UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Analysis and Concept Design for grey water heat recovery to preheat domestic water supply for multi-unit residential high rise building

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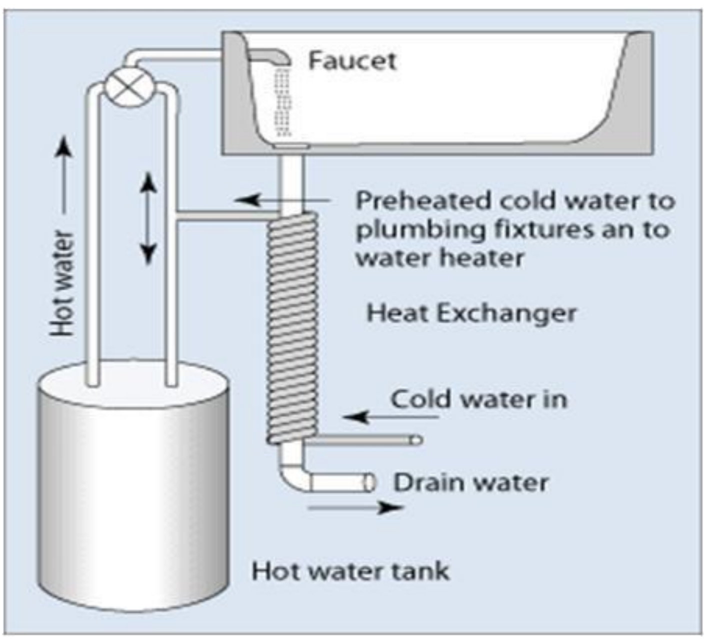

Analysis and Concept Design for grey water heat recovery to preheat domestic water supply for multi-unit residential high rise building

A way to reduce energy consumption

Senthil KumaranVellore Rushya

Preface

The project satisfies the requirements for CEEN 596 – Masters of Engineering in Clean Energy Engineering Final project. Also, this report has been written for a SEEDS (Social, Economic and Environmental Development Studies) project. In addition, this report has been written for Polygon Homes Ltd.

Acknowledgements

I would like to thank the following people for their help and advice throughout this project: Eric Mazzi (UBC Power Smart Instructor), Troy Glasner (President, E3 Eco Group Inc.), Vitaly Lioznyansky (Director of Maintenance, Haro Park Centre Society), Felice Choi (Property Manager, Wesbrook Village Gate Homes), and Raj Ghosh (CEEN student). Also, I would like thank Polygon Homes Ltd. for their financial support and for providing SITKA building documents and site visit.

Finally, I would like to thank my family and friends for their support.

Glossary

CBEEDAC – Canadian Building Energy End-Use Data and Analysis Centre
CEEN – Clean Energy ENgineering
MURB – Multi-Unit Residential Building
GHG – Green House Gas
GJ – Giga Joule
GWHR – Grey Water Heat Recovery
REAP - Residential Environmental Assessment Program

Executive Summary

An analysis of grey water in multi-unit residential buildings was performed followed by a concept design for deployment of the GWHR system with SITKA building as the case study.

In MURBs, most of the energy is used for space heating and water heating. Energy conservation measures such as deploying GWHR system in the path of waste water drainages will help in reducing energy consumption in MURBs.

A literature review was conducted to review different GWHR systems and also to review different water heating techniques in MURBs. The review indicated that most of the MURBs use boilers for their hot water needs and natural gas for heating up the water in boilers. Most of GWHR systems (from different manufacturers) are more or less similar in operation, effectiveness, size and cost.

A concept design is proposed for deploying the GWHR systems for high rise MURB (SITKA) for effective capture of heat from waste grey water.

Calculations for energy, dollar and GHG savings were made along with payback period for two different mass flow rates. It was observed that the calculations mostly depended on the mass flow rates of drained waste grey water. It was also noticed that when mass flow rates increase, energy, dollar and GHG savings also increase and the payback period decreases. The energy savings ranges from 27.91 GJ/year to 83.72 GJ/year; the dollar savings ranges from \$150.69/year to \$452.07/year; and the GHG savings ranges from 1.56 tonne of CO_2/year to 4.69 tonne of CO_2/year. The above values do not

include deployment of GWHR systems for the shower drainages. It was concluded that GWHR systems need to be deployed for shower drainages for high energy savings and they could be deployed for other drainages if subsidies were given by the government for GWHR systems.

For a worthwhile investment, one GWHR system can be installed for the whole SITKA building as the investment of one system can be covered by the energy savings obtained by deployment of one GWHR system.

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1. Introduction

Energy used in the residential sector is important because it represents the third highest percentage in all sectors of Canada shown in Figure 1. According to the CBEEDAC in 2001, thirty-one percent of Canadians lived in apartment buildings and MURBs account for twenty-four percent of overall annual energy consumption in residential sector.

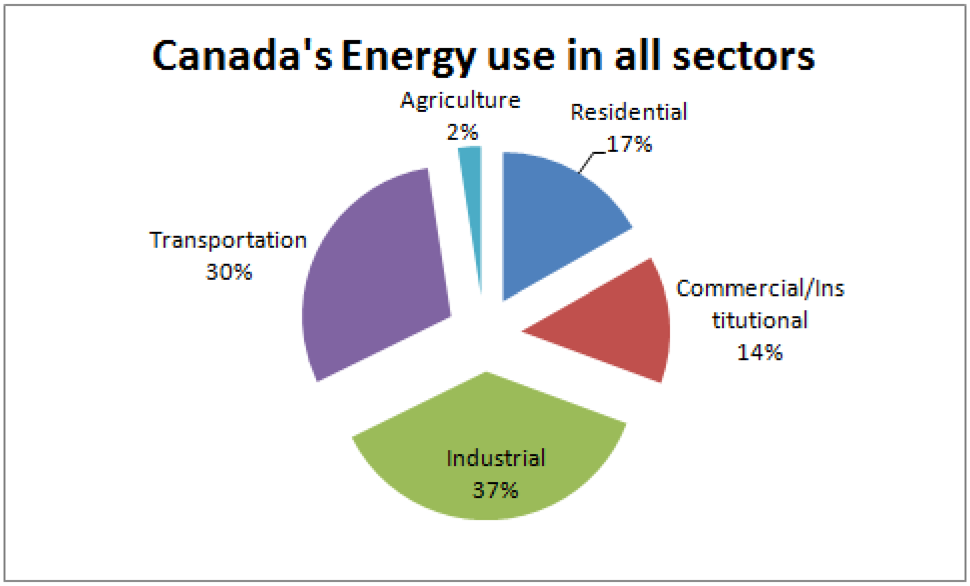

Figure 1 Canada Energy use in all sectors

Polygon homes, through its consultant E3Ecogroup, pursued an investigation of grey water heat recovery for multiunit residential buildings (MURBs).

The goal of the project is to perform a concept design of recovering heat from waste grey water in MURB that goes to drainage unused with SITKA building as the case study. The project shows how much energy can be saved by implementing this simple system in every household (yes! even this system can be installed in single buildings also). This project also shows the GHG savings and the economics involved in installing such a system.

1.1. Study Objectives

The following objectives were developed to investigate the design and performance issues for utilizing GWHR systems in multiunit residential buildings:

1. Review of types and sources of waste water in MURB's.
2. Review of existing GWHR systems.
3. Assess the conceptual design and performance for installing GWHR in the SITKA building.
4. Calculate the energy savings, GHG savings, and the economics associated with installing GWHR in the Sitka building.

2. Background

2.1. Energy conservation[1] in the residential sector

It is important to conserve energy. Otherwise, we may end up using all the useful energy in this world and we may not be able to enjoy the capabilities that energy is able to provide us. Also, more energy used results in climatic changes which in turn affect us in many ways. There are many ways to conserve energy. One way of

[1] Energy conservation refers to efforts made to reduce energy consumption.

conserving energy is by deploying effective energy management[2]. Energy conservation (part of energy management) has become a major area of focus in present day where every person is involved.

A breakdown on the energy usage of Canadians in residential sector by end-use is given in Figure 2. Water heating is one of the main sources of energy usage in any typical home and some of this energy can be saved by using heat recovery system. Heat recovery system proposed can recover considerable amount of heat that goes to the drain as waste. By installing this heat recovery system, energy usage can be brought down that reduces overall energy consumption. The impact of energy savings achieved by installing this system is magnified for multi-unit residential buildings (as these buildings have a lot of hot water appliances).

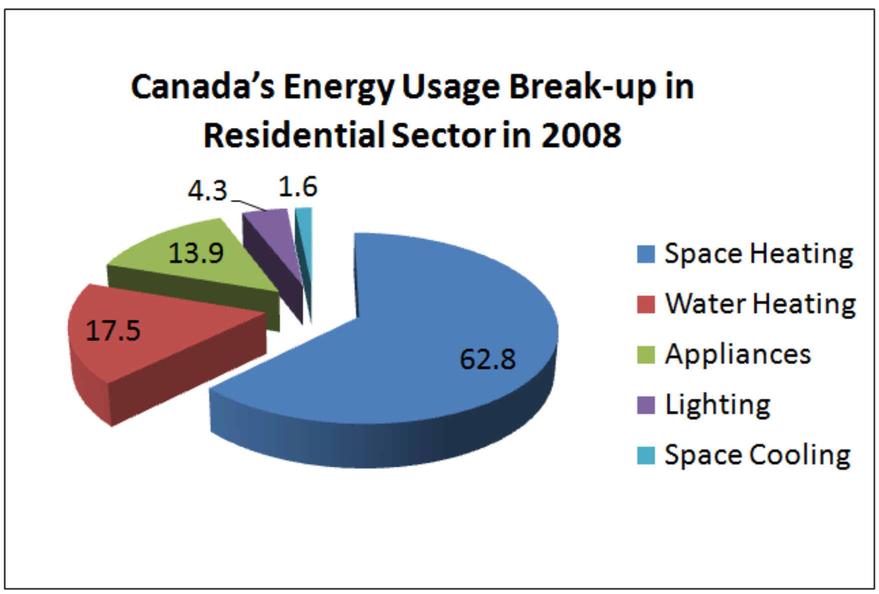

Figure 2 Typical Energy Usage Break-up for Canada in residential sector

[2] Energy Management is the efficient and effective use of energy to maximize profits (minimize costs) and enhance competitive positions according to "Guide to Energy management, Ch.1, Introduction to energy management".

2.2.UBC REAP

REAP rating system was developed to compare the performance of different multi-unit residential buildings in and around UBC. The objective of REAP is to encourage buildings have high quality using standard building practices. The system is similar to LEED and Built Green residential rating systems. REAP also helps for continuous improvements in buildings when needed through changing requirements by UBC. Developers need to earn credits through seven key areas in their building project which impacts environment. The developers submit REAP checklist and supporting documents throughout the building planning and construction phases to check for compliance. The seven areas of focus are as follows.

- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Construction
- Innovation and Design Process

The developers can get incentives from the government because REAP is one program that might provide incentives for heat recovery.

2.3. Black Water vs. Grey Water

First, it is very important to know the types of waste water that are drained to the drainage. Waste water drained from any household are mainly of two types, the grey water and black water. It is easy for any person to identify these two types of waste water. The difference between the above mentioned two types of waste water is mainly based on the waste that contaminates the water.

The black water is water contaminated by feces and bodily wastes. This water is generally flushed in toilets and is harmful to people and it cannot be reused for any other purposes. But even this water is being treated and recycled using modern technologies and is commonly used for fertilizer purposes. The grey water is water used up for household purposes like laundry, showers, sinks and dishwashers.

For this project, it was decided that only waste grey water will be considered as it contains more recoverable heat than the black water. Also, it requires a great amount of energy to separate the contaminants from black water to use the water again.

2.4. Sources of Grey water

There are many sources (Figure 3[3]) of waste hot grey water that is being generated in multi-user residential buildings (in single houses as well). They are listed below.

2.4.1. Showers

Showers are great source of waste hot grey water that gets drained through the drainage. Every household (be it a single house or apartment unit) has one shower (some households have two) and obviously every household members in the house takes shower at least once in a day (some residents take shower in hot water even in summer and maybe two showers a day). This amounts to

[3] http://www.shopping.com/LG-WM2233H/info, http://showerdesign.blogspot.com/ , http://www.kohler.ca/ , http://www.ianfosterservices.co.uk/id52.html

considerable amount of heat that goes waste which could be recovered by installing a heat recovery system on the drainage pipes.

2.4.2. Dishwashers

Dishwashers are also good source of waste hot grey water. There will be one dishwasher which might be used at least once a day. This also accounts for a good amount of heat that can be recovered by installing this system. There is one problem however with this source as not every household can afford a dishwasher.

2.4.3. Kitchen Sink

This is another source of waste grey water where lot of heat can be recovered by installing this system. In many households, utensils are washed in the sinks instead of dishwashers. Heat can only be recovered from the kitchen sink when hot water is used for washing utensils. Otherwise there is not much heat that can be recovered from the kitchen sinks.

Also, in some houses (this is the case with houses in SITKA building) the drainage system is planned in such a way that the dishwasher and the kitchen sink drain into the same drainage pipe.

2.4.4. Washers / Dryers

Washers are a source of hot waste grey water but not the dryers due to the fact that dryers use the air generally to dry the clothes and so heat can be recovered only from washers. Here again, the washer is generally used once in two days or once in a week but there are houses which use washer at least once a day.

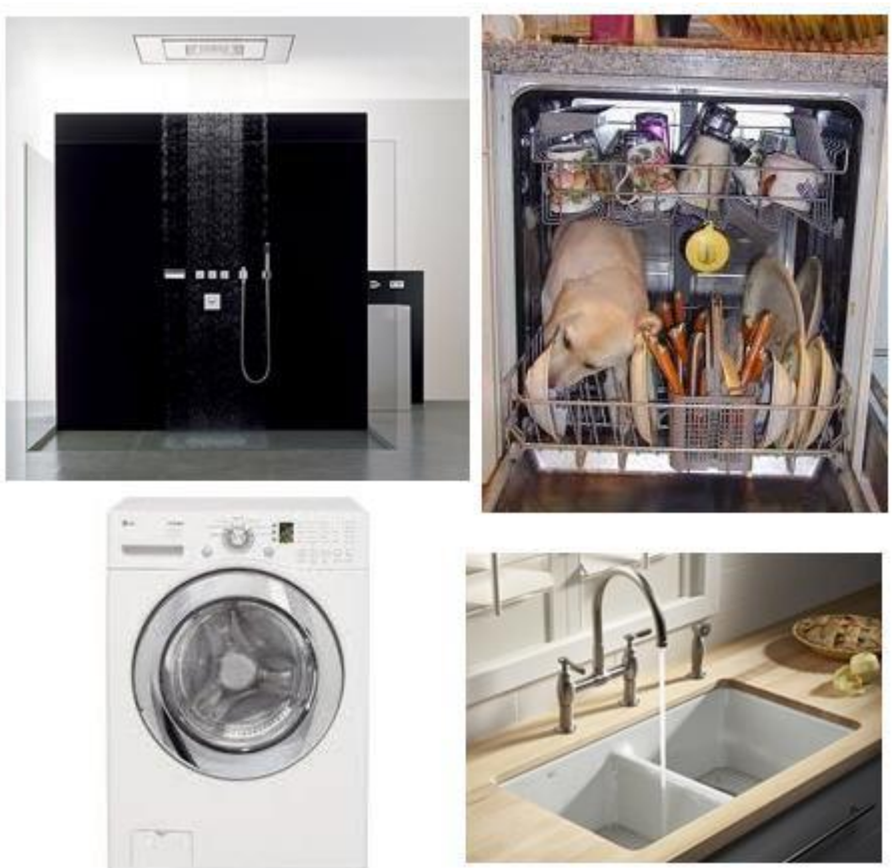

Figure 3 Sources of hot waste grey water

2.5. Grey Water Heat Recovery (GWHR) Systems

2.5.1. How GWHR Works

The operation for this waste GWHR system is based on simple principle of gravity film counter flow heat exchanger (Figure 4) i.e.., exchange of heat from hot part to cold part of the instrument. The heat exchanger is placed in such a way that the wide pipe of the exchanger is placed in the path of wide drainage pipes of the grey water sources and the cold water inlet pipe is connected to the narrow pipe of the exchanger that goes around the wide pipe of the exchanger in a helical fashion. The hot waste grey water passing through the drainage pipes (of the sources) flow through the wide part of the exchanger where heat is transferred to the narrow pipe of the exchanger heating up the cold water flowing through it.

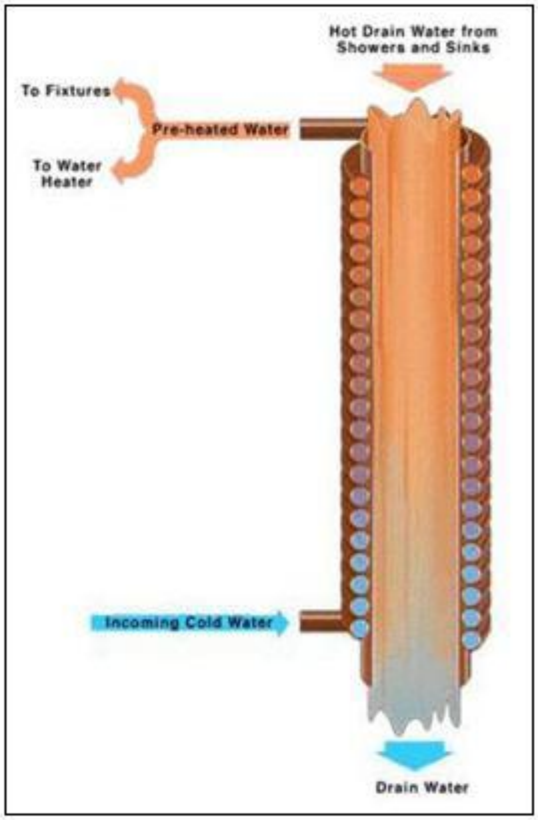

Figure 4 Heat Exchanger

The heat transfer mechanism (Figure 5) that happens in the counter flow heat exchanger is a combination of conduction and convection. Heat transfer by convection occurs at two places, (i) as the hot waste grey water comes in contact with the sides of the wide pipe of the exchanger and (ii) as the cold water comes in contact with the sides of the narrow pipe of the exchanger. Heat transfer by conduction occurs in parallel with convection from the wide pipe of the heat exchanger to the narrow pipe of the heat exchanger.

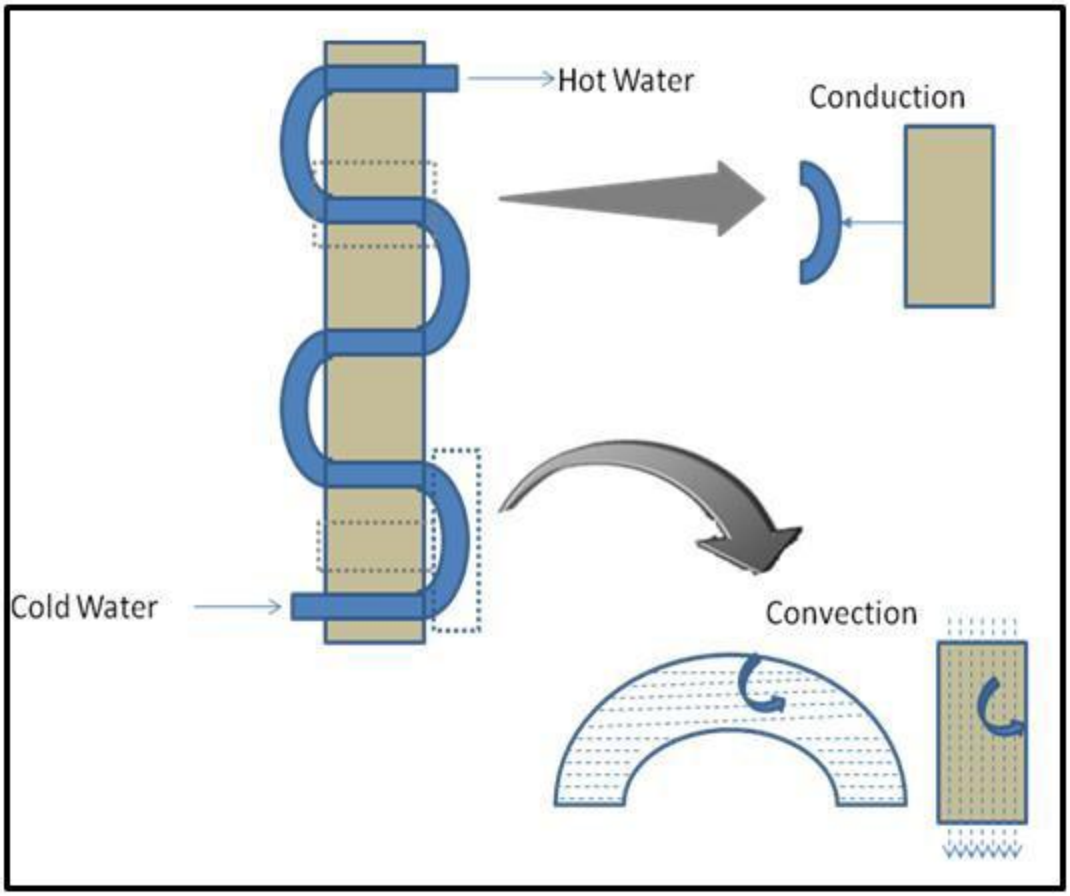

Figure 5 Heat Transfer by Conduction and Convection

3. Methodology

3.1.Initial analysis of heat recovery systems

The heat recovery system that was considered is from Watercycles Energy Recovery Inc. These systems are basically double-walled heat exchangers and are available in two different sizes (3” and 4”) according to drain pipe of respective sizes.

There are two types of this system, namely single GWHR and split GWHR systems as shown in Figure 6. Some of the units are used for residential and commercial purposes but some of them are used for only residential purposes and each has their own advantages (suitable for different applications). Consumers can select the appropriate one (or a combination of these units) depending on the building needs by going through the datasheet of the products and talking to the company's representative.

Figure 6 Two types of heat exchangers (single GWHR and split GWHR systems)

3.2.Investigation of Existing Systems

Existing GWHR systems were investigated to become familiar with practical design issues and system performance. The method of investigation was to perform site visits to inspect the system, take photos, and discuss performance with maintenance staff. Two existing systems were investigated: Haro Park Centre, and Wesbrook.

3.2.1. Existing GWHR System at Haro Park Centre

Haro Park Centre (Figure 7) for elderly care in downtown Vancouver has installed two such units for their dishwasher drainage. One system recovers heat from the drained waste hot grey water without the waste being drained and another system recovers heat from the waste that is being dumped. Heat recovered from both the units is mixed and sent to boiler room where the boiler uses this heat to burn less natural gas to heat the incoming cold water. There is also a future plan to install another unit to recover heat from the laundry drained hot grey water. A couple of visits were made to this place to study the installed unit and the building manager, Mr. Vitaly shared a lot of information with me.

Figure 7 Haro Park Centre

There was an audit performed on this system (Figure 8) in the Haro Park Centre by CEEN student Raj Ghosh (as a part of his CEEN course study and community engagement project). According to his findings, the annual energy savings because of this heat recovery unit is 61 GJ and the annual GHG savings is 3,391 tonne. But these data were obtained by establishing a constant water flow for entire duration of measurements.

Figure 8 Heat Exchanger at Haro Park

3.2.2. Existing GWHR System at Wesbrook Mall

A different type of unit is installed at Wesbrook mall, namely the pre-heat recovery system. This system is different in its operation as it absorbs heat removed by the cooling system like refrigerators, food processing systems etc…, The heat removed then heats up the incoming cold water which can be used for dishwashers, laundry, cleaning etc.., But the system seems a bit expensive and is not a simple one. Data could not be obtained for this system to check the energy savings and hence the GHG emissions reduction due to this installed pre-heat recovery system.

3.3. Analysis and Concept Design for Sitka Building

The Sitka building was analyzed for the purpose of illustrating how grey water heat recovery (GWHR) systems perform. A site visit was made, facilitated with the help of Polygon staff. SITKA, located in the east campus of UBC is a 14-level (floors) high rise building with sophisticated interiors, gourmet kitchens, luxury bathrooms and custom choice systems. SITKA has a gold rating in REAP[4].

Each unit in the building has hot grey water drainage sources in two bathrooms each of which is with a shower and a sink, a washer/dryer, a dishwasher and a kitchen sink.

3.3.1. Plumbing details

Water from the Metro Vancouver water line enters the basement into second mechanical room. It is pumped up all the way to main mechanical room located at the top floor. The main mechanical room also has the conventional natural gas boiler where the incoming cold water is heated up and sent to the units in the buildings. Hot water is supplied through two sets of main pipes, one set supplying hot and cold water to bottom seven floors and the other set supplying hot and

[4] A new UBC-made rating system for residential building performance and it is similar to Leadership in Energy and Environmental Design (LEED), an internationally recognized rating system.

cold water to top seven floors of the building. At each floor, water supply to each unit is taken from this set of water supplies.

3.3.2. Drainage details

The drainage layout of the building (Figure 9) is of utmost importance while considering installation of GWHR system. As explained before, the scope of this concept study is restricted to installation of heat recovery system on drained waste grey water. If there is any mixing of grey and black water in any part of the building, that part is not considered for the study as it is difficult to recover any considerable amount of heat from the black water.

The layout of the building suggests that all the similar type of drainage pipes is a riser type, where the unit one above the other of the building are joined to the same drain. (Ex. Drainage pipes for washer/dryer in units A from levels 1, 2, 3, 4 etc.., are connected together in a riser type, until they drain to the main drain sump at basement). All the similar types of drainage pipes are connected to main drainage sump at basement which is in turn connected to main Metro Vancouver sewer line.

There are some differences in similar type of drainage pipes, one of which is that dishwasher drainage pipe is connected with kitchen drainage pipe in each of the unit before they are connected to the riser for kitchens / dishwashers. Also, the bathroom sink, toilet and shower drainage pipes of each unit are connected together in each floor before they are connected to drainage riser.

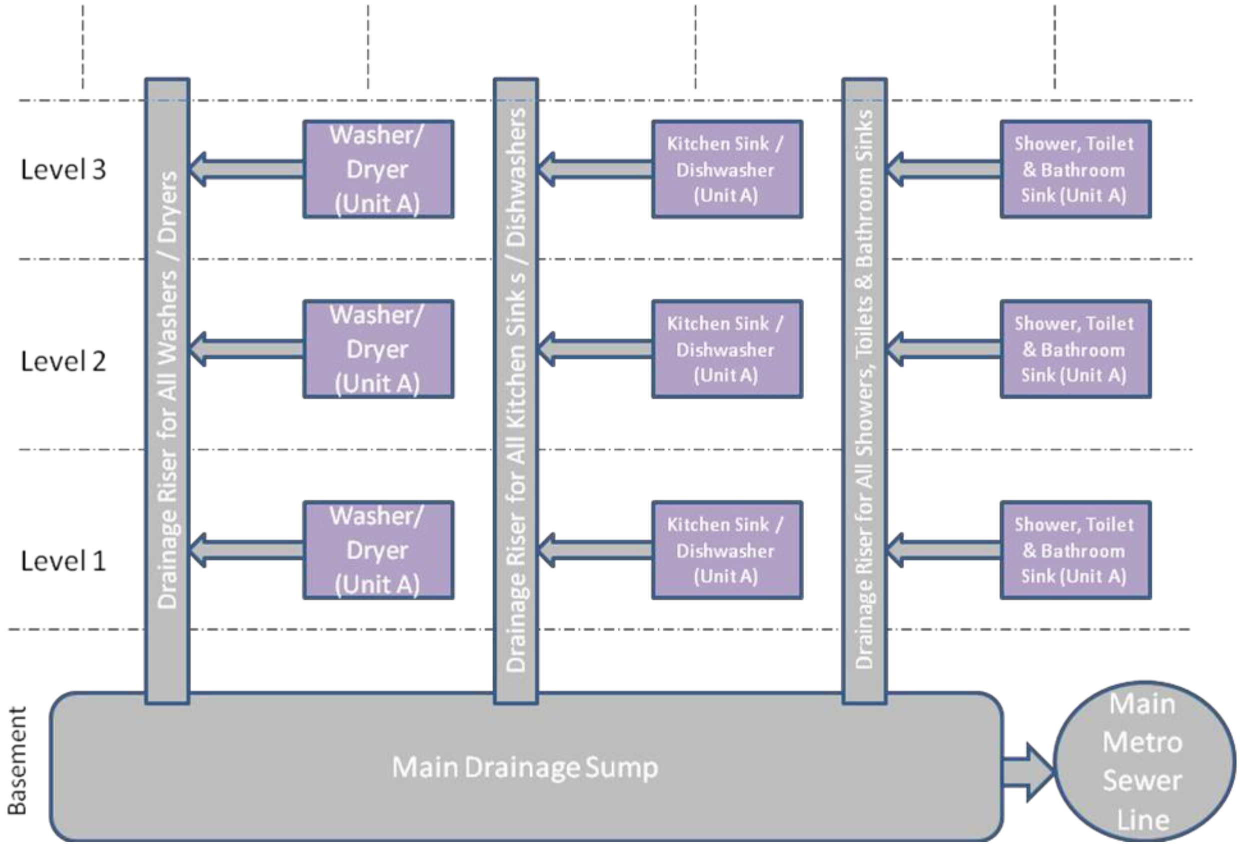

Figure 9 Drainage details at SITKA

From the drainage details, it is understood that heat recovery system can be deployed in two drainage risers, washers/dryers and kitchen sinks/dishwashers. The heat recovery system cannot be placed in bathroom drainage riser path as it contains black water and there is not enough heat that can be recovered from that riser.

3.3.3. Concept design of the heat recovery system for SITKA

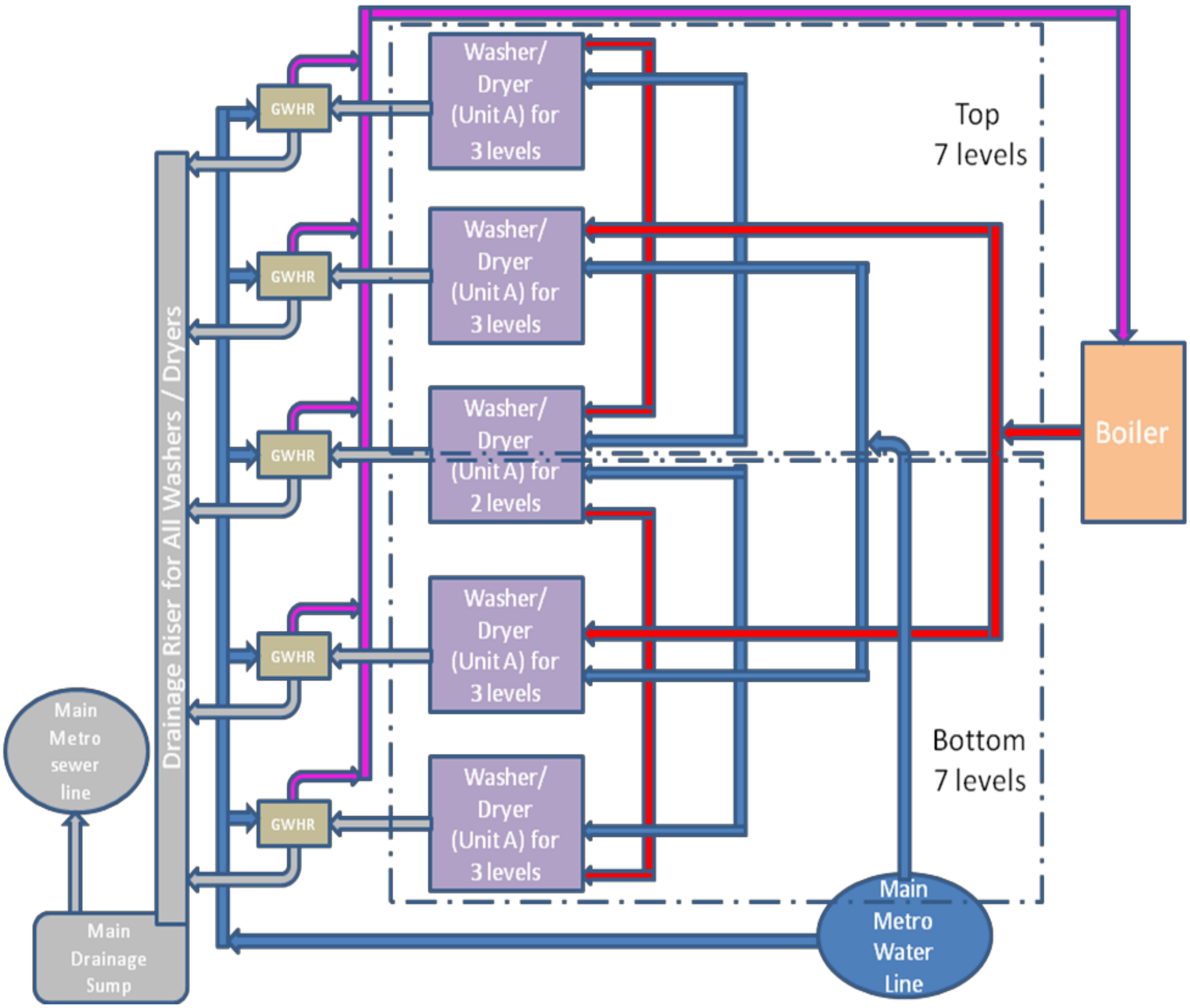

Figure 10 Concept design of proposed HRS in the path of drainage

The design that I am proposing is shown in the Figure 10. The connection to the water lines and the drainage lines is explained in earlier sections.

The design suggested is simply a deployment of heat recovery systems at the drainage outlet of washer / dryer one for every two / three levels (floors) for a similar type of unit in each level. The recovered heat is sent to the boiler and the water after heat removal is drained through the drainage riser for washers / dryers. Same set of heat recovery systems can be placed for recovering heat from drainage outlet of kitchen sinks / dishwashers. But the heat recovery systems cannot be used (as this study considers only waste grey water) to recover heat from drainage outlet of drainages of bathroom sinks / showers / toilets. The main problem as already mentioned is the mixing of waste black and grey water.

The advantages about the design incorporating only one heat recovery system for same unit type for three levels (floors) of buildings is due to the fact that this should be a more viable option from economic point of view for the builder to consider instead of having one system for each drainage outlet for each unit type at each level. Also, there cannot be just one system for the entire building as the hot drained waste grey water coming from the top levels (may be after three levels) may not be hot by the time it reaches the basement.

3.4. Basic Equations for Analyzing GWHR

3.4.1. Heat Recovered from waste grey water

Heat recovered (q[5]) from waste grey water is given by the following basic equations. All these equations are equal to one another except that the first two formulae are empirical and the last one is based on principles of physics and chemistry. Either of the formula can be used to calculate the heat recovered from waste grey water.

$$q = [(\dot{m} * C_p * \Delta T)_{hot}] * \text{effectiveness} = [(\dot{m} * C_p * \Delta T)_{cold}] * \text{effectiveness}$$
$$= [U * A * f * \Delta T_{lm}] * \text{effectiveness}$$

Where,

q = heat recovered (in Btu/hr),

$\dot{m}$ = mass flow rate of the waste grey water (in lb/hr),

C_p= specific heat of water (in Btu/lb °F),

ΔT= change in temperature of water during heat recovery (in °F)

f = correction factor (generally equal to 1, no units),

UA = Overall heat transfer coefficient (Btu/ft^2 hr °F)

ΔT_{lm} = logarithmic mean temperature difference = $\dfrac{(T_{hi}-T_{co})-(T_{ho}-T_{ci})}{\ln\left[\dfrac{(T_{hi}-T_{co})}{(T_{ho}-T_{ci})}\right]}$ (in °F),

T_{hi} = Incoming drained hot water temperature (in °F),

[5] For this project, I have used the empirical formula, $q = (\dot{m} * C_p * \Delta T)_{hot}$

T_{ho} = Outgoing drained water temperature (in °F),

T_{co} = Outgoing heat recovered water temperature (in °F), and

T_{ci} = Incoming cold water temperature (in °F).

3.4.2. Savings (Energy & Money) with Simple Payback[6]

Energy savings is calculated as the annual fuel consumed utilizing the GWHR system, as compared to a baseline system. For the Sitka building, the baseline hot water heating systems is a boiler (heating done using natural gas) at the main mechanical room at the terrace of the building.

3.4.2.1. Dollar Savings

Dollar Savings from the amount of heat recovered can be found out using a simple formula.

$$Dollar\ Savings = Energy\ Savings * fuel\ cost$$

3.4.2.2. Energy Savings

Energy Savings is simply given by

$$Energy\ Savings = q * (hours\ of\ operation/year)$$

[6] Payback is the length of time required to recover the cost of an investment.

3.4.2.3. Simple Payback

Simple payback formula is given below.

$$Simple\ Payback = \frac{(Capital\ cost\ of\ new\ installed\ system)}{Dollar\ Savings}$$

4. Results and Discussion

For SITKA building, the heat recovered and energy savings is only from dishwashers and clothes washer. Heat recovered and energy savings from kitchen sinks is negligible. For bathroom sinks and showers, the heat recovered and the energy savings are not included (for the total energy savings for the building) as water from these systems mixes with the toilet drained black water. A sample calculation is shown in appendix.

4.1. Assumptions

Reasonable assumptions (mentioned below) were made while calculating heat recovered from waste hot water, energy savings, dollar savings and GHG savings.

- *Number of GWHR systems*: This number is calculated based on the fact that 5 systems are needed for three households (for effective heat recovery) along each of the drainage riser (ex. Dishwasher) and 6 houses are present at each building levels.

- *Temperature maintenance*: The temperature of drained hot water entering the GWHR system remains at 36 °C and the outgoing drained water remains at 24 °C.
- *Flow rate of drained hot water*: Mass flow rate of drained hot water is calculated based on two data, (i) per capita hot water usage for dishwashers, clothes washer and showers as per the CBEEDAC report and (ii) number of people per household as per the Statistics Canada 2006 report.
- *Machine specific parameters*: Hot water usage per capita data was taken from CBEEDAC document on *Domestic Water Heating and Water Heater Energy Consumption in Canada*.
- *Capital cost of the GWHR system*: The cost of one of the Watercycles company's product (DX – 3058) is taken as the capital cost of the GWHR system.
- *Fuel Cost*: Fuel cost is taken from Fortic BC site.
- *Effectiveness of GWHR system*: Approximated to 45% based on DWHR Test Report from SRC[7] on Watercycles' model DX – 3058.

4.2.Impact of Energy

The energy savings for installing one GWHR system for SITKA building ranges from 0.93 GJ / yr [i.e.., 0.17 GJ / yr (dishwashers) and 0.76 GJ / yr (clothes washers)] to

[7] SRC – Saskatchewan Research Council

2.79 GJ / yr [i.e.., 0.52 GJ / yr (dishwashers) and 2.27 GJ / yr (clothes washers)] and the total energy savings for installing 30 such GWHR systems for the whole SITKA building ranges from 27.9 GJ / yr [i.e.., 5.23 GJ / yr (dishwashers) and 22.67 GJ / yr (clothes washers)] to 83.72 GJ / yr [i.e.., 15.7 GJ / yr (dishwashers) and 68.02 GJ / yr (clothes washers)].

This is the energy impact for SITKA building in present case and if the GWHR system is employed for shower drainage (if this drainage contains only Grey water), then the energy savings ranging from 1.22 GJ / yr to 3.66 GJ / yr gets added to the energy savings (this is for installing one GWHR system). The energy savings ranging from 36.57 GJ / yr to 109.7 GJ / yr gets added to the total energy savings. Then the total energy savings for the SITKA building would become a range from 64.47 GJ / yr to 193.42 GJ / yr.

4.3.Environmental Impact (GHG savings)

The GHG savings that can be obtained from installing the GWHR systems for the whole SITKA building ranges from 1.56 tons of CO_2 / yr [i.e., 0.29 tons of CO_2 / yr (dishwashers) and 1.27 tons of CO_2 / yr (clothes washers)] to 4.69 tons of CO_2 / yr [i.e., 0.88 tons of CO_2 / yr (dishwashers) and 3.81 tons of CO_2 / yr (clothes washers)].

Similar to energy savings, if GWHR system is deployed for shower drainages, the GHG savings range from 2.05 tons of CO_2 / yr to 6.14 tons of CO_2 / yr making a total GHG savings which range from 3.61 tons of CO_2 / yr to 10.83 tons of CO_2 / yr.

4.4.Economic Impact (Dollar savings)

The money saved from installing the GWHR systems for the whole SITKA building ranges from $ 111.62 / yr [i.e., $ 20.93 / yr (dishwashers) and $ 90.69 /yr (clothes washers)] to $ 334.87 / yr [i.e., $ 62.79 / yr (dishwashers) and $ 272.08 /yr (clothes washers)].

If GWHR system is used for shower drainages, then the money saved will be from $146.27 / yr to $438.82 / yr leading to total savings of $ 257.90 / yr to $ 773.69 / yr for the SITKA building.

If a $25/tonne of CO2 avoided is added, then the money saved for whole SITKA ranges from $150.69 /yr to $452.07 /yr. If system installed for shower drainages, then the money saved ranges from $348.16/yr to $1044.48/yr.

The capital investment needed for such a large scale investment is around $ 36, 000 ($18, 000 for dishwasher drainages [30 systems * $600 / system], $18, 000 for clothes washer drainages) for the whole SITKA building which is huge. But if we consider the alternate design of employing one GWHR system for the whole building (compromising on the quality of heat recovered), then the capital investment would be just $600. It is a worthwhile investment as money saved (due to energy savings) is $66.96 / year ($11.16 per set of 3 same unit households with clothes washer and dishwasher combined * 6 units per floor). Then a simple payback for 10 year period leads to a savings of $669.60 ($66.96/year * 10 years). Thus the $ 600 investment is covered by the energy savings from one GWHR system for the whole building.

4.5.Payback

The payback ranges from as high as 860 years to 286.68 years (for dishwashers) and 198 years to 66 years (for clothes washers). For showers, the payback is from 123 years to 41 years.

The tables show the overall energy savings, dollar savings, GHG savings and the payback for installing the GWHR systems in SITKA building according to the conceptual design for two mass flow rates of drained hot water (based on the time the drained water flows through the system). The net present value for installation of this GWHR system is not calculated as the payback period is very high for all the cases (i.e., for dishwashers, clothes washer and showers).

Table 1 Summary of savings when the mass flow rate of hot drained water is from one household

Parameters	Dishwasher	Clothes Washer	SITKA Total	Showers	Grand Total
Energy Savings (GJ/yr)	5.23	22.67	27.91	36.57	64.47
Dollar Savings ($/yr)	20.93	90.69	111.62	146.27	257.90
Payback (yr)	860.04	198.47		123.06	
GHG emission factor (kg of CO2 / GJ of NG)	56.00	56.00	56.00	56.00	56.00
GHG savings (tonne CO2/yr)	0.29	1.27	1.56	2.05	3.61
Dollar Savings (includes a $25/tonne of CO2 avoided) ($/yr)	28.25	122.44	150.69	197.47	348.16

Table 2 Summary of savings when the mass flow rate of hot drained water is from three households

Parameters	Dishwasher	Clothes Washer	SITKA Total	Showers	Grand Total
Energy Savings (GJ/yr)	15.70	68.02	83.72	109.70	193.42
Dollar Savings ($/yr)	62.79	272.08	334.87	438.82	773.69
Payback (yr)	286.68	66.16		41.02	
GHG emission factor (kg of CO2 / GJ of NG)	56.00	56.00	56.00	56.00	56.00
GHG savings (tonne CO2/yr)	0.88	3.81	4.69	6.14	10.83
Dollar Savings (includes a $25/tonne of CO2 avoided) ($/yr)	84.76	367.31	452.07	592.40	1044.48

The time of operation of machines (dishwasher and clothes washer) plays an important role whether they are being operated simultaneously or at different times. If all houses at the 3 levels operate the machines (dishwasher / clothes washer) simultaneously, then the drained hot water flows through the GWHR system simultaneously and the heat recovered will be more as there will be an increase in the mass flow rate. The machine operation times depend on the behavior of the household residents.

The behavior of residents plays an important role in heat recovery effectiveness, in that if households of SITKA residents were persuaded to use cold water settings for dishwashers and washing machines and to minimize the shower time usage, then heat recovered will be very less and insignificant. There are programs which deals with such sustainable human behavior (like the McKenzie-Mohr's CBSM[8]) which when implemented will be effective in reducing energy consumption. Then it can be argued that if such behavior changes are in place, then installing GWHR systems doesn't make sense as heat recovered will be less due to less hot water being used. Also the mass flow rates can be controlled (can be increased) such that three households can operate their machines at the same time in a day.

The heat recovered from the waste water depends on the mass flow rate flowing through the GWHR systems and the effectiveness of the system to capture the heat from the drained waste grey water. There are many systems in market with different manufacturers claiming different effectiveness to their systems. These claims need to be checked with practical implementation of such systems. There are some studies conducted on finding the amount of heat recovered and the effectiveness of the system

[8] Community based Social Marketing – A book on how to make changes in human behavior to save energy and lessen energy consumption.

by practically deploying the GWHR system. One such study was performed by Zaloum, Lafrance and Gusdorf for natural resources, Canada.

5. Limitations

There are a lot of limitations to the analysis study carried out here. The limitations are explained below.

5.1. Limitation to Watercycles' test data.

This project was limited to use the test data from a single manufacturer, i.e.., Watercycles. There are other manufacturers in the market namely, Powerpipe, GFX, etc… An analysis of test data from these manufacturers can give us an idea on how much of heat can be recovered.

5.2. Limitation to SITKA plumbing system.

As seen from the plumbing system explained in earlier section, the design of the plumbing system itself a limitation in that it is not optimized for heat recovery. If the GWHR system needs to be installed in the SITKA building, then there will be a lot of additional plumbing required.

5.3. Limitation to data on cost and detailed performance of heat recovery systems.

There is not a lot of data available on the cost of different heat recovery systems (particularly from different manufacturers) so that analysis could be made on which is the best cost-effective system for SITKA building. Also very important fact is the unavailability of performance data on the different heat recovery systems i.e.., how much heat can be recovered from this system practically from a multi-unit residential building setup like SITKA.

5.4. Uncertainties in daily (diurnal) and seasonal variations.

There are a lot of uncertainties associated with GWHR systems' working with respect to daily and seasonal variations. Whether the GWHR system recovers heat effectively even if it operates during any part of the day or year (during different seasons of the year) is not known.

6. Conclusion

From the calculations, we can understand that the amount of energy that can be saved from deploying GWHR system is less for a MURB like SITKA. The energy savings for the SITKA building can be much more significant if the system is deployed for shower drainage as well (as seen from the tables and impacts sections). Therefore the GWHR system works more efficiently when used for shower water drainage.

Even though there are energy savings (including shower drainage) and hence the GHG savings from using the GWHR systems, the system is not a beneficial investment from economic point of view as the systems does not have an effective payback period. In fact, the payback period is too high for having these systems for the dishwasher and clothes washer drainages but it makes sense to have these systems for the shower drainages as the payback period is comparatively less. GWHR systems could be deployed for dishwasher and clothes washer drainages if subsidies are given by the government for covering the cost of the systems.

If mass flow rate of drained hot water increases, then energy savings would also increase; this in turn increases the dollar savings. This will decrease the payback period but this means that we are increasing the hot water usage per capita which will increase the energy consumption per capita (this is generally referred to as *'rebound effect'*[9]). Behavioral changes of household residents also affect the mass flow rate as discussed in the results and discussion section.

For MURBs, the GWHR systems should be deployed for shower drainages from the economic point of view. But from energy and environmental point of view, it is better to deploy the GWHR systems for dishwasher and clothes washer drainages as well.

7. Recommendations for future work

The drainage for showers and bathroom sinks are linked with the toilet drainage. From the point of design recommendations, if the two parts are separated from toilet drainage pipes, then heat can be recovered from these places in the house which will result in more energy, dollar and GHG savings. Another design recommendation will be to combine all grey hot water drainages together into one drainpipe i.e.., combine the hot waste grey water drainages from dishwasher, clothes washer and showers together so that heat recovery can be more effective.

The behavioral aspects of the household residents in MURBs must be studied which will help in understanding how the residents operate their machines (dishwashers and clothes washers). Also, the time taken for residents to take shower can be studied from the behavioral aspects which will help in calculating the exact amount of water used by the residents.

[9] Increased level of energy services in response to efficiency gains (ex. Buying a energy efficient car like Toyota Prius make encourage the owner to drive more kilometers than he/she would drive).

It would also be interesting to install a test unit GWHR system in a MURB for drainages of dishwasher, clothes washer & shower and check the results for energy, dollar and GHG savings. Another point of interest would be to include seasonal variations while calculating all the savings.

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9. Appendices

9.1. Appendix 1: Sample Calculation

Common Data:

Number of GWHR units to be deployed at SITKA building

= 30 (6 units at 3 or 2 levels * 5)

Incoming drained hot water temperature (T_{in}) = 36 °C

Outgoing drained water temperature (T_{out}) = 24 °C

Specific heat of water (C_p) = 4.1855 J/g-K = 0.999497 Btu/lb-°F

Fuel Cost of NG = $ 4 / GJ

Cost of a GWHR unit[10] = $ 600.00

Effectiveness of the system = 45%

GHG emission factor[11] = 56 kg of CO_2 / GJ of NG

Temperature Change (ΔT) = T_{out} - T_{in} = 36 °C - 24 °C = 12 °C

= 53.6 °F (i.e.., [12°C * 9/5] + 32)

Number of people per household in Canada[12] = 2.5

Data:

Per capita hot water usage (for dishwasher[13]) = 3.4 L /day

= 0.9 gallons / day (i.e.., 3.4 L * 0.264)

(*Note*: This data of per capita hot water usage changes for clothes washer and showers)

Calculations:

Single Household drained water (for dishwasher alone):

Mass flow rate of drained hot water from single household ($\dot{m}$) = 2.25 gallons / day (i.e.., 2.5 * 0.9)

= 18.7875 lb/ day (i.e.., 2.25* 8.35)

Heat recovered (q) = $\dot{m}$ * C_p * ΔT * effectiveness = 18.7875 lb/day * 0.999497 Btu/lb- °F * 95 °F *45%

= 452.9267 Btu / day

[10] http://www.theresourcestore.ca/proddetail.php?prod=DX-3058
[11] http://oee.nrcan.gc.ca/industrial/technical-info/benchmarking/csi/appendix-b.cfm?attr=0
[12] http://www40.statcan.ca/l01/cst01/FAMIL53A-eng.htm
[13] From CBEEDAC report on "Domestic Water Heating and Water Heater Energy Consumption in Canada".

Energy Savings = (q * [days / yr]) = 452.9267 * 365 = 165318.3 Btu / yr

= 48.45 kWh / yr (i.e.., 165318.3 / 3412)

= 0.1744 GJ / yr (i.e.., 165318.3 *1055 / 10^9)

Dollar Savings = energy savings * fuel cost = 0. 1744 GJ / yr * 4 $ / GJ

= $ 0.70 / yr

Simple payback = Capital cost of new installed system / Dollar savings

= $ 600 / $ 0.70 / yr

= 860 years

Energy Savings for the total SITKA building = 0. 1744 * 30 GWHR systems = 5.23 GJ / yr

Dollar Savings for the total SITKA building = 0.70 * 30 systems = $ 20.93 / yr

GHG Savings = 5.23 GJ / yr * 56 kg / GJ / 1000 = 0.29 tons of CO_2 / yr

Dollar Savings (including $25/tonne of CO2 avoided) = $20.93 + ($25 / tonne of CO2 avoided * 0.29 tonne of CO2/yr) = $28.25 /yr

Thre e hous e holds ' dra ine d wa ter (for dishwasher alone):

Mass flow rate of drained hot water from single household ($\dot{m}$) = 56.3625 lb / day (i.e.., 18.7875 * 3)

Heat recovered (q) = $\dot{m}$ * C_p * ΔT *effectiveness = 56.3625 lb / day * 0.999497 Btu/lb- °F * 95 °F * 45%

= 1358.78 Btu / day

Energy Savings = (q * [days / yr]) = 1358.78 * 365 = 495954.8 Btu / yr

= 145.36 kWh / yr (i.e.., 495954.8 / 3412) = 0.5232 GJ / yr (i.e.., 495954.8 *1055 / 10^9)

Dollar Savings = energy savings * fuel cost = 0.5232 GJ / yr * 4 $ / GJ = $ 2.09 / yr

Simple payback = Capital cost of new installed system / Dollar savings = $ 600 / $ 2.09 / yr

= 286.7 years

Energy Savings for the total SITKA building = 0.5232 * 30 GWHR systems = 15.70 GJ / yr

Dollar Savings for the total SITKA building = 2.09 * 30 systems = $ 62.79 / yr

GHG Savings = 15.70 GJ / yr * 56 kg / GJ / 1000 = 0.88 tons of CO_2 / yr

Dollar Savings (including $25/tonne of CO2 avoided) = $62.79 + ($25 / tonne of CO2 avoided * 0.88 tonne of CO2/yr) = $84.76 /yr