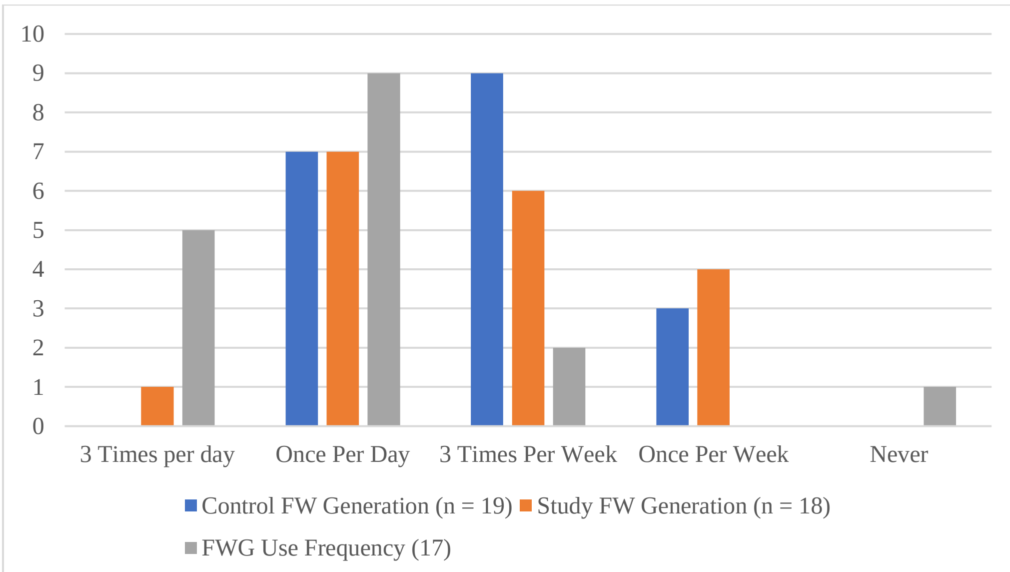

Figure 29. Reported FWG Use Frequency Compared with Control and Study Period Food Waste Generation Frequency

The study period survey asked residents what type of food waste they commonly dispose of in the FWGs to determine the success of educational materials and gain insights that would assist with the interpretation of the solid waste and wastewater characterization (Figure 30). More than ten respondents reported disposing of fruit, vegetables, and plate scrapings primarily in the FWGs, with eight respondents reporting also using the FWGs for meat. Three respondents reported disposing of FOG and dairy products in the FWGs, which are both non-FWG eligible categories as indicated in the educational materials provided to the residents. From these responses, it was concluded that the majority of survey responding units dispose of FWG eligible contents, especially fruit and vegetables. Plate scrapings are a marketed FWG convenience, and these results show that residents perceive their disposal of this category via FWGs. In general, the educational materials provided to residents were successful in conveying that fruits, vegetables, meat, and plate scrapings are FWG eligible. Educational materials to residents could be improved by specifically emphasizing that FOG containing FW and dairy products should not be disposed of in FWGs.

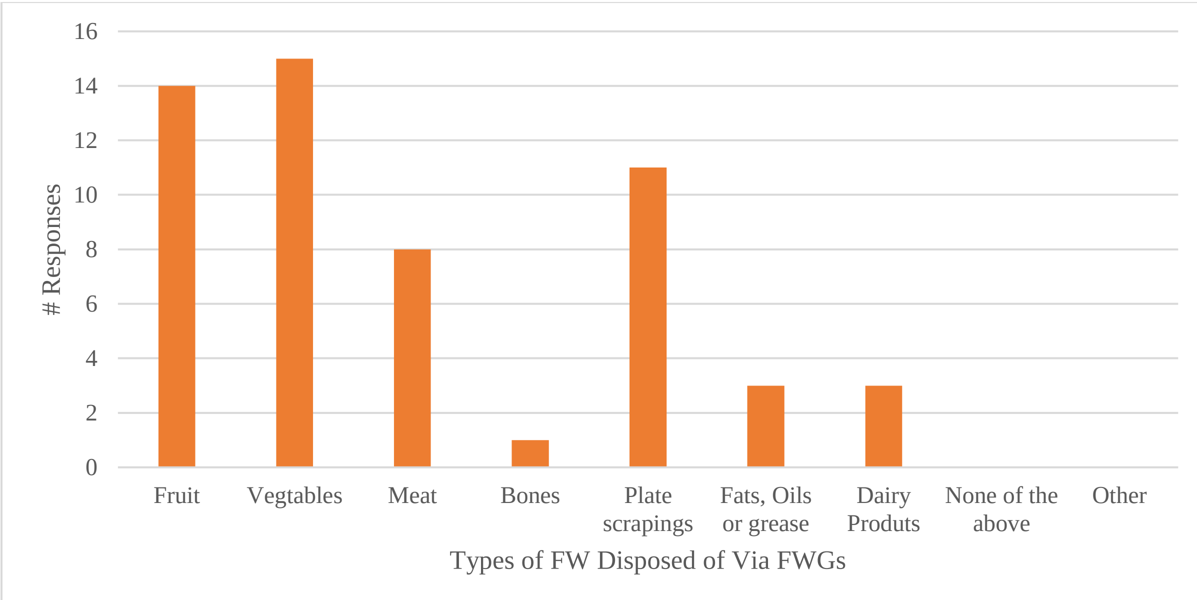

Figure 30. Reported Categories of FW Disposed of Via FWG in Study Period Survey

The study period survey polled residents on the factors that influence their decision to use, or not use, FWG devices in a MURB setting that also provided access to green bins (Figure 31). The most commonly reported factor was the increased convenience of the FWG relative to the green bin, with eight out of 18 respondents stating this influenced their decision to use the FWG. Four individuals stated that the green bin replaced the need for the FWG, which when compared to the number of reports of the FWG being more convenient, suggests that different residents have different preferences and FW disposal methods were not consistent in all units of the building. The study building housed residents >65 years of age, and these responses could be indicative of different levels of mobility and levels of difficulty using green bins or FWGs. In a MURB setting, especially with variable levels of mobility of residents, a single method of FW disposal may not benefit all residents equally, and increased levels of convenience when disposing of FW may be experienced if residents are provided with multiple means of FW disposal that do not include the mixed waste stream.

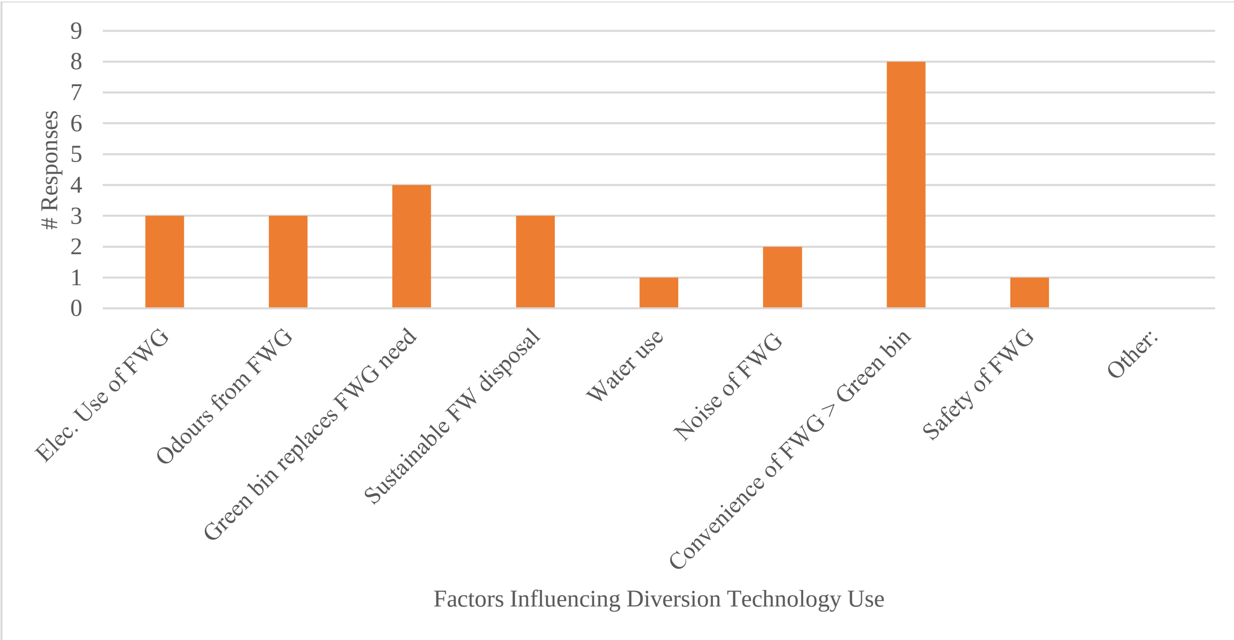

Figure 31. Reported Factors of Influence Regarding FWG Use

The residents were also questioned as to whether there were other factors that acted as barriers or motivators to FWG use (Figure 31). Three respondents reported that perceived electricity use, odours from the FWG, and sustainability were all factors when considering using the FWG. Two respondents reported noise influencing their use, and one report of water use and safety concerns of FWGs was reported. Electricity use reported in the literature from FWGs is very low when compared to other household appliances (Iacovidou, et al., 2012), and this study has found no FWG influence on potable water consumption. Overall the results indicated that these factors had modest influence on FWG use, however, future educational materials for FWGs and green bins may be enhanced by including more information regarding these factors.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

A holistic and comprehensive pilot study was conducted at a multi-unit residential building in southern Ontario with the objective of determining the impacts of food waste grinders on waste generation in this setting. The FWGs were provided to 100% of the 44-54 residents that occupied the study building's 32 units, which provided residents with two means of food waste diversion including the existing green bins available at the study building. Baseline conditions were monitored for four months to characterize pre-FWG conditions in a control period, after which FWGs were provided, and all relevant streams were monitored for an additional 11 months in a study period.

A variety of methodologies were employed to determine the impact of providing FWGs to the study building. Potable water consumption was monitored throughout the study and measured at a five-minute resolution to identify the impact that FWGs may have on this metric, as this affects potable water delivery and is also indicative of wastewater volumes. Variability assessments were conducted for wastewater quality parameters in both the control and study period to develop the long-term wastewater monitoring program. The long-term wastewater monitoring program was conducted employing monthly sampling events which each employed flow-weighted daily composites. These composites characterized common wastewater analytes such as dissolved and suspended solids, nitrogen and phosphorous nutrients, biochemical oxygen demands and for the presence of fat, oil and grease. In addition to these wastewater quality parameters, the wastewater was tested for particles that could be retained on a quarter inch sieve to identify the level of particles that may negatively influence wastewater conveyance. Six solid waste audits were conducted throughout the study to determine the impacts FWG use had on organic waste diversion and the presence of organic waste in the mixed waste stream. The user's perspective and experience of using the devices was assessed through two surveys. Employing the described methodologies, data was collected for a period of approximately 15 months between January 2021 and March 2022.

Potable water consumption was monitored throughout the study and additionally polled during survey 2 to address concerns regarding the possibility for FWGs to impact potable water consumption. It was found that there was no significant difference in the average potable water consumption between the control and study periods, implying that the water used for FWG use was small enough to be masked by the natural variability of potable water usage. In survey 2, approximately three of 18 respondents stated that water usage was a factor of influence regarding their use of the FWG devices, indicating that in general, the respondents do not consider the potable water usage from the devices large enough to influence their decision to use the devices or not. Paired with the observation that potable water demand didn't increase, it would follow that a municipality implementing FWG devices in MURBs would not need to address potable water concerns in educational materials related to the FWG implementation and that the impact to potable water consumption due to FWGs is negligible.

As FWGs add ground food waste to the wastewater stream, it was hypothesized that the devices may cause sewer-use bylaw exceedances and impact the conveyance of wastewater. Throughout the wastewater monitoring program, no particles were retained on a quarter inch sieve in both the control and study periods. Furthermore, wastewater concentration analysis found that TSS concentrations were below the specified MAC in the respective sewer-use bylaw of the municipality (350 mg/L), and suspended solid concentrations were not found to increase at a significant level. FWGs were found to increase the amount of fixed dissolved solids, which are not expected to cause issues within sewer systems. Other MACs defined in the sewer-use bylaw were also not exceeded in either period, implying that on average, the introduction of FWGs did not cause MAC exceedances. FOG concentrations were found to increase at a significant level, however, the concentrations of FOG in both periods were more than 100 mg/L below the MAC for FOG of 150 mg/L, though it must be noted that the FOG content characterized in this study was lower than typically expected for municipal wastewater. The results suggest that sewer systems receiving FWG impacted wastewater will not experience conveyance hindrance from particulates but could be negatively impacted by increased FOG content depending on the pre-existing conditions of the wastewater.

As FWGs add organic wastes to the wastewater stream, it was anticipated that the nutrient content in the FW would increase the wastewater treatment requirements and require an increased treatment capacity at existing WWTPs. From the analysis of wastewater loadings, it was determined that no nutrient analyte (BOD_5, $sBOD_5$, TKN, NH_3, NH_4, NO_2, NO_3, TP, PO_4) loadings increased at a significant level, however, the standard deviations of several of these analytes (BOD_5, $sBOD_5$, TP) loading increased significantly (Table 14). The FDS loading increased at a significant level, which is a wastewater component that is often not removed during wastewater treatment as the species within FDS are biologically inert and do not necessarily partake in chemical or physical processes. This FDS content would therefore be increased in WWTP effluent, which should be evaluated before FWG introduction. The FOG loading also increased at a significant level, suggesting that WTTPs would require additional FOG removal capacity in headworks and primary settlers. The increase in variability in wastewater loadings may not necessarily increase the variability of wastewater observed at a WWTP, however, surveying results indicate that FWG use may be related to FW production, implying that many users of FWGs may use the devices at similar times of day, thereby increasing the variability of wastewater received at a WWTP. This increased variability may require larger factors of safety to be considered when designing new treatment processes, such as increased intermittent aeration requirements and sludge production. These lines of evidence suggest that FWG implementation in MURBs will not substantially impact the average loading to WWTPs, however, operational adjustments and increased factors of safety may be required to ensure that possible increases in wastewater variability are addressed. Furthermore, WWTPs exhibiting high levels of pre-existing FDS in effluent may require special attention regarding FWG implementation.

Table 14. Summary of Wastewater Loading Impacts due to FWG Use

Analyte	Significant Increase in Average Loading [g/unit/day] (%, p_{ave})	Significant Increase in Standard Deviation [g/unit/day] (%, p_{var})
TDS	15 (14, 0.01)	18 (154, < 0.01)
VDS	No Increase	18 (212, <0.01)
FDS	9 (16, 0.01)	No Increase
TSS	No Increase	15 (183, <0.01)
VSS	No Increase	14 (174, <0.01)
FSS	No Increase	1 (62, 0.02)
TKN	No Increase	2 (56, 0.02)
(NH_3+NH_4)-N	No Increase	No Increase
(NO_2+NO_3)-N	Not Detected	Not Detected
TP	No Increase	0.2 (64, 0.01)
PO_4	No Increase	No Increase
BOD_5	No Increase	19 (96, <0.01)
$sBOD_5$	No Increase	12 (97, <0.01)
mFOG	Not Detected	Not Detected
avFOG	4 (45, 0.01)	2, (51, 0.03)

As solid waste diversion is the primary motivator for exploring FWGs in MURBs, the level of organics diversion and perceived diversion was analyzed collectively. The level of organics generated in the mixed waste stream (fugitive organics) was not affected by the introduction of FWGs, and the solid waste results suggest that only organic waste that was already being disposed of via the green bin stream was disposed of via the FWG, specifically unavoidable food waste. It must be noted that this building exhibited high levels of green bin generation, however, a large fraction of organics waste was still disposed of in the mixed waste stream. Survey results implied that many survey respondents used both the FWG and green bin for FW disposal, and very few respondents reported using the mixed waste stream for food waste. With high levels of use reported for both the FWGs and GBs, it would appear that the organic waste that residents were disposing of within the mixed waste stream was not being considered in the same manner as FW being generated in the green bin, or alternatively there may have been some residents not using either method to dispose of FW. Overall, it appears that residents use FWGs for wastes that can also be disposed of in the green bin, and that residents may not necessarily consider FW being disposed of in the mixed waste stream for either diversion technology available to them.

As with the introduction of any new device, ensuring that the intended audience is open to using the devices is key to a successful implementation. Multiple lines of evidence indicate that residents did indeed use the FWGs for FW, as indicated by the decrease in unavoidable FW found in the solid waste audit results. Associated with these lines of technical evidence for FWG use, many survey respondents reported using the FWGs and several also reported preferring the FWGs over the GBs due to convenience. Some residents still preferred the GB, indicating that providing just one of the two technologies to a MURB population will still inconvenience a fraction of the population as the majority of survey respondents reported using both the FWG and the GB. In the second survey, more residents reported issues using their GB than in the control period survey, specifically complaints about odours of the GB increased. It is possible that having access to the FWGs increased the resident's awareness of their grievances with the GBs, and then preferred the FWGs which was not reported to cause foul odours. This suggests that residents of MURBs who dislike using GBs may divert more of their waste via the FWG, though residents who reported foul odours from the GB still reported using it despite the odours. In the study survey, most respondents indicated they did not experience issues using the FWG devices and were also comfortable using them based on the instructions provided from the building manager regarding the proper use and care for the devices. It can be concluded that residents were in general open to using the FWG devices in a MURB setting and that providing FWGs to MURBs with GBs results in both technologies being used by residents who prefer one over the other.

5.2 Recommendations

The methodologies and results of this study has identified aspects that could be improved upon or addressed in subsequent studies regarding the implementation or use of food waste grinders. One limitation experienced in this study was the narrow demographic of the study building and the low population/unit count. Future studies could benefit from using larger study buildings with less specific demographics to gain a deeper understanding of how different members of the community may interact with organic waste diversion technologies. Future studies may also explore implementing FWGs in multi-unit residential buildings that do not have access to green bins to determine what level of organic waste diversion could be achieved by relying exclusively on FWGs in a MURB setting. It is possible that FWGs had a lesser impact on wastewater characteristics due to green bins remaining a popular method of food waste disposal. Though the lack of wastewater impacts observed in this study was desirable from a wastewater treatment perspective, it is currently poorly understood what effect implementing FWGs in MURBs without green bins would have on wastewater characteristics.

This study observed considerable data variability which may have masked some FWG influences, especially in solid waste auditing. Future studies may benefit from a more rigorous solid waste audit sampling plan that includes more sampling events or conducting studies at buildings with known waste characteristics that are already part of an existing monitoring program. These additional samples would create a better defined pre-FWG implementation solid waste profile for the building and may be able to more accurately describe the impact that FWGs have in this regard.

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Appendices

Appendix A: Literature Database Query Keywords

Literature Database Query Keywords:

- “food waste grinder”
- “food waste disposer”
- “garburators”
- “food waste”
- “food waste + wastewater treatment”
- “food waste + sewer system”
- “food waste + wastewater collection”
- “potable water consumption”
- “solid waste diversion”
- “organic waste diversion”
- “apartment buildings (and multi-unit residential buildings) + solid waste diversion (and organic waste diversion)”
- “multi-unit residential buildings + solid waste diversion (and organic waste diversion)”
- “waste disposal behaviour(s)”
- “organic waste disposal behaviour(s)”
- “food waste disposal behaviour(s)”
- “apartment buildings (and multi-unit residential buildings) + food waste disposal (and organic waste disposal) behaviour(s)”

Appendix B: Field Sampling Procedure

FWG Study: Field Sampling Procedure

Benjamin Beelen

Last Updated: February 18, 2021 – Font sizes adjusted for this document.

This field sampling plan includes information for creating flow weighted composites in the field as well as evaluating the presence of particles retained by a 6.3 mm (1/4") sieve.

The procedure consists of initially preparing a flow weighted composite sample and then carrying out a sieving protocol. This document is relevant for the daily variability assessments, as well as the monthly sampling plan. The flow weighted composite and sieving is not required for the hourly variability tests.

1.) Flow Weighted Composite Background:

Composite samples are being collected from [redacted], to understand the impacts of food waste grinders on the wastewater quality leaving the building. Composite samples, with the objective of being representative of the average effluent conditions of the building over a given day, are being used to evaluate many of the water quality parameters of interest. It is expected that the buildings flow rate will vary by hour of the day, and thus a flow weighted composite sample is desirable. The procedure below outlines the steps to create a representative flow weighted composite sample. Each day, 24 x 1L samples will be taken by an auto sampler which require manual flow weighted mixing.

Flow Weighted Composite Equipment Required:

- **1 x 1L graduated beaker or container**
- **1 x 4L jug for temporary composite mixing for normal sampling events**
- **1 x 10L jug for temporary composite mixing for triplicate sampling events**
- **Table of mixing volumes (within this document)**

2.) Particle Size Evaluation Background:

The potential presence of large particles that may cause clogging of sewer structures will be examined using a combination of visual techniques and mass-based techniques. Photographs will be taken by the [redacted] personnel responsible for collecting wastewater samples after being trained by the University of Waterloo during the first sampling visits. The University of Waterloo will be responsible for analyzing samples for solids mass.

This plan outlines the procedures for creating photos of particles and determining the dry mass of particles captured on a sieve.

- **1 x ¼" Sieve (6.3 mm)**
- **1 x 500 mL graduated beaker or container**
- **Camera**
  - **Any camera that can take high resolution photos and include the sheet on page 5 will do, such as a phone camera**

Flow Weighted Composite Procedure:

1. Obtain 24 x 1 L sample bottles from auto sampler and order them from (10:00-11:00 AM) - (9:00-10:00 AM)[1], following the order presented in the **table on the following page**
2. Starting with the sample from 10:00-11:00 AM, measure out the volume specified in the table of shaken sample into the **1 L graduated beaker**
3. Dump this measured volume of sample into the temporary composite mixing jug (4L or 10L jug if triplicate)
4. Rinse the **1 L graduated beaker** out with ~75 mL of the next sample twice or clean water
5. Move on to the next sample (i.e. 11:00am-12:00pm, then 12:00pm-1:00pm)
6. Repeat step 2 - 5 until all 24 samples have sample in the composite jug (4 L total for non-triplicate, 10 L for triplicate)

Once composite has been formed in the temporary mixing jug)

7. Shake the composite jug for 10 seconds, ensuring that no particles have settled to the bottom of the jug or adhered to the side of the jug
8. Pour composite into sample bottles from the composite mixing jug
9. Record the time of the composite as the time and date the auto sampler began taking samples to the time and date that the auto sampler stopped taking samples

[1] The 1am(-2am) sample or 12pm(-1am) sample referred to in this document refer to any sample taken within those times. Does not need to be specifically taken at 1am

Sample Time Range	Volume (mL)	Sample Time Range	Volume (mL)
10am-11am	200 | (500)	10pm-11pm	250 | (625)
11am-12pm	200 | (500)	11pm-12am	200 | (500)
12pm-1pm	200 | (500)	12am-1am	100 | (250)
1pm-2pm	200 | (500)	1am-2am	100 | (250)
2pm-3pm	150 | (375)	2am-3am	50 | (100)
3pm-4pm	200 | (500)	3am-4am	50 | (125)
4pm-5pm	200 | (500)	4am-5am	50 | (125)
5pm-6pm	250 | (625)	5am-6am	50 | (125)
6pm-7pm	250 | (625)	6am-7am	100 | (250)
7pm-8pm	250 | (625)	7am-8am	100 | (250)
8pm-9pm	250 | (625)	8am-9am	150 | (400)
9pm-10pm	250 | (625)	9am-10am	200 | (500)
Non-Triplicate Volume | (Triplicate Volume)			
4 L Total | 10 L Total			

If there is no sample collected or insufficient sample to produce the quantities in the table above, evenly mix the adjacent samples to the desired quantity. For example, if sample 8-9am had no sample in it, mix samples 7-8am and 9-10am to reach the quantity for sample 8-9am. If there is insufficient sample to do this mixing, record the missing time period and skip the missing period's sample.

If no samples are collected for the autosamplers run time (no samples taken), a rescheduling of the sample must take place. Each month requires 2 weekdays and 2 weekend days, if the sample missing is a weekday, then the replacement must be scheduled on a weekday. If the sample missing is a weekend, the replacement sample must take place on a weekend day. **The cause of the malfunction in the missing samples should be identified before rescheduling the autosampler if possible.**

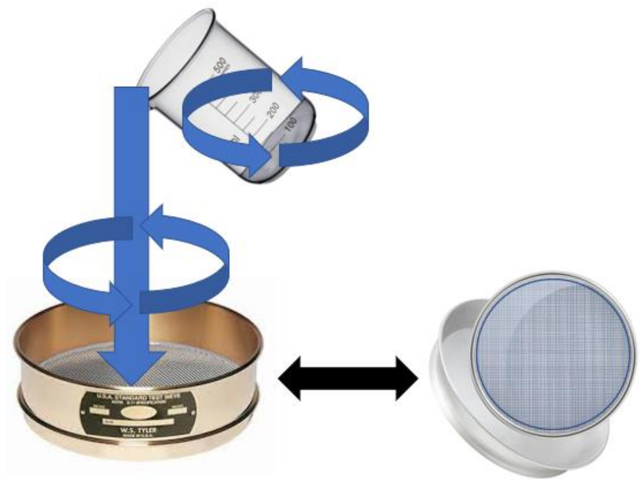
Should any issues arise during sampling, please call:

Benjamin Beelen at [redacted]

Particle Size Evaluation (Sieving and Photo)

Part A: Sieving and Photography (To be completed by [redacted])

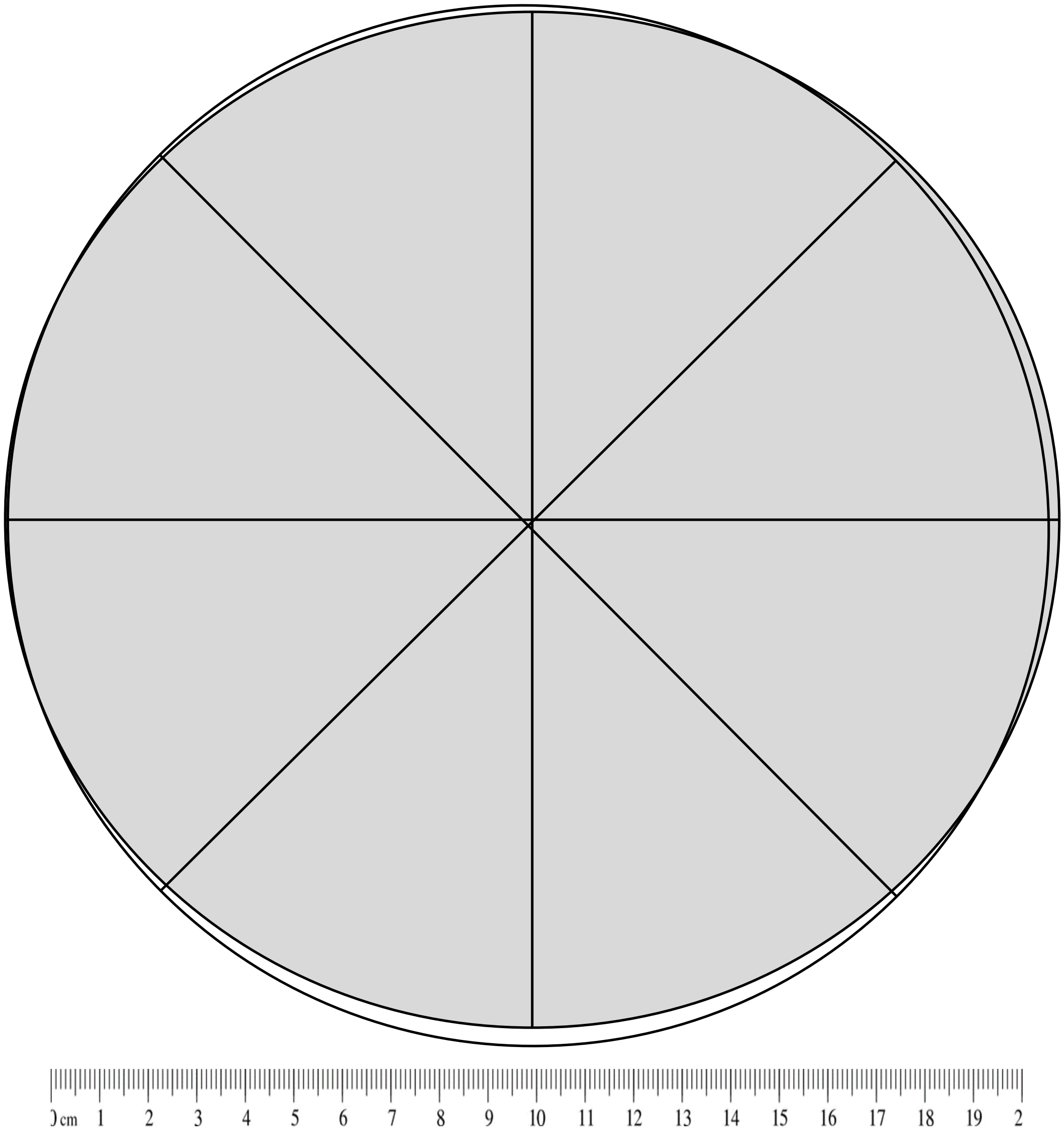
1. Measure 500mL of composite sample into the clean (rinsed) beaker, ensuring composite has been well mixed prior to measuring
2. Pour the measured 500 mL through a ¼" sieve in a manner that covers all surface area of the sieve evenly
    - **a.** All surface area of the sieve should have some liquid poured over it, as to not allow particles trapped on sieve to retain smaller particles
    - **b.** The following figure visualizes this process:



    - **c.** Wash beaker after pouring sample out with clean water
3. Place sieve over an 11x8.5" paper sheet with the sample ID written on the sheet in the top left corner
4. Take photo of the screen, ruler, and sample ID in the following layout with the camera directly above the screen and facing straight down:

SAMPLE ID

DATE



Warning: Example provided; margins adjusted for thesis submission

NOT TO SCALE

Appendix C: Solid Waste Audit Material Categories

Collection Stream	Material Category	Material Stream	Material Sub-Category
Green Bin, Blue Bin, Mixed Waste	Recycling	Paper (Larger than 2” x 2”)	Newspaper
			Telephone Books and Directories
			Magazines and Catalogues
			Mixed Fine Paper
			Books
		Paper Packaging	Cardboard- (larger than 5"x 5")
			Boxboard
			Kraft Paper
			Molded Pulp
			Composite Cans
			Gable Top
			Alcohol Containers- All Paper Packaging
			Aseptic Other Containers
		Plastics	PET Beverage Bottles
			PET Alcohol Bottles
			PET Other Bottles and Jars
			HDPE Beverage Bottles
			PVC Bottles and Jars
			Other Plastic Bottles, Jars and Jugs
			PET Food Packaging
			HDPE Other
			Polystyrene Rigid Food Packaging
			Wide Mouth Tubs and Lids
			Large HDPE and PP Pails and Lids
		Metals	Alcoholic Beverage Cans- Aluminum and Steel
			Aluminum Food and Beverage Cans
			Aluminum Foil and Foil Trays
			Other Containers- Aluminum
			Food and Other Beverage Cans- Steel
			Aerosol Cans- Steel
			Paint Cans- Steel
		Glass	Non- Alcoholic Glass Containers- All Colours
			Alcoholic Beverage Glass- All Colours
	Organics	Non- Food Waste Organics	Yard Waste
			Grass Clippings
			Wood Waste (small amounts)
			Pet Waste
			Diapers
			Sanitary

			Tissue and Towelling
			Shredded Paper (small amounts)
			Soiled Cardboard
			Soiled Boxboard
			Soiled Kraft Paper
			Certified Compostable Plastic Bin Liners
		Food Waste	Unavoidable Food Waste
			Possibly Avoidable Food Waste
			Avoidable Food Waste- Bakery
			Avoidable Food Waste- Meat and Fish
			Avoidable Food Waste- Dried Food
			Avoidable Food Waste- Fruit and Vegetables
			Avoidable Food Waste- Other
	Other Waste	Household Special Waste	Batteries
			Partially Full/ Full Paint Cans
			Partially Full/ Full Propane tanks (1 lbs)
			Partially Full/Full Pressurized Aerosol Cans
			Motor Oil
			Other HSW Liquids
			Other HSW
		Waste Electrical Electronic Equipment	Computer Monitors
			Computer Components
			Computer Peripheral Devices
			Audio/Video Equipment
			Telecom Equipment
			Other Electronics
		Bulky Items	Mattresses
			Wood Furniture or Fixtures
			Plastic Furniture or Fixtures
			Metal Furniture or Fixtures
			Other Large Bulky Items
		Small Household Items	Textiles
			Toys
			Ceramics
			Other Household Items
		Construction and Renovation Material	Carpeting
			Concrete
			Wood- Clean
			Wood- Treated
			Drywall- Clean
			Drywall- Used

			Shingles
			Other Construction and Renovation
		Non- Recyclable Plastics	Polyethylene Plastic Bags and Film- Carry Out Bags
			Other Polyethylene Plastic Films and Bags- Packaging and Non-Packaging
			Other Plastic Films and Bags
			Rigid Plastic Packaging- Non- Food
			Expanded Polystyrene
			Other Durable Plastic Items
			Other Non- Recyclable Plastics
			Black Plastics #1
			Black Plastics #2
			Black Plastics #3
			Black Plastics #4
			Black Plastics #5
			Black Plastics #6
			Black Plastics #7
			Black Plastics Other
		Other Non- Recyclable Containers/ Packaging	Laminated Paper and Bags
			Coffee Pods
			Hot Beverage Paper Cups
			Hot Beverage Cup Lids- All Colours
			Cups, Ice-Cream Containers and Other Paper Containers with Plastic/ Wax Lining
		Contaminated Recyclables	Newspaper in PE Bag
		Other Waste	Compostable Packaging
			Tires
			Rubber
			Scrap Metal
			Material Too Small to Process
			Snow/Ice
			Face Masks
			Gloves
			Other Waste

Appendix D. Survey Advertisements and Resident Contact Materials

Survey #1 Introduction Letter:

October 2020

Dear Resident of [redacted]

[redacted]

[redacted] and the University of Waterloo are leading a 16-month research study on **food waste grinders** in your building. An under-sink food waste grinder has been installed in your unit. The goal of the study is to understand how you use your food waste grinder and what impacts under-sink food waste grinders have on food and organic waste.

This research study is being done in partnership with your building owner - the [redacted].

Each household will receive a **$25 gift card** to NoFrills for participating in the survey**.** If you participate you will be asked to complete 2 short surveys (10 minutes each). These surveys will ask you how you deal with food waste. The survey questions are general, for example *"How frequently do you generate food waste in your apartment unit?"* The first survey is within this package. The second survey is planned for 16 months later at the end of the study.

You can complete one survey on your own or with our help:

- On your own with the paper survey provided, please mail completed surveys using the provided pre-stamped envelop
- On your own through an online survey
- During a follow up phone call, which you can expect in the coming weeks

[redacted] always wants to improve the services we provide to residents. The results of the survey will tell [redacted] about residents' habits using the green bin and food waste grinders. The study results will be used to inform future sustainable waste management programs. The results of the study will be compiled into a report and provided to [redacted] in February 2022.

Your involvement in the surveys is entirely voluntary and there are no known or anticipated risks to participate in this study. Your identity will be kept confidential and the information collected in these surveys will be grouped with other participants. You will not be asked to give your name or be identified in any report resulting from this study. You may skip any question you are not comfortable answering and still be eligible for the gift card. The gift card received is taxable it is your responsibility to report this for income tax purposes.

The data collected will be kept for a period of at least 2 years in a secure location at the University of Waterloo. If you wish to withdraw from the study at any time during the study period even after submitting a survey, please notify either myself or Professor Wayne Parker (contact provided below) and we will remove you from the study. The code on your survey is linked to your apartment number to allow us to mail the gift cards and withdraw your data should you decide to within the study period. There is not link between your name and survey responses.

You can expect your gift card by mail within 8 weeks of completing the survey (8 weeks from mailing your survey back, 8 weeks from completing the phone call **or** 8 weeks from completing the online survey).

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. If you have questions for the Committee contact the Office of Research Ethics, [redacted]

If you have questions about the study or survey, please contact me or Professor Wayne Parker at [redacted]

Sincerely,

Benjamin Beelen

MASc Candidate

University of Waterloo

[redacted]

Survey #1 Thank You Letter

University of Waterloo

Dear [redacted]

Thank you for participating in the recent survey conducted by the University of Waterloo and [redacted]. The survey is an important part of this study to understand and assess the impacts of under-sink food waste grinders.

The results of the survey will tell [redacted] about residents' habits using the green bin and food waste grinders. The study results will be used to inform future sustainable waste management programs. Results of this study will be shared with you as they become available and should you decide to want to withdraw your survey answers from the study, please contact me at the information below. This process remains anonymous.

While we are minimizing the amount of personal information collected, any data pertaining to you as an individual participant will be kept confidential. All information provided will be kept confidential and will be grouped with responses from other participants. You will not be asked to give your name or be identified in any report resulting from this study. The data collected will be kept for a period of at least 2 years in a secure location at the University of Waterloo.

The results of the study will be compiled into a report and provided to [redacted] in 2022.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#3 41967). If you have questions for the Committee, contact the Office of Research Ethics, at [redacted]

If you have questions about the study or survey, please contact me or Professor Wayne Parker [redacted]

Benjamin Beelen

MASc Candidate

Dept of Civil and Environmental Engineering

University of Waterloo

[redacted]

Survey #1 Poster:

FWG Activation Letter:

April 2021

University of Waterloo

Dear Resident of [redacted]

We are pleased to inform you that the food waste grinder which is installed in your kitchen sink is now available for your use. The accompanying brochure provides information on the types of waste that can be placed in the food waste grinder and the green bin. There is also a magnet for your quick reference to this information.

The University of Waterloo will be studying food waste disposal at [redacted] for the next year to better understand how waste grinders are being used by residents. If you have any questions regarding this study, please contact me [redacted]. If you have questions regarding the use of the food waste grinder, please contact your building manager.

Sincerely,

Benjamin Beelen

MASc Candidate

University of Waterloo

[redacted]

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. If you have questions for the ethics Committee, contact the Office of Research Ethics, a[redacted]

FWG Use Brochure Page 1:

ABOUT THE FOOD WASTE GRINDER PILOT PROGRAM

[redacted]

- Water use changes and wastewater quality changes
- Waste disposal habits of residents
- Residents attitudes towards using either their food waste grinder or their green bin
- Changes in the amount of garbage being generated

Residents of the building will be engaged over the course of the project through information sharing and tenant surveys.

ABOUT THE FOOD WASTE GRINDER

A food waste grinder has been installed under the kitchen sink of each unit.

After running cold water and turning on the grinder, food waste can be disposed down the sink drain. The food waste grinder will spin and grind food into fine particles and liquid. Running the water during and after use, flushes the small particles and liquid down the drain.

A detailed manual on use and cleaning of this device will be provided from the manufacturer through your building manager.

GREEN BIN TIPS:

- Line your kitchen container with certified compostable, paper or plastic bags. Certified compostable or paper bags are preferred
- Certified compostable bags are different than biodegradable bags. To ensure your bags are compostable, look for this logo:

COMPOSTABLE

WHAT HAPPENS TO YOUR GREEN BIN MATERIAL AFTER IT IS COLLECTED?

Processing of all collected materials is managed by [redacted] Green bin organics are delivered to a transfer station and then loaded onto transport trailers and shipped to licensed facilities under contract with [redacted]

[redacted]

WHAT GOES WHERE?

[redacted]

UNIVERSITY OF WATERLOO

[redacted]

FWG Use Brochure Page 2:

WHERE DOES IT GO?

GREEN BIN OR GRINDER?	Green Bin	Grinder
Bird seed	●	
Butter, margarine, grease and lard	●	
Cake, cookies and candy	●	●
Coffee grounds	●	●
Coffee filters and tea bags	●	
Dairy products	●	
Diapers	●	
Eggs and shells	●	●
Fruits and vegetables (raw or cooked)	●	●
Fur and hair	●	
Herbs and spices	●	●
Houseplants	●	
Incontinence products	●	
Kraft paper (non-waxed)	●	
Meat, fish and seafood (including bones)	●	●

GREEN BIN OR GRINDER?	Green Bin	Grinder
Microwavable popcorn bags	●	
Muffin wrappers	●	
Newspaper (soiled)	●	
Nuts and shells	●	●
Paper flour and sugar bags	●	
Paper towels, napkins and tissues	●	
Pasta, bread, cereals, rice and grains	●	●
Pet bedding	●	
Pet food	●	●
Pet waste (including cat litter)	●	
Sanitary products	●	
Sauces and soups	●	
Soiled paper cartons, paper plates and cardboard	●	
Shredded paper (small amounts)	●	

For more information visit [redacted]

WHAT GOES IN THE GARBAGE?

- Artificial flowers
- Baby wipes
- Bandages/gauze
- Candles
- Cigarette butts
- Cereal/cracker box liner bag
- Coffee pods
- Corks
- Cotton balls, ear cleaners and makeup removal pads
- Cutlery (metal, plastic, compostable, bamboo)
- Elastic bands
- Disposable mop sheets
- Dryer lint and dryer sheets
- Foam take-out containers
- Fruit stickers (labels)
- Gum
- Gloves/masks
- Milk bags
- Plastic bags and wrap
- Sanitizing wipes
- Vacuum cleaner bags
- Waxed paper, butcher paper, meat wrap
- Wooden chopsticks, stir sticks and toothpicks

For additional City of Markham recycling depot information, visit markham.ca

WHY ARE FATS, OILS AND GREASE (FOG) A CONCERN?

How you dispose of FOG can seriously impact your home and the environment. When poured down your sinks, drains or toilets, they cool and can clog the pipes that take the wastewater from your house to the treatment plant. Cool it, Scrape it, Green Bin it.

For more information visit [redacted]

FWG Use Fridge Magnet:

WHERE DOES IT GO?

GREEN BIN OR GRINDER?	Green bin	Grinder
Bird seed	●	
Butter, margarine, grease and lard	●	
Cake, cookies and candy	●	●
Coffee grounds	●	●
Coffee filters and tea bags	●	
Dairy products	●	
Diapers	●	
Eggs and shells	●	●
Fruits and vegetables (raw or cooked)	●	●
Fur and hair	●	
Herbs and spices	●	●
Houseplants	●	
Incontinence products	●	
Kraft paper (non-waxed)	●	
Meat, fish and seafood (including bones)	●	●
Microwavable popcorn bags	●	
Muffin wrappers	●	
Newspaper (soiled)	●	
Nuts and shells	●	●
Paper flour and sugar bags	●	
Paper towels, napkins and tissues	●	
Pasta, bread, cereals, rice and grains	●	●
Pet bedding	●	
Pet food	●	●
Pet waste (including cat litter)	●	
Sanitary products	●	
Sauces and soups	●	
Soiled paper cartons, paper plates and cardboard	●	
Shredded paper (small amounts)	●	

[redacted]

Survey #2 Introduction Letter:

February 14, 2022

Dear Resident of [redacted]

[redacted] Ontario

Approximately 1 year ago you may have been asked to complete a survey regarding a joint [redacted] University of Waterloo research study on food waste grinders in your building. This research study is being done in partnership with your building owner - [redacted]. This follow up survey is the second and last survey that you will be asked to complete for this study.

Each household will receive a $25 gift card to NoFrills for participating in the survey. This survey will ask you how you deal with food waste. The survey questions are general, for example "How frequently do you generate food waste in your apartment unit?"

You can complete one survey on your own or with our help:

- On your own with the paper survey provided, please mail completed surveys using the provided pre-stamped envelop
- During a follow up phone call, which you can expect in the coming weeks

[redacted] always wants to improve the services we provide to residents. The results of the survey will tell [redacted] about residents' habits using the green bin and food waste grinders. The study results will be used to inform future sustainable waste management programs. The results of the study will be compiled into a report and provided to [redacted] in February 2022.

Your involvement in the surveys is entirely voluntary and there are no known or anticipated risks to participate in this study. Your identity will be kept confidential, and the information collected in these surveys will be grouped with other participants. You will not be asked to give your name or be identified in any report resulting from this study. You may skip any question you are not comfortable answering and still be eligible for the gift card. The gift card received is taxable and it is your responsibility to report this for income tax purposes

The data collected will be kept for a period of at least 2 years in a secure location at the University of Waterloo. If you wish to withdraw from the study at any time during the study period even after submitting a survey, please notify either myself or Professor Wayne Parker (contact provided below) and we will remove you from the study. The code on your survey is linked to your apartment number to allow us to mail the gift cards and withdraw your data should you decide to within the study period. There is no link between your name and survey responses.

You can expect your gift card by mail within 8 weeks of completing the survey (8 weeks from mailing your survey back, 8 weeks from completing the phone call or 8 weeks from completing the online survey).

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. If you have questions for the Committee contact the Office of Research Ethics, at [redacted]

If you have questions about the study or survey, please contact me or Professor Wayne Parker [redacted]

Sincerely,

Benjamin Beelen

MASc Candidate

University of Waterloo

[redacted]

Survey #2 Thank You Letter:

University of Waterloo

Dear [redacted]

Thank you for participating in the recent survey conducted by the University of Waterloo and [redacted]. The survey is an important part of this study to understand and assess the impacts of under-sink food waste grinders.

The results of the survey will tell [redacted] about residents' habits using the green bin and food waste grinders. The study results will be used to inform future sustainable waste management programs. Results of this study will be shared with you as they become available and should you decide to want to withdraw your survey answers from the study, please contact me at the information below. This process remains anonymous.

While we are minimizing the amount of personal information collected, any data pertaining to you as an individual participant will be kept confidential. All information provided will be kept confidential and will be grouped with responses from other participants. You will not be asked to give your name or be identified in any report resulting from this study. The data collected will be kept for a period of at least 2 years in a secure location at the University of Waterloo.

The results of the study will be compiled into a report and provided to [redacted] in 2022.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#3 41967). If you have questions for the Committee, contact the Office of Research Ethics, at [redacted]

If you have questions about the study or survey, please contact me or Professor Wayne Parker at [redacted]

Benjamin Beelen

MASc Candidate

Dept of Civil and Environmental Engineering

University of Waterloo

[redacted]

Survey #2 Poster:

Phone Call Survey Script:

Hello,

My name is Benjamin Beelen and I am a Masters Student at the University of Waterloo. The University of Waterloo and [redacted] are conducting a study on the under-sink food waste grinders that have been installed by your building owner in your unit. This phone call should take about 10 to 15 minutes, is this an ok time for you?

No – Offer to reschedule at a time convenient to the resident

Yes – Continue with script

You should have received a parcel by mail with information about this study, including a paper survey for you to mail back. Are you familiar with this?

No – Respond:

As part of our research study, we are conducting a survey of residents in this building. [redacted] is offering a $25 gift card to NoFrills for participating in this survey. This study will help [redacted] understand how residents dispose of food and organic wastes. The results will influence food waste disposal in [redacted].

Food waste grinders can be used to dispose of food wastes by breaking them up and washing them down the drain into the sewer.

This would divert them from the garbage stream and save space in landfills.

Participation in the survey is completely voluntary and if you are interested in participating, we could fill out the survey today over the phone or you can complete the online version of the survey. (Continue with Script)

Yes – Continue with script

Have you already completed the online survey or the paper survey and mailed it back using the pre-stamped envelop?

Yes – Respond:

Thank you for completing the paper survey. Once we have received it, I will be sending you your gift card. Do you have any questions regarding the study? I would be happy to answer them now (Answer any questions then continue script)

No – Respond:

If you would like, we can complete the survey over the phone, but I ask that you recycle the paper survey and envelop that we provided you. (Continue with over-the-phone survey).

Just as a reminder, you can withdraw from the study at any time by contacting me at the address indicated in the letter.

If you ever have any other questions, please contact me at [redacted]

Thank you very much for your time and I hope you have a great day.

(End Call)

Appendix E: Survey Questionnaire

ID: (Four unique numbers)
Multi-Residential Food Waste Grinder Impacts Study: ***Resident Survey***

IF YOU DO NOT WANT TO PARTICIPATE IN THE SURVEY PLEASE CHECK ☐ THIS BOX AND MAIL BACK THE SURVEY WITH THE PRESTAMPLED ENVELOPE, YOUR HOUSEHOLD WILL BE REMOVED FROM OUR LIST OF UNITS FOR FOLLOW-UP CONTACTS.
You can expect a follow-up phone call in the coming weeks to clarify any questions you may have and complete the survey on the phone if you have not already. If you complete this survey yourself, please return it by mail using the provided pre-stamped envelope.

SURVEY QUESTIONS

Questions 1-5 are included in both survey 1 and 2. Questions 6-9 are unique to survey 2.

1.) How many people reside full time in your home? _____________

2.) What is the age range of the full time residents of your home? If there are two or more full time residents, check all that apply

☐ 15-24
☐ 25-34
☐ 35-54
☐ 55-64
☐ 65 and above

3.) The following questions apply to **food waste** that includes:

- Fruit and vegetable peels, stems, leaves (removed during food preparation)
- Spoiled produce (uneaten produce kept for too long – wilted, discoloured, mushy)
- Bones or spoiled or uneaten meat
- Food scraps (plate scrapings)
- Uneaten leftovers (stored for later, but then left too long)
- Food past its best before date (meat, dairy, sauces, dips, dressings, etc)

3a.) How often do you throw out food waste in your home?

☐ 3 times per day
☐ Once per day

☐ 3 times per week
☐ Once per week
☐ Other: _________

3b.) Do you generate more food waste in any particular season?

☐ Winter
☐ Spring
☐ Summer
☐ Fall
☐ No difference between seasons
☐ Not Sure

Is there a reason why it differs between seasons?

____

3c.) When you have food waste what do you do with it most often?

☐ Put it in the garbage
☐ Put it in the green bin
☐ Put it in the waste grinder
☐ Don't know
☐ Other:____

4.) The following questions apply to **used paper products** including:

a. Facial tissue, napkins, paper towels • Flour and sugar bags • Kraft paper (non-waxed) • Microwavable popcorn bags • Muffin paper • Paper plates (food-soiled)

4a.) How often do you throw out these paper products in your home?

☐ 3 times per day
☐ Once per day
☐ 3 times per week
☐ Once per week
☐ Other ______________

4b.) Do you generate more used paper products in any particular season?

☐ Winter
☐ Spring
☐ Summer
☐ Fall
☐ No difference between seasons
☐ Don’t know

Is there a reason why it differs between seasons?
____

4c.) When you have used paper products what do you do with them most often?

☐ Put them in the garbage
☐ Put them in the green bin
☐ Put them in the waste grinder
☐ Don’t know
☐ Other:____

5.) The following questions apply to **organic waste** including:

- Diapers
- Adult incontinence products
- Pet waste
- Old potting soil

5a.) How often do you throw out organic waste in your home?

☐ 3 times per day
☐ Once per day
☐ 3 times per week
☐ Once per week
☐ Other _____________

5b.) Do you generate more organic waste in any particular season?

☐ Winter
☐ Spring
☐ Summer
☐ Fall
☐ No difference between seasons
☐ Not Sure
Is there a reason why it differs between seasons?
____

5c.) When you have organic waste what do you do with it most often?

☐ Put it in the garbage
☐ Put it in the green bin
☐ Put it in the waste grinder
☐ Don't know
☐ Other:____

5d.) If you use your countertop green bin, how frequently do you empty it?
☐ More than once per week
☐ Once per week
☐ 2-3 times per week
☐ More than 3 times per week

5e.) If you don't use your countertop green bin, why not?

☐ Difficult to carry green bin to collection location
☐ Smell
☐ Flies
☐ "Yuck Factor"
☐ Other:__________________________________

6.) Have you received instruction on how to use your food waste grinder?

☐ Yes
☐ No

7.) Are you comfortable using your food waste grinder?

☐ Yes
☐ No
☐ Yes, but with exceptions
Please list any exceptions: ___________________________________

8.a) How often do you use your food waste grinder?

☐ 3 times per day
☐ Once per day
☐ 3 times per week
☐ Once per week
☐ Never
☐ Other _____________

8.b) Which of the following items do you dispose of using your food waste grinder?

☐ Fruit
☐ Vegetables
☐ Meat
☐ Bones
☐ Plate scrapings
☐ Fats, oils or grease
☐ Dairy products (milk, butter, cheese, yogurt)
☐ None of the above
☐ Other: ____
____

8.c) From the following list, please select the items that influence your decision about whether you will use the food waste grinder (FWG):

☐ Electricity use
☐ Odours from FWG
☐ Access to green bin replaces need for FWG
☐ Sustainable food waste disposal
☐ Water use
☐ Noise of FWG
☐ Convenience of FWG compared to green bin
☐ Safety of FWG
☐ Other:____
____

9.) Have you experienced any problems or issues with your food waste grinder?

☐ Yes

☐ No

If yes, please explain____
____
____

Do you have any other comments you would like to share with us (Please do not include your name or any identifying information):

Appendix F: Supplemental Tables

Parameter	Control (L/unit/day)	Study (L/unit/day)	P-Value
Average	233	233	0.49
Standard Deviation	24	20	0.03
Median	230	228	N/A
Max	336	286	
Min	194	179	
10th Percentile	207	204	
90th Percentile	253	255	
Count (Days)	68	333	

Table 15. Summary of Changes in Wastewater Composition with FWGs

Category	Analyte	Δ Loading (Study - Control) [g/unit/day (%)]	Δ Concentration (Study - Control) [mg/L (%)]*	p_{ave}	p_{var}
Solids	***TS***	***18 (12.3%)***	**76.3 (12.4%)**	***0.01***	***0.00***
	VS	*8 (9.9%)*	*36.3 (10%)*	*0.11*	*0.00*
	FS	**9 (15.6%)**	**39.9 (15.7%)**	**0.00**	**0.12**
	TDS	***15 (14.4%)***	***62.8 (14.5%)***	***0.00***	***0.00***
	VDS	*5 (12.1%)*	*23.3 (12.2%)*	*0.11*	*0.00*
	FDS	**9 (16.2%)**	**39.4 (16.3%)**	**0.00**	**0.24**
	TSS	*3 (7.3%)*	*13.5 (7.4%)*	*0.21*	*0.00*
	VSS	*3 (7.5%)*	*13 (7.6%)*	*0.21*	*0.00*
	FSS	*0 (8.7%)*	*0.4 (4%)*	*0.27*	*0.02*
Nutrients	*TKN*	*-2 (-9.4%)*	*-7.4 (-9.4%)*	*0.94*	*0.02*
	(NH3+NH4) -N	-2 (-19.0%)	-9.7 (-18.9%)	0.99	0.84
	(NO3+NO2) -N	N/A	N/A	N/A	N/A
	NO3-N	N/A	N/A	N/A	N/A
	NO2-N	N/A	N/A	N/A	N/A
	TP	*0 (-5.0%)*	*-0.4 (-5.0%)*	*0.80*	*0.01*
	PO4	0 (-6.7%)	-0.3 (-6.7%)	0.78	0.11
Biochemical Oxygen Demands	*BOD5*	*0 (-0.6%)*	*-1.4 (-0.5%)*	*0.52*	*0.00*
	sBOD	*2 (6.1%)*	*10.1 (6.2%)*	*0.30*	*0.00*
Fats, Oils and Grease	***FOG Total***	**4 (45.1%)**	***15.2 (45.2%)***	***0.01***	***0.03***
	FOG Mineral	N/A	N/A	N/A	N/A
	FOG Animal/Veg	**4 (49.0%)**	**15.7 (49.1%)**	***0.01***	***0.03***

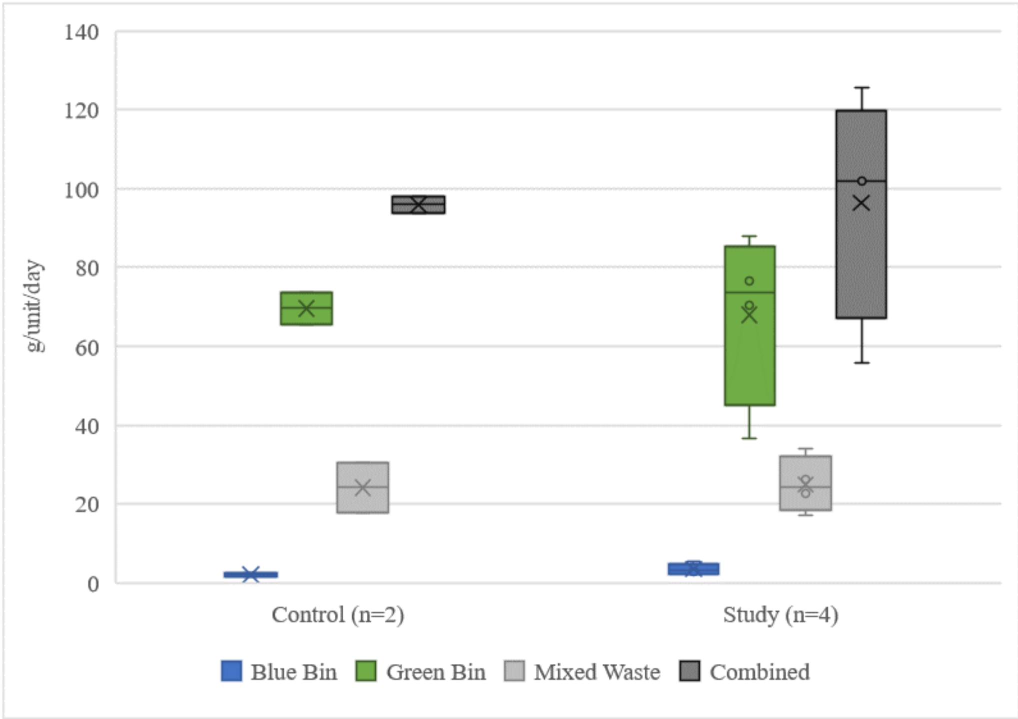
Bold parameters indicate a significant increase ($p < 0.05$) in average loading
Italic parameters indicate a significant increase ($p < 0.05$) in standard deviation

Table 16. Summary of Categorical Solid Waste Audit Results

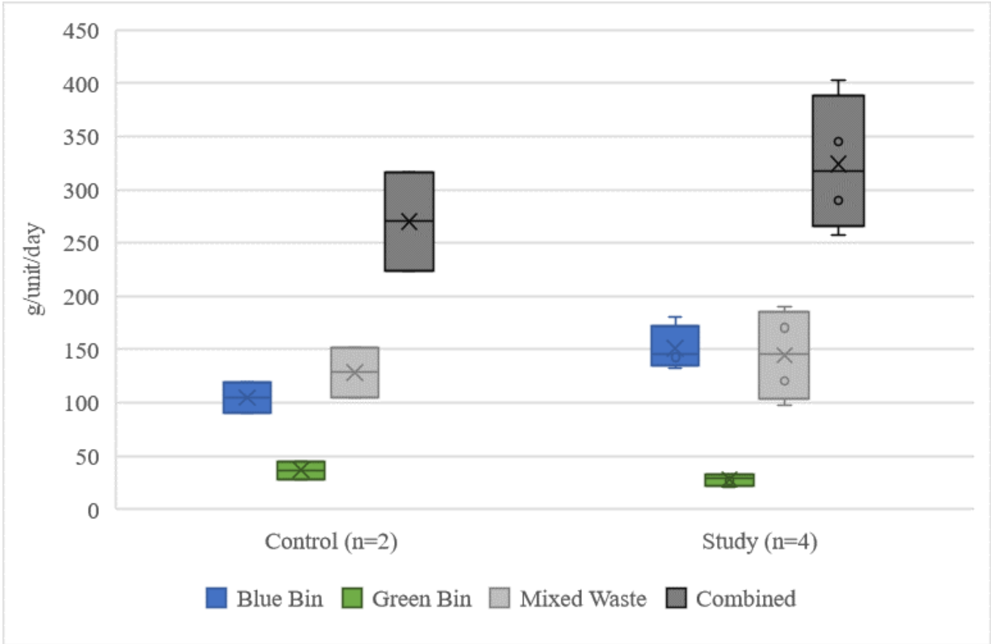
Stream	Total Waste Generation	Non-Organics Generation	Organics Generation	Food Waste Generation	Avoidable Food Waste Generation	Unavoidable Food Waste Generation	Non-Food Waste Organics Generation
	Difference [Study – Control Generation (g/unit/day)] (% Change)						
Blue Bin	+53 (48%)	+46 (44%)	+7 (150%)	+6 (220%)	+2 (112%)	+4 (361%)	+1 (64%)
Green Bin	***-79 (-19%) (p = 0.02)***	-9 (-24%)	***-71 (-19%) (p = 0.09)***	***-69 (-23%) (p = 0.03)***	+6 (9%)	***-75 (-32%) (p = 0.02)***	-2 (-2%)
Mixed Waste	+28 (13%)	+16 (13%)	+12 (14%)	+11 (18%)	+9 (24%)	+2 (8%)	+1 (3%)
Total Waste	+2 (0%)	+54 (20%)	-51 (-11%)	-52 (-14%)	+17 (15%)	***-69 (-26%) (p = 0.03)***	0 (0%)

Bold Italics indicate statistically significant change, with a p-value indicated.

Appendix G: Supplemental Figures



Supplemental Figure – Non-Food Waste Organics Generation by Stream



Supplemental Figure – Non-Organics Generation by Stream

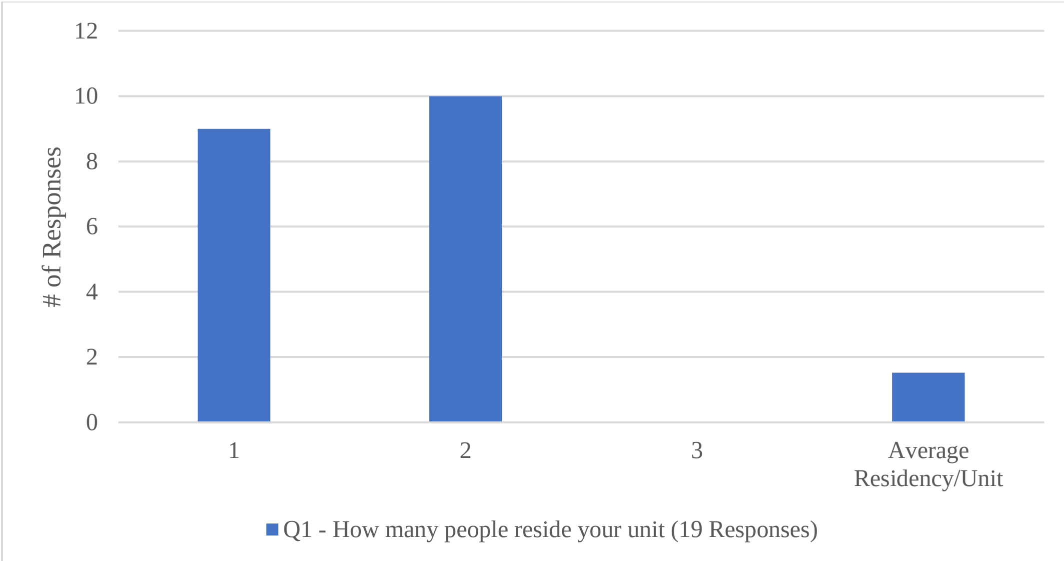
Appendix H: Detailed Individual Survey Results

App. H: Survey 1 – Control Period Survey Results

This survey was provided to residents in three ways: paper which was delivered to each unit, over the phone, and online. The paper survey was provided in both English and Simplified Chinese based on feedback from the building manager. Phone numbers and emails were collected by the building manager with the written consent of each tenant. Phone surveys were available in English, Cantonese, and Mandarin. The online survey was available in English only. The survey period was between January 18, 2021, and March 8, 2021. Of 29 occupied units during the survey period, 19 completed the survey, all using the paper version corresponding to a 66 % participation rate. Of the 29 units, three withdrew from the study and will not be contacted for survey 2.

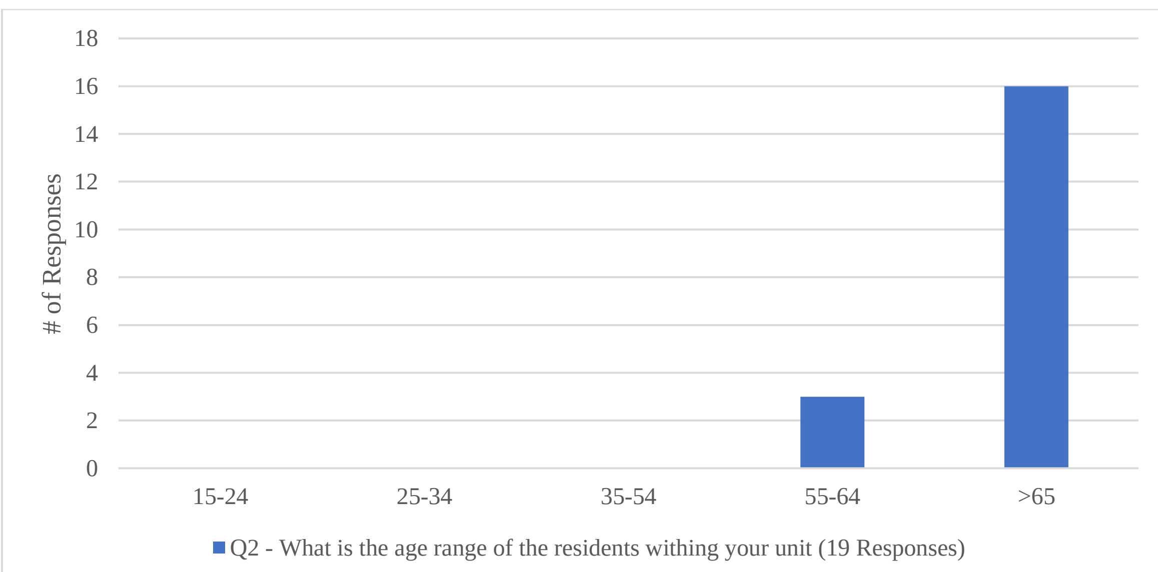
Information describing the demographics of the study building (household size and age range of residents), was collected to frame the responses of this evaluation relative to studies conducted elsewhere. Waste generation is dependent on socio-economic factors (Kannangara, Dua, Ahmadi, & Bensebaa, 2018), and thus for this survey to be compared to other studies, this information was analyzed. Furthermore, the technical results of this study will be impacted by building specific factors such as the number of people in each household/unit using the FWG devices. As a result of this, the demographics of the building were quantified.

The amount of food waste that a household generates is intuitively linked to the number of people within a household and as a result, this information was collected using the survey. The average household size is approximately 1.5 people per unit (Figure 32). There is approximately an equal distribution of single and double occupant households. The study building has 32 units, and thus when fully occupied it is expected that the building will have approximately 48 residents. At the time of the survey, 29 units were occupied corresponding to a population of 44 residents. These population estimates will be used to determine per capita loadings in the technical study as well as frame the results of this survey for future studies. From this evaluation, this survey’s results correspond only to single and double occupant households.



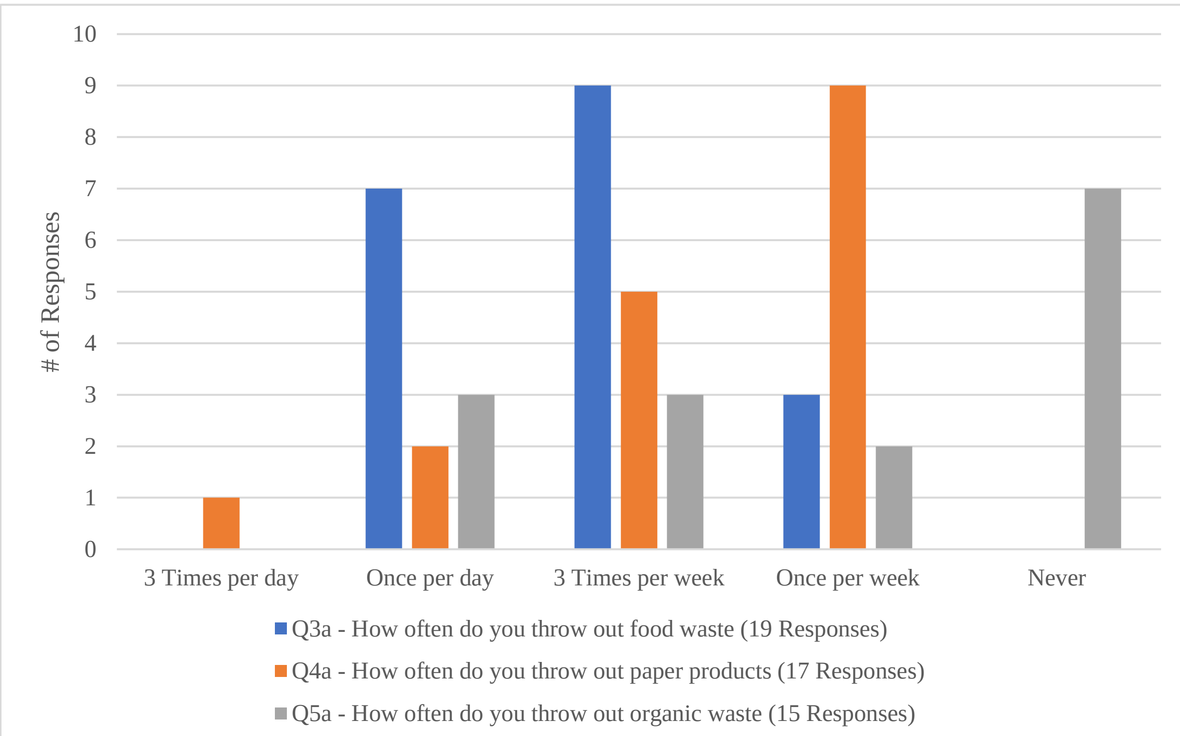
Supplemental – Figure 32. Survey 1: Household Size

The age of the residents within the building may also affect the waste generation habits of residents due to differences in spending and workforce participation among others (Lindh, 2003). All respondents are above the age of 55, with most respondents being 65 years of age or older (Figure 33). From a building of this size and demographics, it is expected that workday effects would not be observed (meaning most residents are in their unit the majority of the day), and that weekend effects of water consumption and waste generation may not be present (caused by being home during the day on weekends), due to most of the residents being close to or above the age of retirement in Canada.



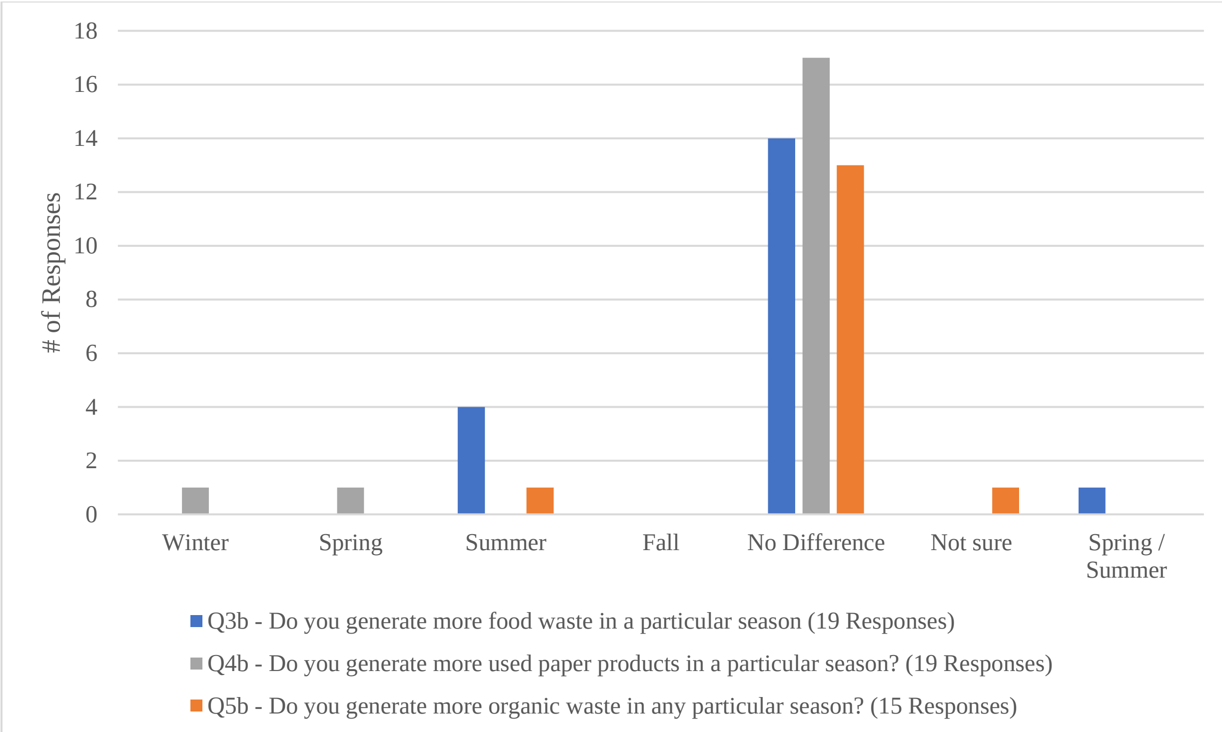
Supplemental – Figure 33. Survey 1: Age Range of Respondents

The frequency of disposal for the waste categories was queried to investigate relationships between generation patterns and disposal pathways. Further, it was anticipated that there would be a relationship between the frequency of disposal and the quantity of waste generated. Food wastes were reported to be disposed of most frequently at “once per day” or “three times per week” (Figure 34). Used paper products and organic wastes were reported to be disposed of progressively less frequently with “once per week” or “never” as the most common responses, respectively. A small number of respondents reported the disposal of organic wastes. It is hypothesized that the green bin stream would contain more food waste and less organic waste. This was confirmed through detailed solid waste audits (reported separately).



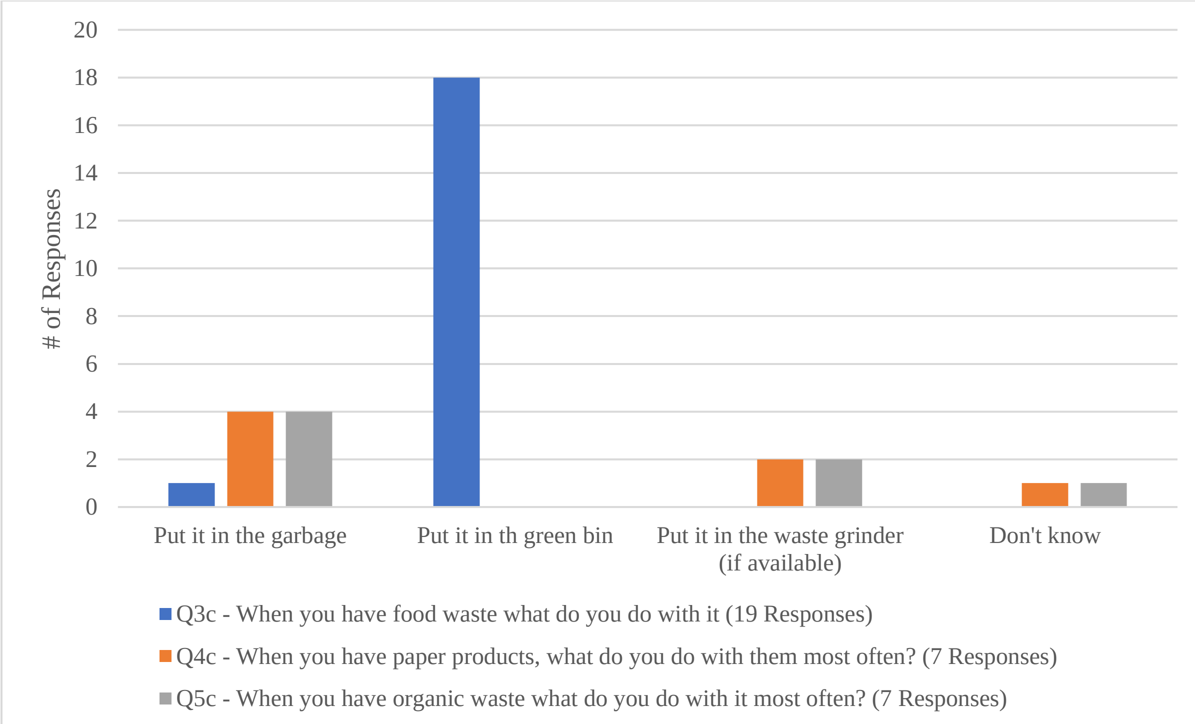
Supplemental – Figure 34. Survey 1: Waste Disposal Frequency

Seasonal differences in waste generation were surveyed to evaluate whether seasonally varying conditions would influence comparisons between the control period and the study period of the project. The control period encompassed one season (January 2021 - April 2021) while the study period spanned 4 seasons (May 2021 - March 2022). If large seasonal differences in waste generation exist, data interpretation would need to be adapted to reflect seasonal differences. Most respondents reported no difference in their seasonal waste generation for any of the categories evaluated (Figure 35). Some responses reported higher food waste generation in the summer. Based on these responses, it is expected that there will be limited seasonality in responses although this will be monitored through waste audits.



Supplemental – Figure 35. Survey 1: Seasonality in Waste Disposal

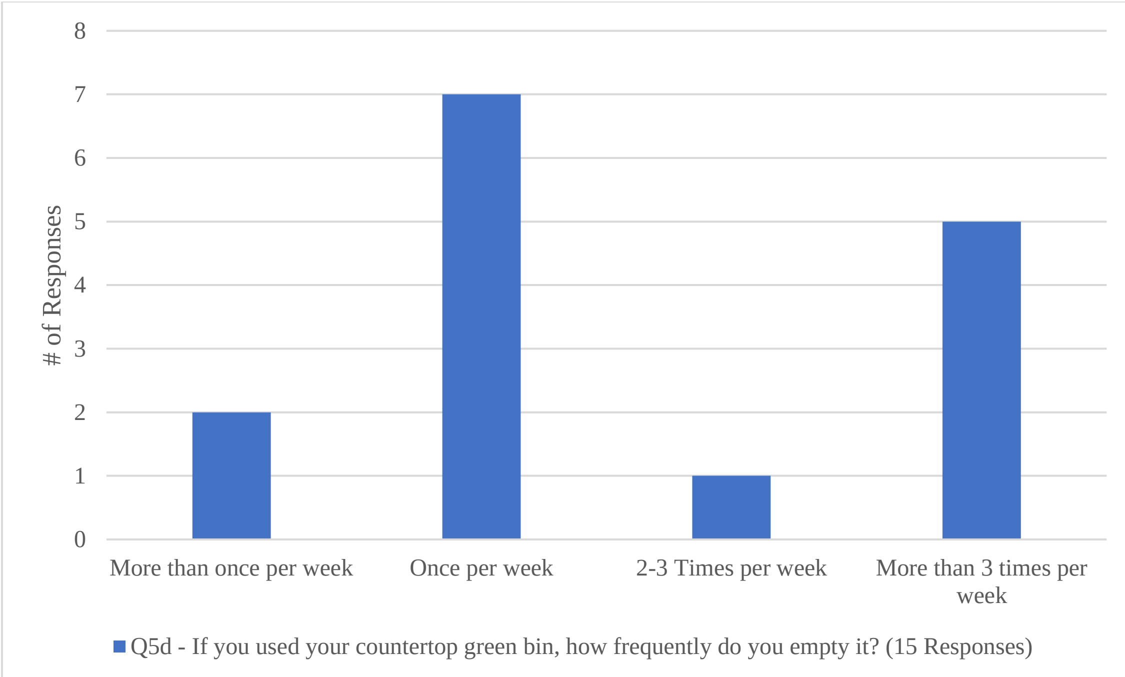
Residents were queried about where they would place the various types of wastes to establish baseline disposal habits before the residents have access to FWGs. The residents of the study building have access to three disposal pathways including a green bin system for organic waste. Most respondents reported that they use the green bin for the disposal of all three of the categories (Figure 36). Almost all respondents reported that they dispose of food waste through the green bin system. From the results, it is apparent that the green bin program is popular with respondents and may be an indication that the study population is responsive to messaging regarding food waste sorting. It is anticipated that this disposal pattern may be modified once residents are provided access to the FWG devices which will be subsequently quarried in survey 2.



Supplemental – Figure 36. Survey 1: Disposal Habits by Category of Waste

The perception of the presence of barriers to green bin use was queried to understand whether access to FWG devices might reduce concerns associated with green bins. The residents were asked if factors like the "yuck" factor, smell, difficulty carrying the green bin to the building's collection point, and the presence of flies reduced the likelihood of green bin use. For example, the use of FWG devices should reduce smells associated with the storage of organic waste, possibly resolving one of the barriers. Only three responses were provided for this question, with two respondents stating that smell was a barrier, and one response stating that carrying the green bin to the collection point was a barrier. It is hypothesized that the low response rate for this question suggests that the residents do not perceive many barriers to green bin use and may reduce the demand for FWG devices, which will be evaluated with survey 2.

The green bin emptying frequency, though not identified as a barrier in responses, was evaluated to understand how often this occurs for residents. Figure 37 shows that respondents reported that they empty their green bin at least "once a week", with an average emptying frequency of "2 - 3 times per week". This further suggests that the green bin program is popular with respondents and that they are willing to frequently empty their green bin to divert organic waste. The green bin disposal frequency will be evaluated after residents are provided access to the FWG devices to assess whether residents are taking advantage of the FWG to reduce the frequency of this activity.



Supplemental - Figure 37. Survey 1: Frequency of Emptying Green Bin

In summary, the following conclusions and observations can be made from the control period survey results:

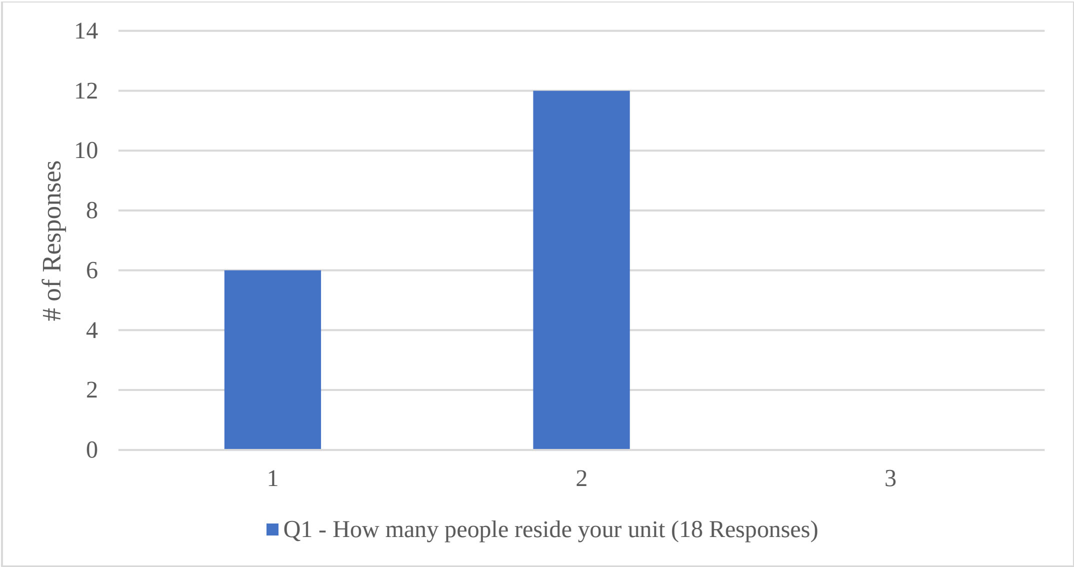
- The survey had a participation rate of 66 % (19/29), with a 10 % withdrawal rate (3/29)
- The average household size in the study building was reported to be 1.5, with no households larger than two occupants
  - This corresponds to a building population of 48 when fully occupied and 44 when the survey was conducted
- All respondents were above the age of 55, with the majority being above 65
- Food waste was reported to be disposed of most frequently when compared to used paper products and organic waste
  - Half of the respondents reported that they did not dispose of organic waste at all
- Almost all respondents reported that they used the green bin to dispose of food waste and that on average they empty the green bin between 1 and 3 times per week
  - Only three of 19 respondents reported that they experienced barriers to green bin use, two for smell and one for difficulty carrying the green bin to the disposal point
- There were minimal to no seasonal differences in waste generation reported

App. H: Survey 2 – Study Period Survey Results

This survey was provided to residents in two ways: paper which was delivered to each unit and over the phone. The paper survey was provided in both English and Simplified Chinese based on feedback from the building manager. Phone numbers were collected by the building manager with the written consent of each tenant. Phone surveys were available in English, Cantonese, and Mandarin. The survey period was between February 14, 2022, and March 28, 2022. Of 28 eligible units, 18 completed the survey, with 17 completed paper surveys and one phone call survey corresponding to a 58 % participation rate.

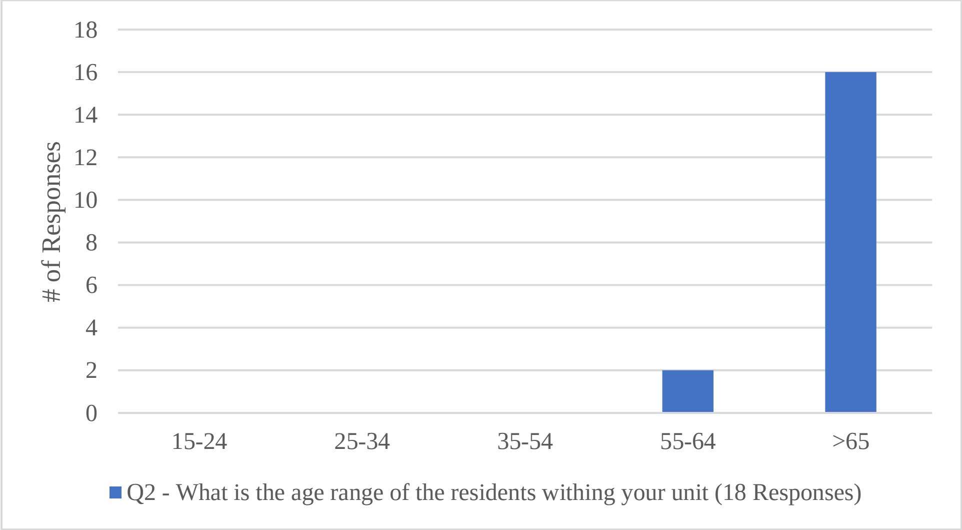
Information describing the demographics of the study building, (household size and age range of residents), was collected to frame the responses of this evaluation relative to studies conducted elsewhere and compare with survey 1. Waste generation is dependent on socio-economic factors (Kannangara, Dua, Ahmadi, & Bensebaa, 2018), and thus for this survey to be compared to other studies, this information was analyzed. Furthermore, the technical results of this study will be impacted by building specific factors such as the number of people in each household/unit using the FWG devices. As a result of this, the demographics of the building were quantified.

The amount of food waste that a household generates is intuitively linked to the number of people within a household and as a result, this information was collected using the survey. The average household size is approximately 1.7 people per unit (Figure 38). There is approximately an equal distribution of single and double occupant households. The study building has 32 units, and thus when fully occupied it is expected that the building would house approximately 54 residents. At the time of the survey, 31 units were occupied corresponding to a population of 52-53 residents. These population estimates will be used to determine per capita loadings in the technical study as well as frame the results of this survey for future studies. From this evaluation, this survey's results correspond only to single and double occupant households.



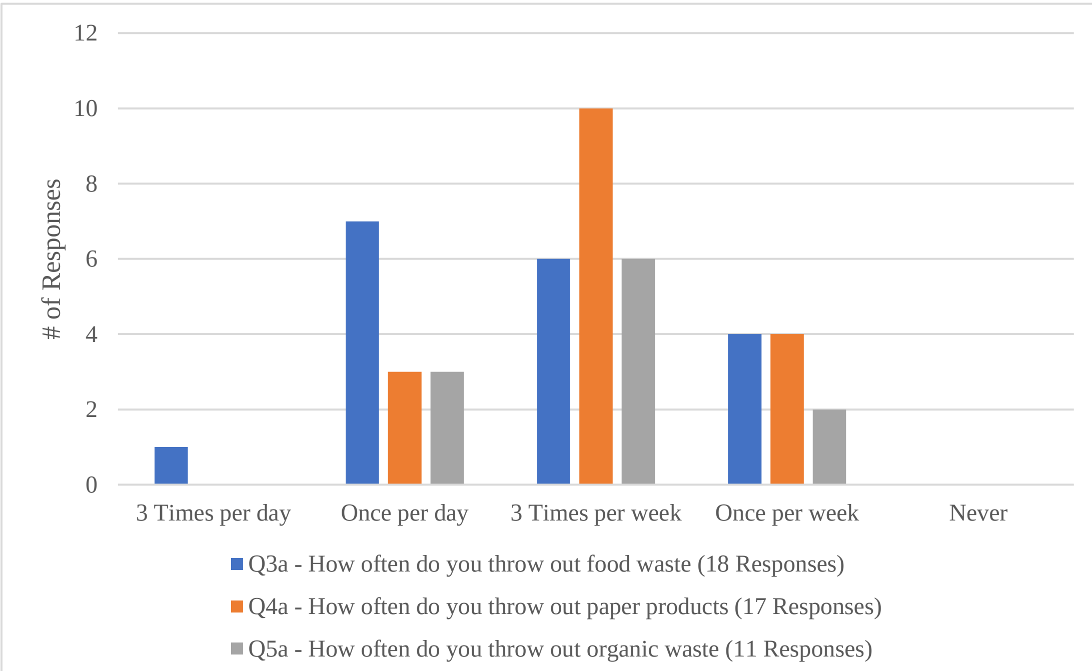
Supplemental - Figure 38. Survey 2: Household Size

The age of the residents within the building may also affect the waste generation habits of residents due to differences in spending and workforce participation among others (Lindh, 2003). All respondents are above the age of 55, with most respondents being 65 years of age or older (Figure 39). The two known units housing persons between the ages of 16 and 26 did not complete the survey. From a building of this size and demographics, it is expected that workday effects would not be observed (meaning most residents are in their unit the majority of the day), and that weekend effects of water consumption and waste generation may not be present (caused by being home during the day on weekends), due to most of the residents being close to or above the age of retirement in Canada.



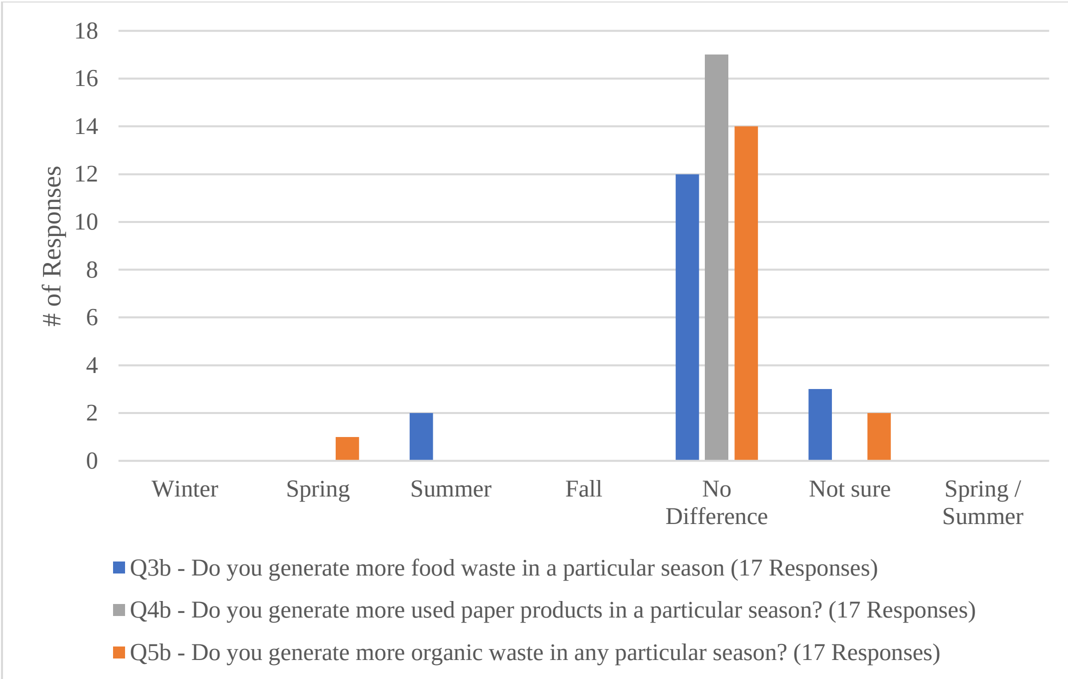
Supplemental – Figure 39. Survey 2: Age Range of Respondents

The frequency of disposal for the waste categories was queried to investigate relationships between generation patterns and disposal pathways. Further, it was anticipated that there would be a relationship between the frequency of disposal and the quantity of waste generated. Food wastes were reported to be disposed of most frequently at “once per day” or “three times per week” (Figure 40). Used paper products and organic wastes were reported to be disposed of progressively less frequently with “once per week” or “three times per week”. Based on this information, it was hypothesized that the green bin stream would contain more food waste and less organic waste. This was confirmed through detailed solid waste audits (reported separately).



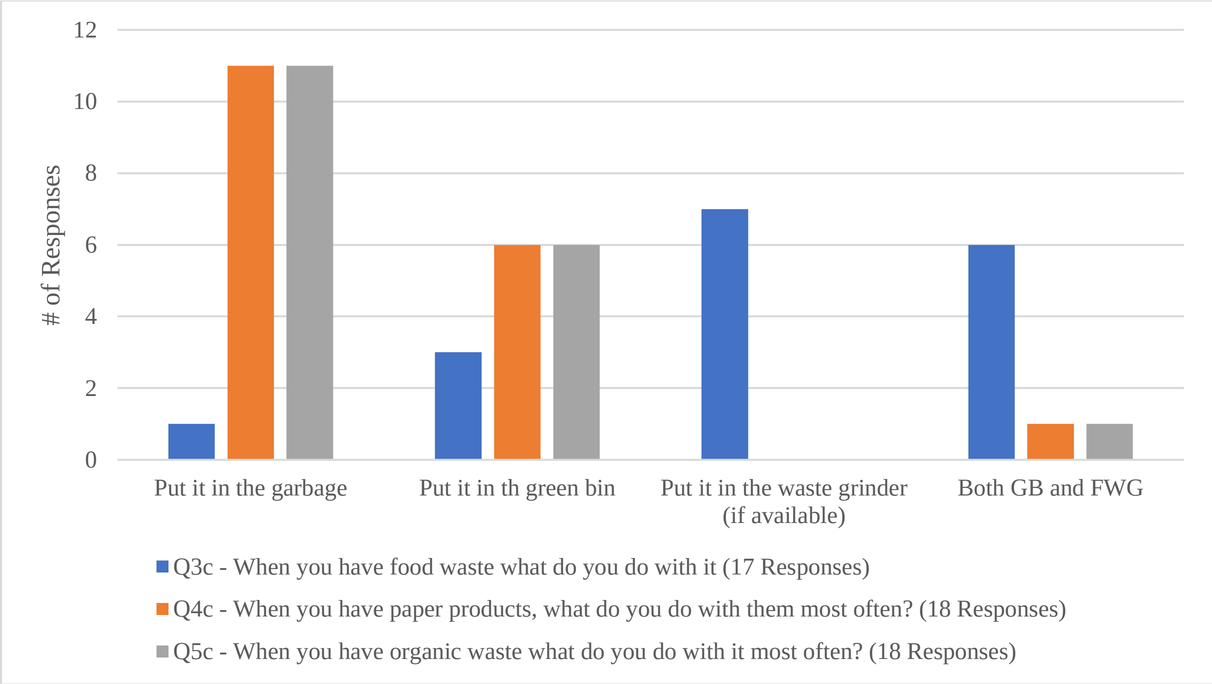
Supplemental – Figure 40. Survey 2: Waste Disposal Frequency

Seasonal differences in waste generation were surveyed to evaluate whether seasonally varying conditions would influence comparisons between the control period and the study period of the project. The control period encompassed one season (January 2021 - April 2021) while the study period spanned 4 seasons (May 2021 - March 2022). If large seasonal differences in waste generation exist, data interpretation would need to be adapted to reflect seasonal differences. Most respondents reported no difference in their seasonal waste generation for any of the categories evaluated in the study period survey (Figure 41). Some responses reported higher food waste generation in the summer. Based on these responses, it is expected that there will be limited seasonality in responses.



Supplemental – Figure 41. Survey 2: Seasonality in Waste Disposal

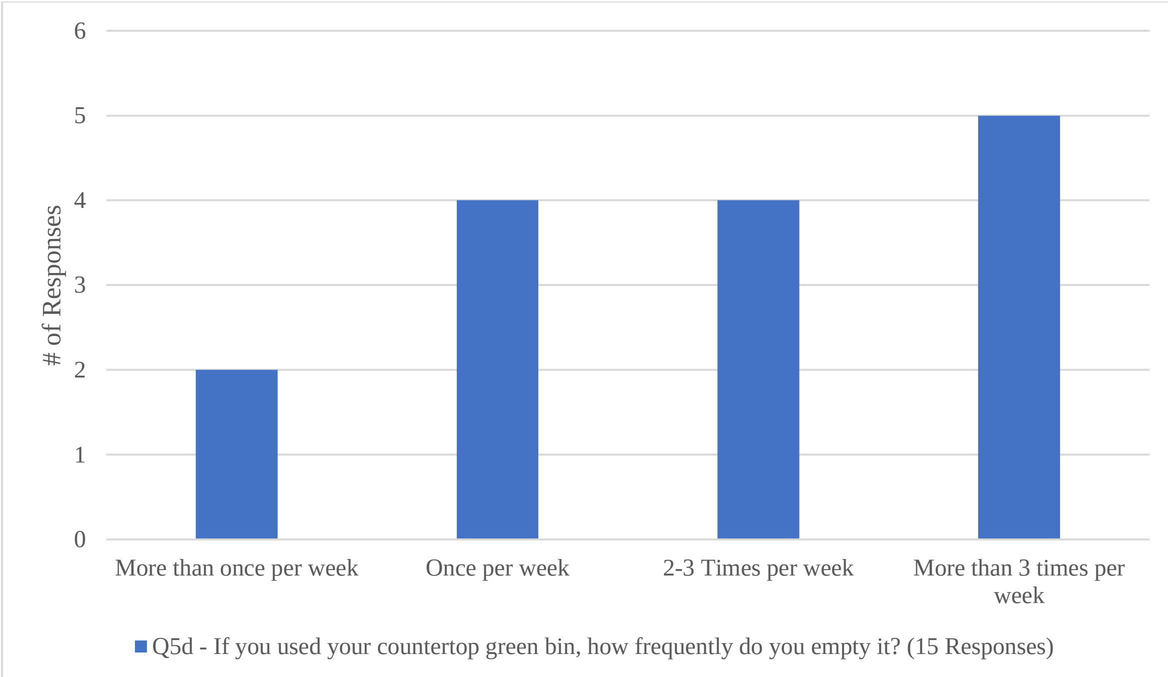
Residents were queried about where they would place the various types of wastes to measure disposal habits while residents had access to FWGs. The residents of the study building have access to three solid waste disposal pathways including a green bin system for organic waste. Most respondents stated that they use both the FWGs and green bins for food waste, with some respondents stating using each individually (Figure 42). The most common disposal method of used paper products and other organic wastes was the garbage, indicating that future green bin educational materials may want to focus on these categories of organic waste, though it is known that these organic waste fractions are lesser when compared to food waste.



Supplemental – Figure 42. Survey 2: Disposal Habits by Category of Waste

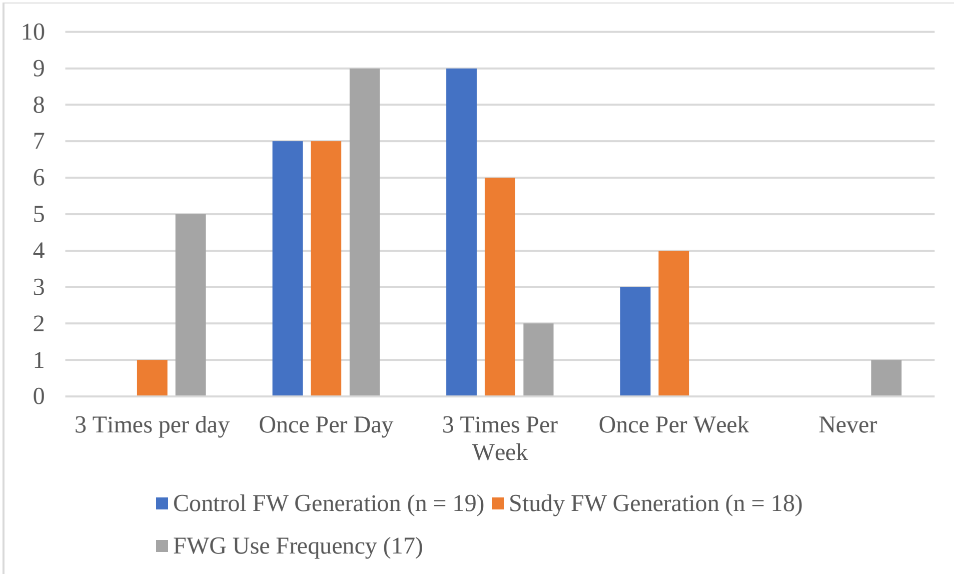
The perception of the presence of barriers to green bin use was queried to understand whether access to FWG devices might reduce concerns associated with green bins. The residents were asked if factors like the "yuck" factor, smell, difficulty carrying the green bin to the building's collection point, and the presence of flies reduced the likelihood of green bin use. For example, the use of FWG devices should reduce smells associated with the storage of organic waste, possibly resolving one of the barriers. Five respondents indicated that odours from the green bin were a barrier, and two respondents reported that carrying the green bin to the collection point was a barrier. It is hypothesized that the low response rate for this question suggests that the residents do not perceive many barriers to green bin use.

The green bin emptying frequency, though not identified as a barrier in responses, was evaluated to understand how often this occurs for residents. Figure 43 shows that respondents reported that they empty their green bin at least "once a week", with an average emptying frequency of "2 - 3 times per week". This further suggests that the green bin program is popular with respondents and that they are willing to frequently empty their green bin to divert organic waste even when FWGs are available.



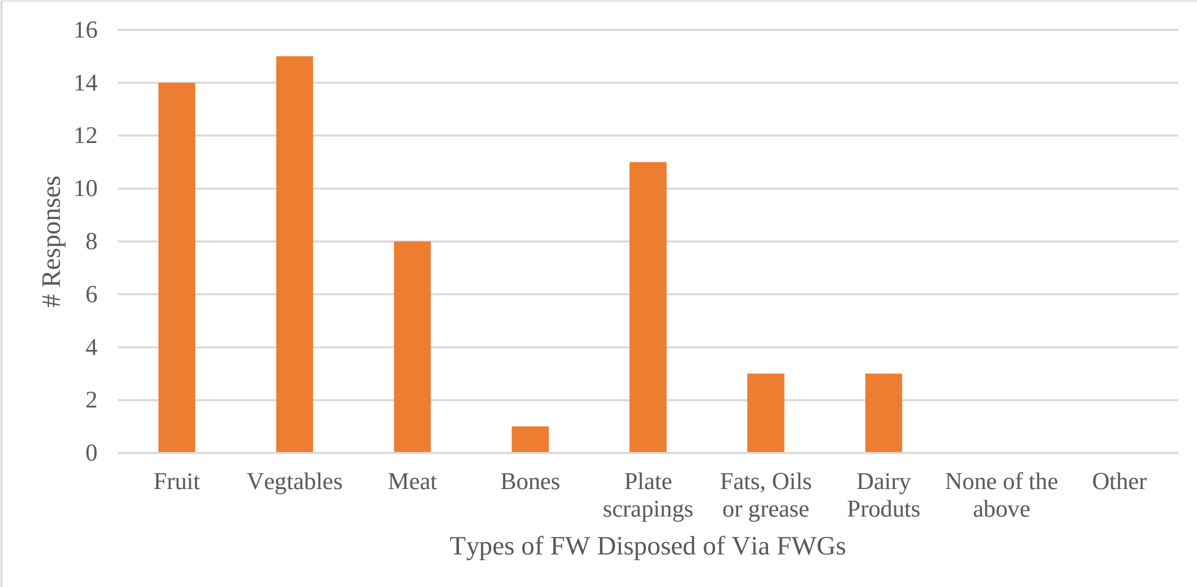
Supplemental - Figure 43. Survey 2: Frequency of Emptying Green Bin

The frequency of FWG use was questioned in the study period survey to determine the extent to which respondents report using their FWG, which was compared with the frequency of food waste generation (Figure 44). The relatively reported frequency of FWG use was comparable to the reported generation frequency of food waste, as can be seen in Figure 44. Most respondents reported using their FWG between three times per day and once per day, with some reporting only using the devices three times per week. These responses also indicate that residents do not perceive their food waste generation as equal to their FWG use, indicating that food waste may be generated at a high frequency than reported. It would also follow that resident use their FWGs often during this food waste generation, with most respondents using their FWGs at least once per day.



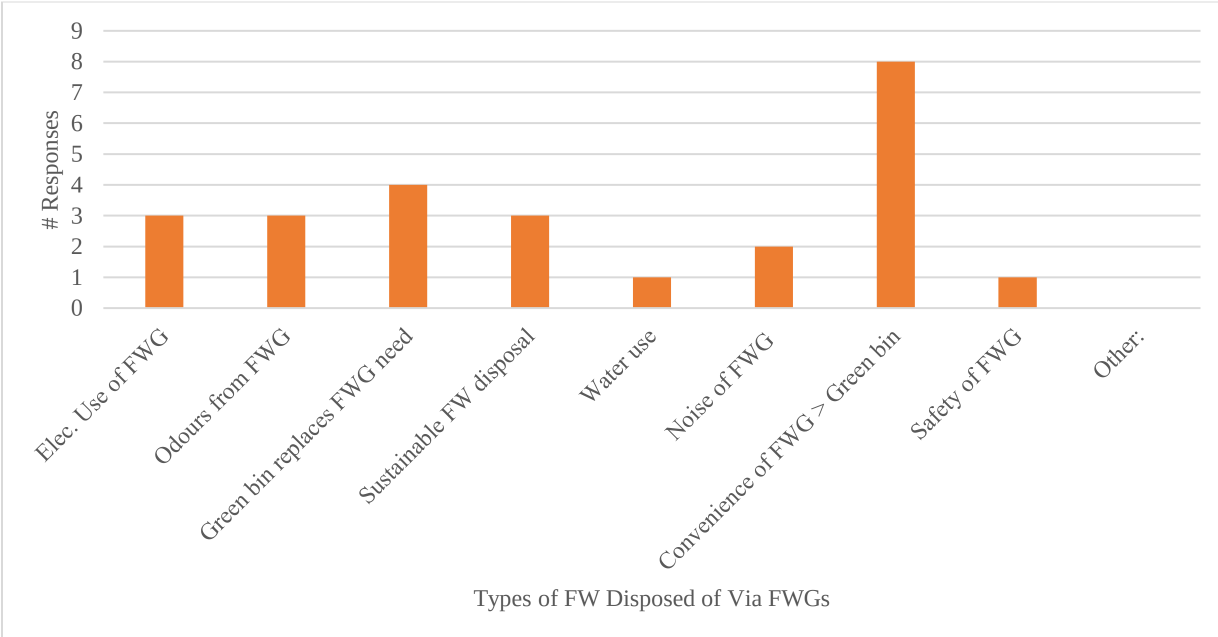
Supplemental – Figure 44. Reported FWG Use Frequency Compared with Control and Study Period Food Waste Generation Frequency

The study period survey asked residents what type of food waste they commonly dispose of in the FWGs to determine the success of educational materials and gain an understanding of what types of materials residents commonly dispose of using the FWG devices (Figure 45). More than ten respondents reported disposing of fruit, vegetables, and plate scrapings primarily in the FWGs, with eight respondents reporting also using the FWGs for meat. Three respondents reported disposing of FOG and dairy products in the FWGs, which are all non-FWG eligible categories based on educational materials provided to the residents. From these responses, it can be determined that the majority of survey responding units dispose of FWG eligible contents, especially fruit and vegetables. Plate scrapings are a common selling point of FWG convenience, and these results show that residents perceive their disposal of this category via FWGs. In general, the educational materials provided to residents were successful in conveying that fruits, vegetables, meat, and plate scrapings are FWG eligible. Educational materials to residents could be improved by specifically addressing FOG and dairy products remain non-sink disposable regardless of having a FWG device installed.



Supplemental – Figure 45. Reported Categories of FW Disposed of Via FWG in Study Period Survey

The study period survey polled residents on what factors influence their decision to use, or not use, the FWG devices in a MURB setting that also provided access to green bins (Figure 46). The most common reported factor was the convenience of the FWG being greater than that of the green bin, which eight respondents out of 18 total respondents stated influenced their decision to use the FWG. Four individuals stated that the green bin replaced the need for the FWG, which when compared to the number of reports of the FWG being more convenient, suggests that different residents have different preferences and FW disposal methods that may not be consistent in all units of the same building. The study building housed residents >65 years of age, and these responses could be indicative of different levels of mobility and levels of difficulty using green bins or FWGs. In a MURB setting, especially with variable levels of mobility of residents, a single method of FW disposal may not benefit all residents, and increased levels of convenience when disposing of FW may be experienced if residents are provided with multiple means of FW disposal that do not include the mixed waste stream.



Supplemental - Figure 46. Reported Factors of Influence Regarding FWG Use

Residents were also questioned on factors that are associated with FWG use to determine barriers and motivators to FWG use (Figure 46). Three respondents reported that perceived electricity use, odours from the FWG, and the sustainability were all factors when considering using the FWG. Two respondents reported noise influencing use, and one report of water use and safety concerns of FWGs were reported. Electricity use reported in the literature from FWGs is very low when compared to other household appliances (Iacovidou, et al., 2012), and this study has found no FWG influence on potable water consumption. The responses to these factors influencing use are low, however, future educational materials for FWGs and green bins may benefit by including information regarding these factors as they may be reducing FWG use on unfounded concerns.

In summary, the following conclusions and observations can be made from the study period survey results:

- The survey had a participation rate of 58% (18/31), though three units had withdrawn during the first survey and were not contacted during survey 2
- The average household size in the study building was reported to be 1.7, with no households larger than two occupants
    - This corresponds to a building population of 54 when fully occupied and 52-53 when the survey was conducted
- All respondents were above the age of 55, with the majority being above 65
- Food waste was reported to be disposed of most frequently when compared to used paper products and organic waste
- There were minimal to no seasonal differences in waste generation reported

- Almost all respondents reported that they used the green bin to dispose of food waste and that on average they empty the green bin between 1 and 3 times per week
    - Two respondents stated that they did not use the green bin due to difficulties carrying it to the collection point
    - Five respondents stated they did not use their green bin due to odours
- Respondents used their FWGs often, which can be correlated to food waste generation frequency
    - Respondents used their FWG primarily for food waste, with most respondents stating they did not use the FWG for used paper products or other organic wastes
- Respondents most often used their FWG for fruit, vegetables, and plate scrapings
    - Some respondents reported using the FWG for FOG and dairy products, which are both non-FWG target materials
- Some respondents found the FWG more convenient than the green bin, and other respondents vice versa.