A Technology-Aided Social Marketing Approach for Domestic Hot Water Consumption Reduction in a Multi-Unit Residential Building

Edgar David Sotelo Iniesta

University of British Columbia

CEEN 596

April 01, 2013

A Technology-Aided Social Marketing Approach for Domestic Hot Water Consumption Reduction in a Multi-Unit Residential Building

CEEN 596 Project Report

The University of British Columbia
Edgar David Sotelo Iniesta
April 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

This project was possible with the support and help of many individuals and organizations. I would like to express my sincere gratitude to all of them.

My thanks and appreciations go to Mr. Ralph Wells not only for his support and advice as a mentor for this project, but also for his tremendous impulse as a champion in the Clement's Green building.

I am highly indebted to Dr. Eric Mazzi who always finds a time slot despite his busy schedule to monitor and advice the progress of all students in the Clean Energy Program.

I also would like to give special thanks to Ms. Brenda Sawada who played an important role with the coordination and communication between all of us.

My grateful thanks are also extended to BuiltSpace Technologies and Enepro Systems for their confidence and good faith in this project. I highly appreciate Rick's and Marcie's support in this project despite all constraints.

I am obliged to Lyle and Lou-Ann Stevens for their support and advice during the process of writing this document and the oral presentation.

I express my gratitude to all my family and friends who are always available, under all circumstance, to share a thought or provide help for anything.

I thank to my parents and sisters for their continuous encouragement in every step I take.

Last but not least, to the incredible power of love incarnated in my beloved wife and daughters who are the most powerful reason to tackle every challenge I face in my life.

1 EXECUTIVE SUMMARY

The purpose of this project was to examine the effectiveness of a behavioral change pilot program aimed to reduce hot water consumption in the Clement's Green residential building located at UBC Vancouver campus. The project was supported by an online communication tool provided by BuiltSpace Technologies and hot water sub-metering provided by Enerpro Systems.

During this project, a new method for providing consumption information to building occupants was pilot tested as a means to stimulate a reduction in hot water consumption. This strategy was underpinned with a behavioral change program following the steps suggested by Doug McKenzie-Mohr [1]. The pilot was launched with a group of nine volunteers who live in the building.

Hot water consumption data was analyzed before and after the deployment of the strategy. There is not enough information to observe statistical evidence of a reduction in hot water consumption due to high variability in the after-deployment dataset. An extension of the after-deployment stage is suggested to overcome this lack of evidence.

Nevertheless, participants agreed that the improvement in availability of consumption information from this pilot was useful to them in regards to understanding their hot water usage and ultimately, this could lead to a reduction in consumption.

2 INTRODUCTION

Energy consumption for the operation of residential buildings is a complex phenomenon that depends on several correlated variables. Therefore, a systematic analysis to identify the main factors affecting energy consumption is a mandatory step in every demand-side management (DSM) initiative.

The importance of understanding consumption patterns was addressed in [2]. Some of the most important factors that affect consumption patterns are cultural factors, energy prices, technological infrastructure and policies. Because of cultural differences, energy consumption patterns are distinct around the world. Hence, it is impossible to design a unique global DSM initiative. Every effort aimed at reducing energy consumption must be developed according to a specific local context.

Several studies suggest that human behavior is also an element that matters in energy consumption trends. Human behavior is distinct in every culture around the world, and its impact on energy consumption cannot be underestimated. According to the words of Lutzenhiser: "The role of human social behavior has been largely overlooked in energy analysis, despite the fact that it significantly amplifies and dampens the effects of technology-based efficiency improvements" [3].

Three arguments of why behavior is an important component on energy consumption patterns are the following:

1. Technical and economic factors do not fully explain energy consumption patterns [3].
2. Behavioral change has the potential to produce energy savings at low cost [4].
3. Rebound effects for DSM and free riders for subsidies are behavioral responses to energy efficiency improvements [5].

Community-Based Social Marketing (CBSM) represents a powerful tool in energy conservation projects based on behavioral changes [1]. This pilot project was focused on implementing CBSM with the help of two complementary technologies (an online communication tool and hot water sub-metering) for achieving energy savings and water consumption reduction in a multi-unit residential building at the University of British Columbia (UBC).

Water sub-metering is a powerful tool for accomplishing a behavior change in people. Data from Environment Canada's Municipal Water and Wastewater Survey (MWWS) shows that "communities with full residential metering have lower water use than those without metering." [6].

Even though sub-metering by itself is a proven measure to achieve water consumption reduction, the importance of providing easy and simple access to consumption information to users has not been subject to study. This project represents a great opportunity to test the effects of a more available and simpler access to consumption information in Multi-unit residential building (MURB) with sub-metering.

2.1 Project background

This pilot project is the result of a synergy between different stakeholders with energy conservation as a common objective. In this section, project's stakeholders and their expected outcomes are addressed.

2.1.1 BuiltSpace Technologies

BuiltSpace Technologies Corporation, a recently-created BC company specialized in a cloud-based building management information system: BuiltSpace.

Among other functions, BuiltSpace is a communication platform between owners, managers, residents, contractors and other stakeholders in a building. All of these actors interact through BuiltSpace with the objective of enhancing a better building management, achieving energy efficiency and conservation objectives.

BuiltSpace gets energy consumption data from other specialized metering systems. The process of BuiltSpace for getting information from third party systems can be conceived as a "System Integration Project".

2.1.2 Enerpro Systems

Enerpro Systems offers engineering services including energy efficiency and sub-metering to their customers. One of their customers is Clement's Green Building, a multi-unit residential building at UBC. Enerpro Systems provides an energy management system for hot water energy in the building. The system collects information and analyzes the hot water demand on a daily basis and then, adjusts the settings of the gas-fired central water boiler to respond to specific patterns of the building's occupants.

Enerpro Systems is also responsible for metering and billing water consumption in the same building.

2.1.3 Clement's Green Building

Clement's Green Building was the third UBC's faculty and staff co-development project. Completed in August 2006, it has 55 two and three bedroom units in four stories comprising an area of 74,405 square feet. It is located in the Hawthorn Place Neighborhood in UBC campus. Clement's Green was named after Frederick Clement, Dean of UBC's Faculty of Agriculture from 1919 to 1949 [7].

Clement's Green was developed by the UBC Properties Trust, constructed by VanMar Construction and it was designed by Raymod Letkeman Architects in accordance with UBC's Residential Environmental Assessment Program (REAP), Clement's Green achieved the REAP Silver rating [8]. Among other features Clement's Green has the following water conservation measures: Dual flush toilets and faucet restrictors in all bathrooms, rainwater sensors on landscape irrigation sprinkler systems, energy star compliant dishwashers and front loading washing machines [9].

Based on the water sub-metering service, provided by Enerpro, every tenant pays for the volume of water supplied to their suite. In this sense, the only suitable option that keeps tenants informed about how much hot water they have used is through their bi-monthly bill.

According to Enerpro, Clement's Green's hot water consumption is 54% lower than the Canadian national average [10]. This huge difference in consumption could be attributed to conservation-oriented design of Clement's Green and effects in behavior due to hot water sub-metering.

2.2 Goals

The objectives of this pilot project are defined as follows:

1. Reduce domestic hot water consumption in the UBC Clement's Green Building compared with its current demand by means of the implementation of social marketing and behavioral change tools.
2. Pilot test the effectiveness of BuiltSpace's and Enerpro's tools as an integrated technology to reduce domestic hot water consumption by means of providing occupants better access to their consumption information.

2.3 Scope

This project is limited by one energy service in one multi-unit residential building:

1. The energy service is domestic hot water (DHW).
2. The multi-unit residential building is Clement's Green Building.

3 DATA SOURCES

This section addresses how a two-system approach for measuring and reporting hot water consumption was selected, followed by explaining how hot water consumption is measured in the building. The mechanism of retrieving consumption data from Enerpro's meters and the storage of that information in BuiltSpace is also analyzed.

3.1 A two-system approach for measure and report consumption

Enerpro Systems provided all the hardware and tools for measuring the consumption while BuiltSpace supplied corresponding tools to communicate the consumption to users. In this sense, every system contributed in their specialized activities, but some kind of integration was required to accommodate a flow of information between them. Several things to consider were taken into account with the objective to balance the trade-off between low latency in the data and servers load. The following business rules were considered when the integration was designed:

1. BuiltSpace can retrieve consumption data from Enerpro once a day, every day.

2. If Enerpro supplies data identified as “duplicated” –data that had been previously obtained and was appropriately stored on BuiltSpace database- then, previous data would be updated in BuiltSpace.
3. If an error occurs during data retrieval, following attempts must be done in further days until successful.

3.1.1 Measuring consumption

All suites in Clement’s Green have their own hot water meter provided by Enerpro Systems. The meters operate by pulse accumulation; one pulse represents a US gallon, and their resolution is limited to record every 10 pulses. Hence the meters register every 10 gallons of water consumed. The information is extracted from the meters through a programmable logic controller (PLC) which pools the meters every 6 hours and stores the pulse accumulator value in a text file. Every row in the file contains the date when the reading was taken, the meter identifier, and the value of the pulse accumulator.

3.1.2 Exporting consumption to BuiltSpace

In order to make the consumption information available to BuiltSpace, Enerpro enabled a File Transfer Protocol server (FTP) where the files created by the PLC were placed. Through a secured authentication mechanism, BuiltSpace was able to connect to the FTP server and download consumption files according to the business rules discussed earlier. Successful data extraction from the FTP server required an organized process orchestrated and executed in BuiltSpace. Figure 1 shows the tasks that comprise such a process. Table 1 shows a high level description for each task.

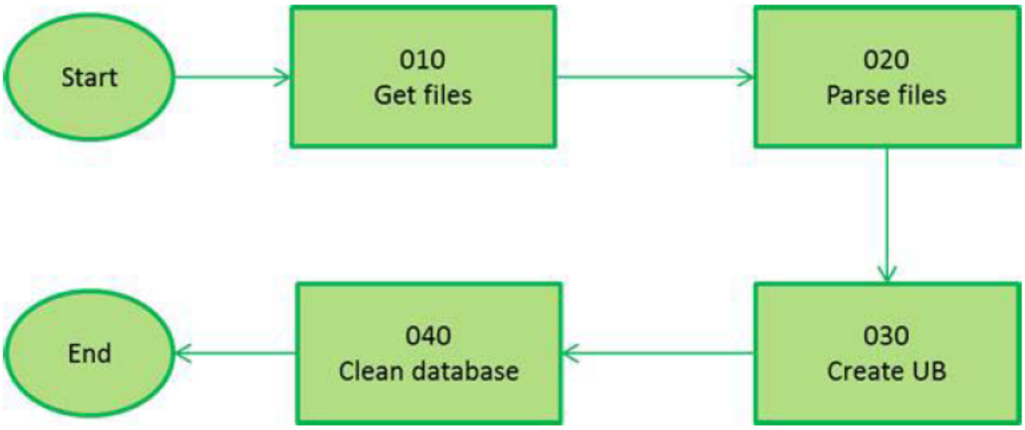


FIGURE 1 -BUSINESS PROCESS FOR BUILTSPACE-ENERPRO DATA INTEGRATION.

Task name	Description	Steps
010 Get files	Retrieve files from FTP server.	1. Checks system time. 2. Retrieves list of Clement's Green meters. 3. Get files from server.
020 Process files	Calculate consumption.	1. Read files. 2. Calculate consumption.
030 Create UB	Creates a utility bill in BuiltSpace for every meter that retrieved valid data from Enerpro	1. Checks if the utility bill exists on BuiltSpace. 2. If a previous exists, then updates the consumption. 3. If it doesn´t exists, then creates a new utility bill with data from response.
040 Clean database	Clear temporary tables on database	1. Clear tables that were used to calculate "yesterday's" consumption.

TABLE 1 - TASK DESCRIPTION FOR DATA INTEGRATION PROCESS.

3.1.3 Communicate consumption to BuiltSpace users

Consumption information is available to the building's occupants once it is stored in BuiltSpace database. Users can know the building hot water consumption through BuiltSpace's building dashboard (shown on Figure 2).

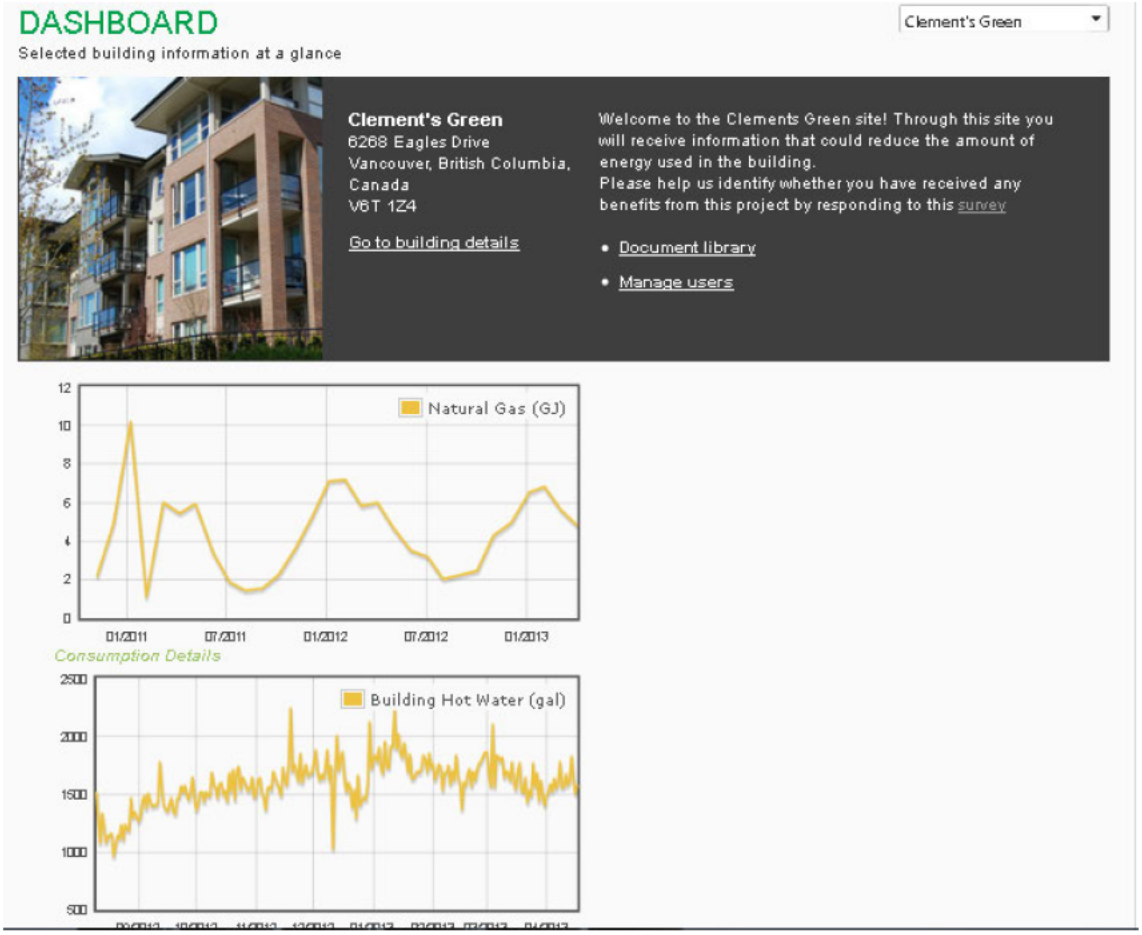
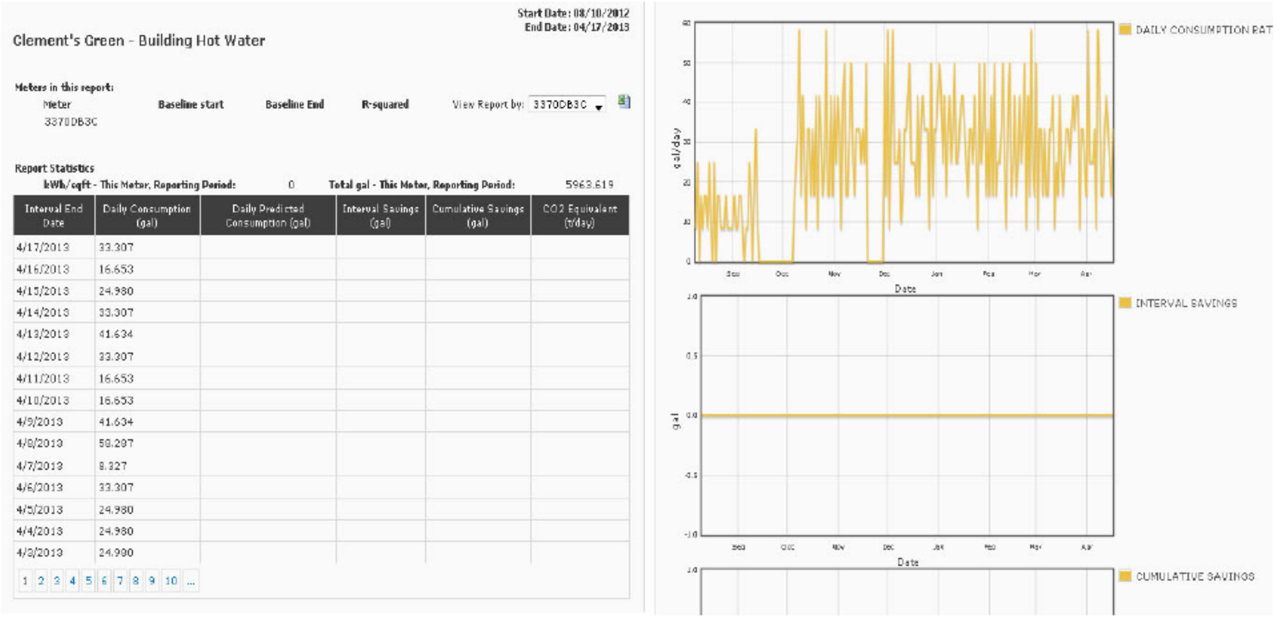


FIGURE 2 - BUILTSPACE'S CLEMENT'S GREEN DASHBOARD.

A BuiltSpace user is now able to see the total building hot water consumption and also it is possible to know their suite consumption through a detailed consumption report. Figure 3 shows an example of a consumption report for a specific suite in Clement's Green.


Clement's Green - Building Hot Water

Start Date: 08/10/2012
End Date: 04/17/2013

Meters in this report:

Meter	Baseline start	Baseline End	R-squared
3370DB3C			

View Report by: 3370DB3C

Report Statistics

kWh/sqft - This Meter, Reporting Period: 0 Total gal - This Meter, Reporting Period: 5963.619

Interval End Date	Daily Consumption (gal)	Daily Predicted Consumption (gal)	Interval Savings (gal)	Cumulative Savings (gal)	CO2 Equivalent (t/day)
4/17/2013	33.307				
4/16/2013	16.653				
4/15/2013	24.980				
4/14/2013	33.307				
4/13/2013	41.634				
4/12/2013	33.307				
4/11/2013	16.653				
4/10/2013	16.653				
4/9/2013	41.634				
4/8/2013	58.287				
4/7/2013	8.327				
4/6/2013	33.307				
4/5/2013	24.980				
4/4/2013	24.980				
4/3/2013	24.980				

1 2 3 4 5 6 7 8 9 10 ...

Figure 3 – Detailed suite consumption report.

During this pilot project, another report with more detailed information was available to active users. The content and the nature of said report will be discussed in the 4.6 section of this document.

4 METHODOLOGY

Because of its multi-stakeholder nature, the project was executed using an approach influenced by a quality improvement project model known as DMAIC. DMAIC stands for define, measure, analyze, improve and control - which are the stages of said methodology. More information about DMAIC can be found in [11] and [12].

A brief summary of the major tasks that were conducted in every stage is included in this section among the branding strategy and participant's engagement. Due to time constraints of this project, a control stage was not implemented.

4.1 Project branding

Branding is not a stage considered in DMAIC methodology, but a well branded project makes people get more involved and allows participants to identify with the project. For these reasons, a project name was selected and a website with all the project information was created. Table 2 shows some branding features developed for this project.

Project name	Albus project
Website	http://www.albus.ca
Project logo	

TABLE 2 -PROJECT BRANDING FEATURES.

4.2 Building occupants participation

An invitation to join the pilot was sent to all building occupants. An electronic message was posted in a building´s forum and some posters were shown at appropriate building locations. Figure 2 shows the invitation poster.

FIGURE 4 – INVITATION POSTER.

A more detailed project description was included in the project website. Interested participants filled in a form that was sent to a BuiltSpace email address. With this information, an account was created in BuiltSpace for every participant. A total of nine users from different suites showed interest in the pilot test. Users in this group were identified as "active users". In the following sections of this document "active users" refers to said group of users, while "passive users" represent the rest of suite occupants who didn't participate in the pilot test.

4.2.1 Sample size and representativeness

The group of nine active users (pilot test volunteers) was treated as a convenience sample. There was no reason to believe this small group accurately reflected the characteristics of the entire population of households in Clement's Green. In fact, the pilot test was executed under the hypothesis that active users have a "greener" attitude than passive users. This was indirectly assessed and confirmed with a statistical test. (See appendix on section 10.4)

4.3 Project stage: Define

In this stage, the problem to be solved is identified. Following a CBSM approach from Doug McKenzie-Mohr [1], behaviors related with hot water consumption in residential buildings were selected. Table 3 shows a list of selected behaviors in the project.

Behaviors to be encouraged	1. Wash clothes in cold water. 2. Take a shower in 5 minutes or less. 3. Turn off shower for soap-up and turn on again for rinse. 4. Use full loads for laundry washing.
Behaviors to be discouraged	5. Wash clothes in hot water. 6. Take a shower for more than 5 minutes. 7. Take a shower without turning off faucet for soaping-up. 8. Use light loads for laundry washing.

TABLE 3 – SELECTED BEHAVIORS.

Adoption levels, barriers and benefits of every behavior were also required to be identified. The following section discusses the method for measuring said behavioral characteristics.

4.4 Project stage: Measure

In this section the approach taken to measure adoption levels, barriers and benefits for identified behaviors is analyzed. Also, the method for determining a baseline for hot water consumption is addressed.

4.4.1 Measuring behavioral characteristics

This was done using BuiltSpace's survey capabilities. A survey aimed to detect barriers and benefits and measure adoption for selected behaviors was developed and launched to active users through BuiltSpace. User's confidentiality was provided by BuiltSpace security features. Figure 5 shows a screenshot of a sample question in the survey. Complete questionnaire is available in Appendix 10.1.

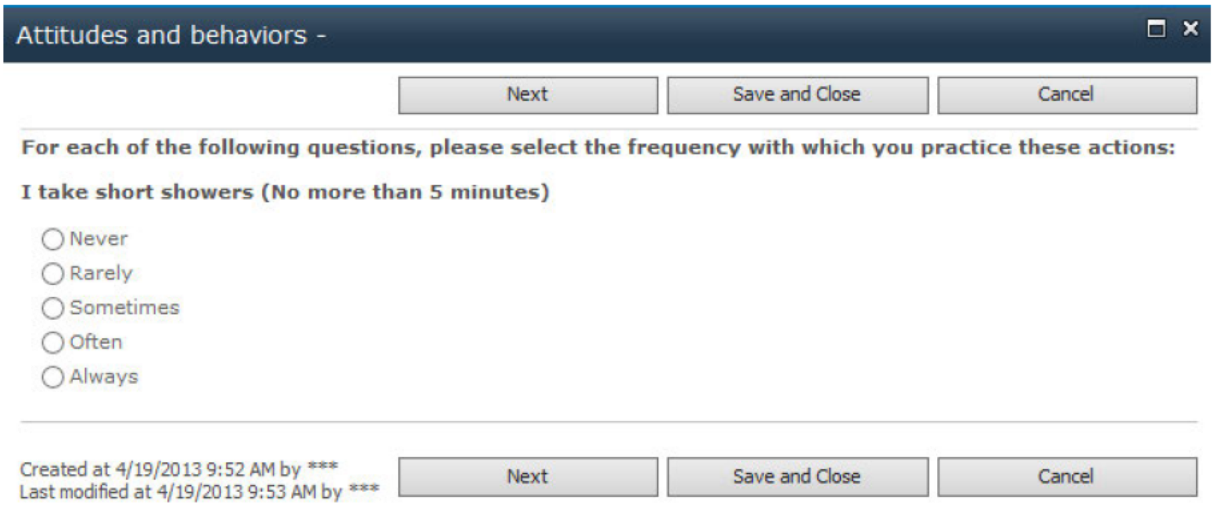


FIGURE 5 – SAMPLE SCREENSHOT OF BARRIERS AND BENEFITS SURVEY.

Based on survey results, a behavior analysis matrix was constructed. This was determined using an indicator that was calculated as the product of three factors: impact, adoption level and barriers.

Impact: This factor measures an estimated effect of the behavior in hot water consumption. A value of 1 indicates the weakest effect, while a value of 4 is for the strongest effect. The valuation was based on data from Environment Canada [6].

Adoption level: Evaluates the penetration level of the behavior in participants. The rationale for assigning a value for adoption level is behaviors with low adoption levels offer better gains. Thus, a value of 1 indicates the highest adoption level while a value of 4 is for the lowest adoption level.

Barriers: The obstacles that inhibit users for engaging in the behavior are gauged by this factor. A value of 4 indicates an activity with the weakest barriers while a value of 1 suggests the opposite. Table 4 shows the behavior analysis matrix.

Behavior	Impact [1 to 4]	Adoption level [1 to 4]	Barriers [1 to 4]	Weight
Wash clothes in cold water	2	1	3	6
5 minute shower	**4**	**2**	**2**	**16**
Turn off shower for soaping-up	3	4	1	12
Use full loads for washing clothes	1	3	4	12

TABLE 4 – BEHAVIOR ANALYSIS MATRIX.

Due to time constraints in the project, only the behavior with the greatest weight was selected as the target for behavioral intervention and this was: Encouraging occupants to take 5 minute showers. A detailed impact assessment is included in Appendix 10.5.

4.4.2 Hot water consumption baseline

This section discusses the method for calculating the hot water consumption baseline. Consumption was analyzed in three levels of aggregation: building total, group comparison (active users and passive users) and individual consumption.

Baseline start date was restricted by the earliest consumption data available in BuiltSpace database. Baseline end date was determined as the date when access to consumption data in BuiltSpace was granted to active users. Although consumption data was calculated on a daily basis, consumption baseline was based on daily average by week[1] (DAW). Using this average assures a Gaussian distribution in the sample, this will be discussed in the next paragraphs. Table 5 indicates consumption baseline properties.

Baseline start	August 10th 2012.
Baseline end	March 22nd 2013.
Unit	Daily average by week (DAW)
Number of weeks	34

TABLE 5 – BASELINE PROPERTIES.

From the quality control perspective, variation within any process is inevitable - it can be small, seemingly negligible or large - but always exists. According to Walter Shewhart [13], we have to deal with two qualitatively different sources of variability: common cause variation and special cause variation. Common cause variation is commonly perceived as "day to day" variation. A process is stable and predictable only if it is affected by common cause variation. On the other hand, special cause variation is the one that makes a process unstable and then, unpredictable.

Variation is also an issue in energy consumption data analysis since there are some factors that could affect consumer behavior. The key is to identify if the consumption is affected by common cause variation. A method called Statistical Process Control (SPC) has the ability to examine a process and the sources of variation in that process using tools that give

[1] For example: let [5, 8, 8, 7, 7, 6, 8] be the daily consumption for a suite in a week. The daily average for that week is the average of those consumption values (7).

weight to objective analysis over subjective opinions and that allow the strength of each source to be determined numerically. SPC charts provide a way to graphically analyze variation. A specific SPC chart was applied to the hot water consumption in order to determine if consumption was affected by common or special variation. From the audit perspective, special cause variation must be isolated in order to set a correct baseline.

The SPC chart utilized to analyze variation in hot water consumption was the Control Chart for Individuals [14]. It is commonly referred as I-chart and it is based on the mean value of the sample and its standard deviation. If a measurement is farther than ±3 standard deviation from the mean, then that measurement is affected by special cause variation. On the other hand, if a measurement is ±3 standard deviation near the mean, then that measurement is under common cause variation only. A requirement for the appropriate use of I-chart is that the SPC argument preserves its validity only if individual measurements are governed by a Gaussian distribution [13]. This has been secured by calculating the daily average by week (DAW) due to the central limit theorem which states that "Irrespective of shape of the distribution of a population, the distribution of sample means is approximately Gaussian when the sample size is large." [12].

A total of 55 I-charts were built (one for each suite) with help of the statistical software Minitab®. This made it possible to identify the special cause variations in every suite and those values were excluded from the baseline. Table 6 shows some special cases that were detected with this analysis method.

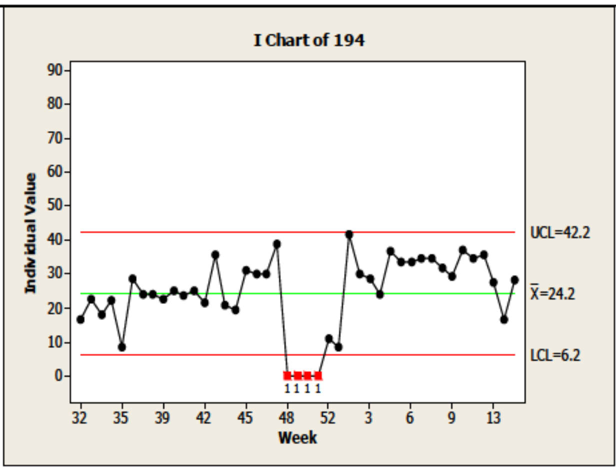
<table>
<tr>
<td>


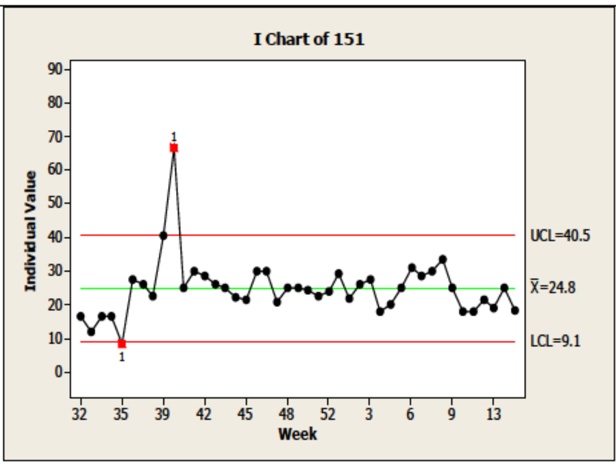
FIGURE 6 - I-CHART FOR SUITE 194.
</td>
<td>Figure 6 shows a period of four weeks with a very low consumption. This consumption could be due to a vacation period and it is not representative and then, should be excluded.</td>
</tr>
<tr>
<td>


FIGURE 7 – I-CHART FOR SUITE 151.
</td>
<td>Figure 7 shows two consumption values affected by special-cause variation. One is a high value while the other is a low value. Both should be excluded.</td>
</tr>
</table>

TABLE 6 – SPECIAL CASES DETECTED WITH SPC.

Once all suites were analyzed and special-cause variation points were excluded, a building consumption and individual suite consumption for active users were estimated. Figure 8 shows a chart with the building average consumption by week. Suite numbers were altered due to privacy restrictions. To avoid confusion, altered suite numbers were consistent in all stages of the project.

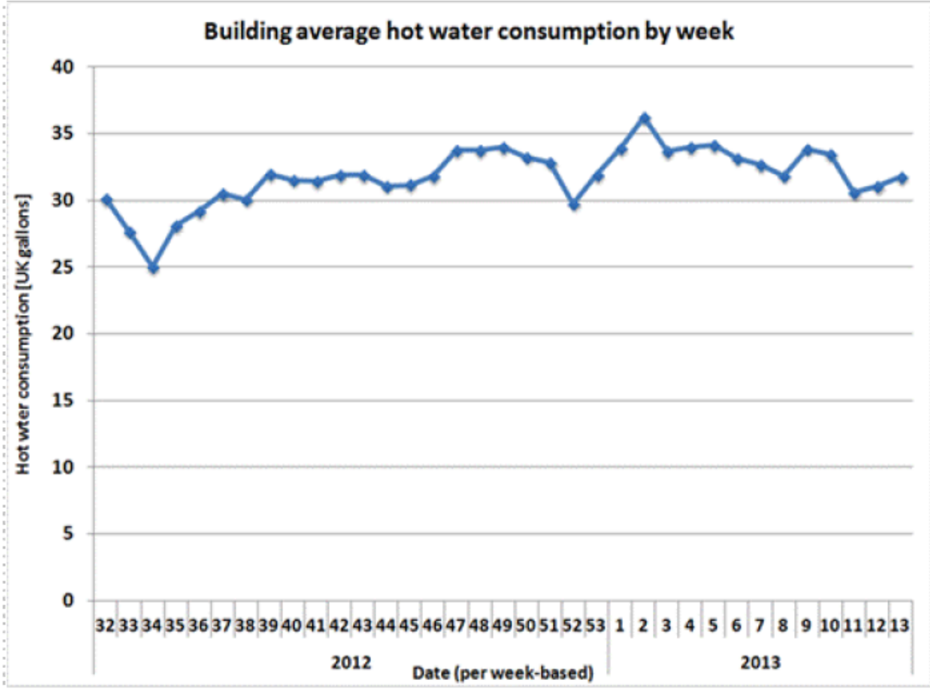


FIGURE 8 - BUILDING AVERAGE HOT WATER CONSUMPTION BY WEEK.

Group or Suite	Weekly average consumption [UK gallons]
Building average	31.49
Active users average	28.84
Passive users average	32.49
135	25.71
5C9	63.18
6BC	18.34
88F	26.07
938	38.01
A25	19.85
B1E	24.96
DF6	23.11
FA3	19.49

TABLE 7 – CONSUMPTION BASELINE CONDITIONS.

Information from Table 7 was used to determine if any improvement was achieved after the pilot test was concluded. This will be discussed in section 5.

4.5 Project stage: Analyze

In this stage, statistical methods and tools were used to identify the effects of other external factors -different than behavior- in hot water consumption. Analyzing the relationship between external factors and hot water consumption is useful to isolate any impact in hot water consumption due to the influence of such variables.

4.5.1 Factors analyzed

Hot water consumption may be affected by other factors different than behavior. Identification of other factors is required in order to measure results achieved by a behavioral change.

The following factors were analyzed to determine the possible effects of them in hot water consumption. Every factor was analyzed in isolation; no interactions between them were analyzed.

1. Outside temperature,
2. Occupancy,
3. Floor level.

Outside temperature: It is known that natural gas is used for heating purposes. Thus, a strong correlation between gas consumption and outside temperature exists. Correlation between outside temperature and hot water consumption was conducted for Clement's Green building through BuiltSpace analysis tools. This analysis was made entirely by a BuiltSpace database process coded by Daniel Fox from BuiltSpace. No evidence of correlation was observed between outside temperature and hot water consumption.

Occupancy: This is perhaps the most important factor in hot water consumption. A suite will consume more hot water if more people live there. Unfortunately, it was not possible to collect occupancy data for Clement's Green. Lack of occupancy data did not represent a risk in the project since occupancy can be considered a constant value in every suite and no changes in occupancy were observed during the pilot test.

Nevertheless, consumption profiles were determined according to hot water consumption levels. Table 8 and Figure 9 show the consumption profile and the number of suites in every one.

Profile name	Consumption [UK gallon per day]	Number of suites in profile
Very low consumption	Lower than 10	3
Low consumption	Between 10 and 20	11
Medium consumption	Between 20 and 30	15
High consumption	Between 30 and 50	13
Very high consumption	More than 50	7

TABLE 8 - CONSUMPTION PROFILES.

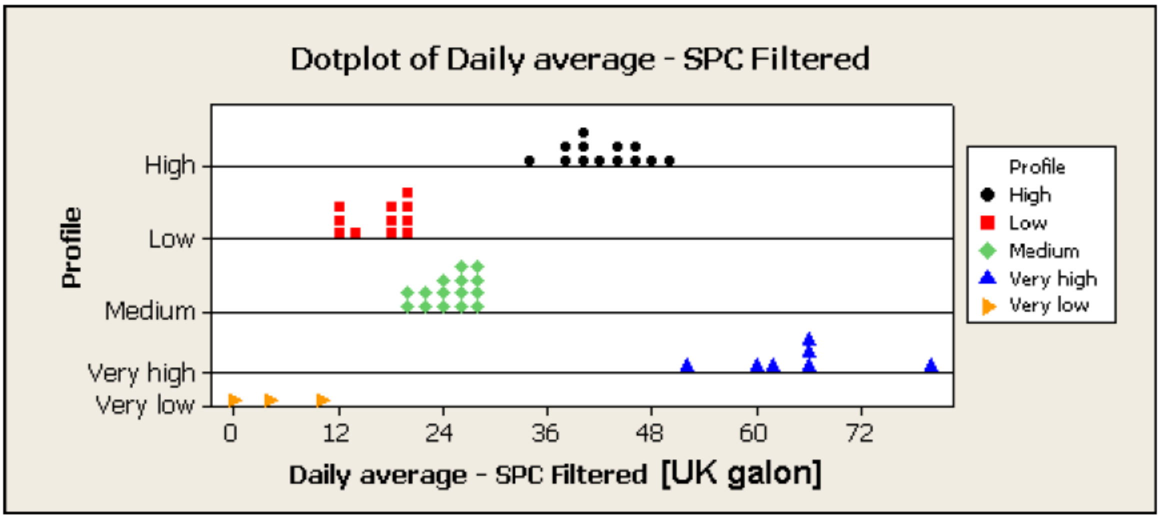


FIGURE 9 - DAILY AVERAGE CONSUMPTION DOTPLOT WITH PROFILES.

Floor level in building: Some active users expressed their concern about a possible correlation between hot water consumption and floor level in the building. They suspected that users in higher floor levels use more hot water due to longer pipe lengths for higher suites.

The effect of the floor level in the building did not impact the results of the project. This analysis was conducted as an added-value to building occupants. A hypothesis test with ANOVA was conducted on the dataset. Table 9 and Figure 10 show the results.

Ho	There is no association between floor level and consumption
Ha	There is a relationship between floor level and consumption
Significance value	0.05
p-value	0.000
Conclusion	A positive correlation between floor level and hot water consumption was found for 1st 2nd and 3rd floor. The 4th level does not follow the same relation. Further analysis is required due to interaction with other factors.

TABLE 9 - FLOOR LEVEL ANOVA.

One-way ANOVA: Daily consumption versus Floor

```
Source    DF      SS    MS      F      P
Floor      3   27386  9129  23.24  0.000
Error   1711  672102   393
Total   1714  699487

S = 19.82   R-Sq = 3.92%   R-Sq(adj) = 3.75%


                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level     N   Mean  StDev  --+---------+---------+---------+-------
1       420  30.58  19.01              (----*-----)
2       350  33.58  19.75                      (-----*-----)
3       455  35.66  22.47                             (----*----)
4       490  25.45  17.82  (----*----)
                           --+---------+---------+---------+-------
                           24.5      28.0      31.5      35.0

Pooled StDev = 19.82
```

FIGURE 10 - FLOOR LEVEL ANOVA RESULTS.

Since the results suggest a correlation, further analysis with consumption profile and occupancy is suggested due to a possible interaction between those factors.

4.6 Project stage: Improve

This stage addresses how a behavioral intervention was conducted with the objective to reduce hot water consumption in active users. Section 4.4.1 provided a matrix with weights for selected behaviors from section 4.3. Due to time constraints in the project, only the biggest-weight behavior was chosen (Take a shower in 5 minutes or less).

A 5-minute shower timer was provided to active users with the objective to encourage them to take 5-minute showers. Figure 11 displays a picture of such timer.

FIGURE 11 - 5-MINUTE SHOWER TIMER.

Timers were delivered to active users in a workshop that took place on April 8th. Any possible change in shower time, and then in hot water consumption was expected the day after.

An additional measure was applied to reduce the hot water consumption: An suite-based hot water consumption report that was sent electronically to every active user since March 22nd. This report was delivered by email and includes the following characteristics:

- A benchmark between users' consumption and building average consumption.
- A benchmark between users' consumption and Canadian national average consumption, based on data from [6].
- An injunctive norm comprising a smiley face based in benchmark result.
- A break-down of daily consumption showing 4 of 6-hour periods in a day.

A sample report is shown in appendix 9.2.

It was expected that a combined effect between the report and the shower timer could reduce hot water consumption in active users.

5 RESULTS

Project findings are discussed in this section. Results were obtained by a comparison in hot water consumption between initial conditions (baseline) and post-intervention stages. Feedback from active users regarding their experience with electronic consumption reports was gathered in a workshop and through a survey. A Complete survey questionnaire has been included as appendix 10.3.

Post-intervention dataset was subject to the same Statistical Process Control (SPC)[2] analysis with the objective to exclude special-cause variation. Table 10 shows post-intervention dataset properties and Table 11 compares properties between baseline and after-intervention datasets.

Post-intervention start	April 9th 2013.
Post-intervention end	April 16th 2013.
Unit	Daily consumption [UK gallons]
Number of days	8

TABLE 10 - POST-INTERVENTION DATASET PROPERTIES.

	STAGE	
Attribute	BASELINE	POST-INTERVENTION
Start	August 10th 2013.	April 9th 2013.
End	March 22nd 2013.	April 16th 2013.
Unit	Daily average by week.	Daily consumption.
Number of elements	34	8

TABLE 11 - DATASET COMPARISON.

A hypothesis test (significance of 0.05) with ANOVA was conducted for every suite with the objective to compare the mean value between baseline and after-implementation stages. Some suites achieved a lower mean than their baseline condition, but the p-value of the test was not low enough to suggest a change with statistical evidence. Figure 12 shows ANOVA results and SPC chart for suite 5C9.

---

[2] SPC was discussed in section 4.4.2.

One-way ANOVA: Value_5C9 versus stage_5C9

```
Source     DF    SS   MS     F      P
stage_5C9   1   422  422  3.53  0.068
Error      40  4782  120
Total      41  5204

S = 10.93   R-Sq = 8.10%   R-Sq(adj) = 5.80%


                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level    N   Mean  StDev  ---------+---------+---------+---------+
After    8  58.29  13.35  (---------------*--------------)
Before  34  66.36  10.35                        (-------*------)
                          ---------+---------+---------+---------+
                                55.0      60.0      65.0      70.0
```

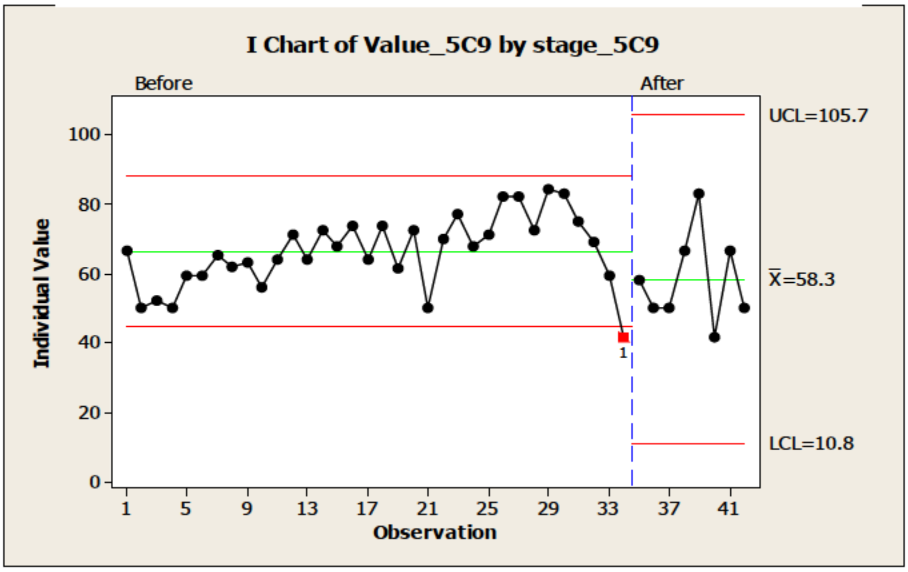


FIGURE 12 - ANOVA RESULTS AND SPC CHART FOR SUITE 5C9.

Table 12 shows a comparison between baseline and post-intervention stages for all active users.

Suite	Mean value consumption [UK gallons] BASELINE	Mean value [UK gallons] AFTER PROJECT	Type of change	Statistical evidence of change?
135	27.14	18.74	Reduction	**Yes**
5C9	66.36	58.29	Reduction	**No**
6BC	19.37	11.45	Reduction	**Yes**
88F	23.43	29.14	Increase	**No**
938	37.91	33.31	Reduction	**No**
A25	20.22	19.78	Reduction	**No**
B1E	27.16	21.86	Reduction	**No**
DF6	21.91	24.98	Increase	**No**
FA3	17.22	22.90	Increase	**Yes**

TABLE 12 – BEFORE AND AFTER CONSUMPTION COMPARISON.

Variation in after-implementation dataset was higher than baseline. This effect was due to the small number of measurements in the dataset (8 days). Central limit theorem is useful to reduce variations in the sample, but it was pointless to generate a daily average by week (DAW) for an 8-day dataset because the sample would have been reduced to 1 week of data (one single point). Because of this variation level, only three users modified their consumption with statistical evidence. One of them had increased his consumption.

Even though there was not enough data to suggest an increase with statistical evidence, other two suites (88F and DF6) got a higher mean than their baseline. This could be the consequence of a conflict between social norms in the consumption report: Users were compared with their neighbours but may perceive they consume much less hot water than the national average and this perception could induce an increase in consumption. Remarkably, suite FA3 -with the lowest consumption in the baseline- increased its consumption with statistical evidence after the pilot test.

Another factor that has a direct impact in variability of after-implementation dataset is the meter resolution. Meters are capable to detect changes for every 10 gallons. This resolution is enough for a bi-monthly bill (status quo), but it is not the case for a daily measurement (project method). A better resolution could reduce variability in the daily consumption, allowing a lower sample size in datasets to estimate changes with statistical evidence.

In terms of usefulness of the weekly reports, participants agreed that the information shown in the weekly consumption reports was easy to understand.

6 LIMITATIONS

The following restrictions limited the project´s results:

1. Lack of a public commitment and social diffusion: Time and effort required to accomplish this step was clearly underestimated. An attempt to request a small and personal commitment by attaching a message in volunteers' mailbox failed due to lack of knowledge in building's bylaws and property restrictions. A well developed strategy requires some days to analyze options' pros and cons.
2. Not enough time in after-implementation stage.
3. Meters resolution.

7 CONCLUSIONS

Hot water consumption data was analyzed before and after the deployment of the strategy. There is not enough data to determine a statistical evidence of a reduction in hot water consumption. An extension of the after-deployment stage is suggested to overcome this lack of evidence.

Nevertheless, participants agreed that the improvement in availability of consumption information from this project was useful to them in regards of understanding their hot water usage and ultimately, this could lead to a consumption reduction.

8 RECOMMENDATIONS FOR FULL SCALE IMPLEMENTATION

Despite the lack of evidence in a reduction in hot water consumption, this project has been an excellent mechanism to generate valuable information to project stakeholders and people interested in following a similar approach. In this section some recommendations for a full scale implementation are discussed.

1. Use BuiltSpace's building dashboard as an online public commitment tool.
2. Allocate enough time to develop a well-managed social diffusion strategy. It was learnt from this project that spontaneous ideas for social diffusion can result in failure if an appropriate analysis is not conducted.
3. Integrate the weekly consumption report directly into BuiltSpace functionality.
4. Increase frequency of meter readings: Users expressed their interest to have 1-hour readings instead of 6-hour.
5. Increase meter resolution: Meters can register changes for every 10 gallons, this resolution is enough for calculating daily consumption, but it is not for a 6-hour reading.

6. Investigate possible correlation between floor level and hot water consumption.
7. Remove or reset the national consumption benchmark from weekly report. Due to the following:
    a. Users may increase their consumption after learning that they already consume much less hot water than the national average. This represents a conflict between a descriptive norm (national benchmark) and an injunctive norm (smiley face).
    b. National consumption benchmark was generated with information from all types of residential buildings and this includes single detached homes which may consume more water than MURBS. A more specific benchmark for MURBS could help to overcome the gap between the national average and the suite average.

9 REFERENCES

[1] D. McKenzie-Mohr, Fostering Sustainable Behavior: An Introduction to Community-based Social Marketing, New Society Publishers, 2011.

[2] P. C. Stern, T. R. Dietz and V. W., Environmentally Significant Consumption: Research Directions, Washington: National Academies Press, 1997.

[3] L. Lutzenhiser, "Social and Behavioral Aspects of Energy Use," *Annual Review of Enegy and the Environment,* vol. 18, pp. 247 - 289, 1993.

[4] Dietz, Gardner, Gilligan, Stern and Vandenbergh, "Household actions can provide a behavioral wedge to rapidily reduce US carbon emissions," *Proceedings of the National Academy of Sciences,* pp. 18452-18456.

[5] UK Energy Research Centre, "The Rebound Effect: An Assessment Of The Evidence For Economy-Wide Energy Savings From Improved Energy Efficiency," 2007.

[6] Enviroment Canada, "Water usage," 2013. [Online]. Available: http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=851B096C-1. [Accessed 19 04 2013].

[7] The University of British Columbia, "UBC Public Affairs Media Release," 09 2005. [Online]. Available: http://www.publicaffairs.ubc.ca/media/releases/2005/mr-05-109.html. [Accessed 05 05 2013].

[8] UBC Properties Trust, "UBC Properties Trust," [Online]. Available: http://www.ubcproperties.com/portfolio_detail.php?category=Type&list=Residential&id=Clements%20Green. [Accessed 29 01 2013].

[9] D. Hendrickson and M. Roseland, "Green Buildings, green consumption: do "green" residential developments reduce post-occupancy consumption levels?," Simon Fraser University, Burnaby, B.C., 2010.

[10] Enepro Systems, "Clement's Green Case Studies," 2011. [Online]. Available: http://www.enerprosystems.com/project_clementgreen.html. [Accessed 27 04 2013].

[11] J. M. Juran, Quality Control, Mc-Graw Hill, 2005.

[12] R. A. Munro and e. al, The Certified Sig Sigma Green Belt Handbook, Milwaukee: Quality Press, 2007.

[13] J. R. Thompson and J. Koronacki, Statistical Process Control, CRC Press, 2002.

[14] H. M. Wadsworth, Statistical Process Control, Mc-Graw Hill, 2005.

[15] S. Bin, "Greening Work Styles: An Analysis of Energy Behavior Programs in the Workplace," Washington, D.C, 2012.

[16] GLOBE Foundation, "The Endless Energy Project," 2007.

[17] Environment Canada, "2011 Municipal Water Use Report," Minister of the Environment, Ottawa, 2011.

10 Appendices

10.1 Barriers and benefits survey

Description

Thank you for taking the time to complete this online survey. This research project will attempt to identify some improvement opportunities about hot water and energy conservation in Clement's Green Building. This survey is part of the requirement for a Master of Engineering (M.Eng.) degree at University of British Columbia and my credentials with UBC can be confirmed by contacting M.Eng. Program Coordinator, Dr. Eric Mazzi at [redacted]

The estimated time to respond this survey is between 5 to 10 minutes. The questions will explore your interest in water and energy conservation and how your daily activities in your home impact your water and energy consumption. In addition to submitting my final report to UBC in partial fulfillment for the M.Eng. Program, I will also be sharing my research findings to the University Neighborhoods Association (UNA) and the UBC Alma Mater Society (AMS).

The information you provide will be summarized, in the body of the final report. At no time will any specific comments be attributed to you unless your specific agreement has been obtained beforehand. All documentation will be kept strictly confidential. You are not compelled to participate in this survey. If you do choose to participate, you are free to withdraw at any time without prejudice. Similarly, if you choose not to participate in this survey, this information will also be maintained in confidence. If you have any questions regarding this research project please contact David Sotelo at [redacted]. Your completion of this survey will constitute your informed consent.

Questions

Section 1 – Concern and commitment

1. How concerned are you about the impacts on our environment due to the following activities?
    - Electricity generation
    - Fossil fuel-powered transportation
    - Natural gas used for heating buildings
    - Water consumption
    - Waste management
2. How committed are you in order to minimize the impacts on our environment due to the following activities?
    - Electricity generation
    - Fossil fuel-powered transportation
    - Natural gas used for heating buildings
    - Water consumption
    - Waste management

Section 2: Attitudes.

For each of the following questions, please make a selection within the range that best represents your opinion. (Totally agree, agree, neutral, disagree and totally disagree)

3. We have lots of energy in BC so there's no reason to conserve energy.
4. We have lots of water in BC so there's no reason to conserve water.
5. I have little control over the amount of hot water used in Clement's Green building, so even if I tried to conserve hot water in my apartment wouldn't make a difference.
6. Energy conservation is an important issue these days so people should try to do everything they can to save energy.
7. Water conservation is an important issue these days so people should try to do everything they can to save water.
8. Our energy in BC is clean so it has no impact on the environment.
9. I'm interested in use less hot water in my home since I pay the hot water bill.
10. If I tried to conserve energy and/or water I'd have to give up certain comforts and conveniences and I don't want to do that.

Section 3: Behaviors.

For each of the following questions, please select the frequency with which you practice these actions (Never, Rarely, Sometimes, Often, Always)

11. I take short showers (No more than 5 minutes)
    a. You have said you rarely or never take short showers. Could you identify any special reason from the following list that impedes you to spend five or less minutes for shower?
12. When I am taking a shower, I turn off the showerhead to soap up and shampoo, and turn it back on to rinse.
    a. You have said you rarely or never turn-off the faucet for soap-up. Could you identify any special reason from the following list that impedes you to conduct those steps?
13. I use cold water for cloth washing
    a. You have said you rarely or never use cold water for cloth washing. Could you identify any special reason from the following list that impedes you to use cold water for cloth wash?
14. I use full loads in the washing machine.
    a. You have said you rarely or never use full loads in your washing machine. Could you identify any special reason from the following list that impedes you to use full loads?

10.2 Weekly consumption report

Clements Green Building - Suite: XXX Meter: XXXXXXXX

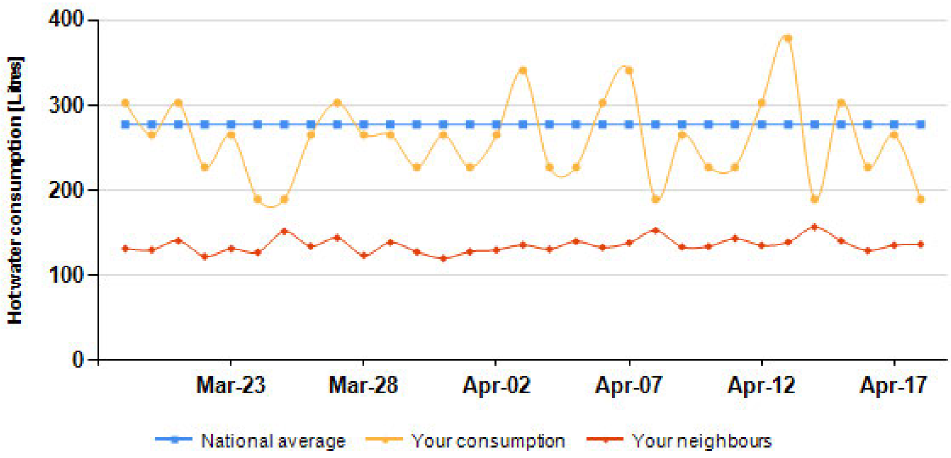
Domestic hot water consumption report - suite based

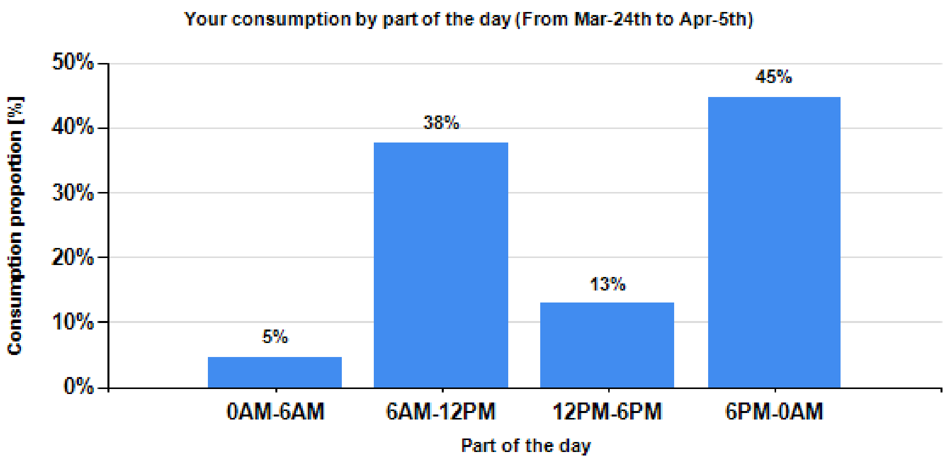
	Period starts	**19 Mar 2013**			**Period ends**	**19 Apr 2013**	
This period	**National average**	**8,870**	**litres**	**Daily average**	**National average**	**277**	**litres/day**
	Your neighbours	**4,035**	**litres**		**Your neighbours**	**126**	**litres/day**
	Your consumption	**8,025**	**litres**		**Your consumption**	**259**	**litres/day**

Benchmarking your consumption:

Your daily average consumption is below national daily average

Your daily average consumption is above your neighbours daily average





Assumptions:
1.-National DHW consumption is 132 litres per person per day.
2.-National building occupancy is 2.1 people per suite.
3.-Breakdown was calculated with data from Mar-24th to Apr-5th.

10.3 Outcomes perception survey

Description

Thank you for taking the time to complete this online survey. The estimated time to complete this survey is between 10 to 15 minutes. The following questions will explore your thoughts about the outcomes you could perceive from this project. In addition to submitting my final report to UBC in partial fulfillment for the M.Eng. program, I will also be sharing my research findings to the University Neighborhoods Association (UNA) and the UBC Alma Mater Society (AMS).

The information you provide will be summarized, in the body of the final report. At no time will any specific comments be attributed to you unless your specific agreement has been obtained beforehand. All documentation will be kept strictly confidential. You are not compelled to participate in this survey. If you do choose to participate, you are free to withdraw at any time without prejudice. Similarly, if you choose not to participate in this survey, this information will also be maintained in confidence. If you have any questions regarding this research project please contact David Sotelo at [redacted]. Your completion of this survey will constitute your informed consent.

Price: A $10.00 gift card from a local grocery store (tba) will be awarded to one lucky survey respondent. The draw will be conducted at 4:30 PM on April 22nd in UBC's Chemical and Biological Engineering building.

Questions

Section 1 – Impact on awareness

My participation in this project has changed my bearings about energy or water conservation in the following way:

- I am less concerned than before.
- I am equally concerned as before.
- I am more concerned than before.

Section 2 – Benefits from report please make a selection within the range that best represents your opinion.

The frequency of the report was… (activate branch logic to lower and higher responses)

- Lower than expected. A more frequent report will be more useful for me.
- Appropriate. A weekly report is appropriate for me.
- Higher than expected. A less frequent report will be more useful for me.

You said the frequency of the report was lower or higher than expected. Could you provide a suggestion about the frequency that you think is more appropriate?

The information shown in the report was…(branch logic for difficult and very difficult, add comment)

- Very easy to understand: Just a brief overview is required to understand the information shown in the report.
- Easy to understand: A bit of time to analyze the content of the report by me is required but I did not depend on anyone to explain it to me.
- Difficult to understand: I tried to understand the report by myself but the information was unclear until somebody explained it to me.
- Very difficult to understand: Even with help from others, the information shown in the report was quite difficult to understand.

You said that the report is not easy to understand. Could you comment about the difficulties you experienced understanding the report?

The report provided me with a better understanding of my hot water consumption.

- Strongly disagree
- Disagree

- Neutral
- Agree
- Strongly agree

The report enabled me to compare my hot water consumption against my neighbours.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

With the information provided by the report, I think I could conserve more hot water.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

Section 3 – Intervention.
For each of the following sentences please make a selection within the range that best represents your opinion.

I received the shower timer and...(branch in first answer to question 8, second to 9)

- I have not installed it, therefore I have not used it.
- I have installed it but I have not used it to measure my shower time.
- I have installed it and I have used it to measure my shower time.
- I have installed it, I have used it to measure my shower time and I have persuaded my family members to use it as well.

You said you have not installed the shower timer. Could you provide a reason for not installing it?

- Lack of time.
- Measuring the time spent in the shower is ineffective to reduce my hot water consumption.
- I have tried to install it but the device doesn't stick easily.
- Other reason

You said you have installed the shower timer but you are not using it to measure your shower time. Could you provide a reason for not using it?

- I forgot to measure my time.
- Measuring the time spent in the shower is ineffective to reduce my hot water consumption.
- I have tried to install it but the device doesn't stick easily.
- Other reason

The shower timer has helped me or my family reduce our shower time.

- Strongly disagree, Disagree, Neutral, Agree, Strongly agree.

The shower timer helped me or my family reduce our overall hot water consumption.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

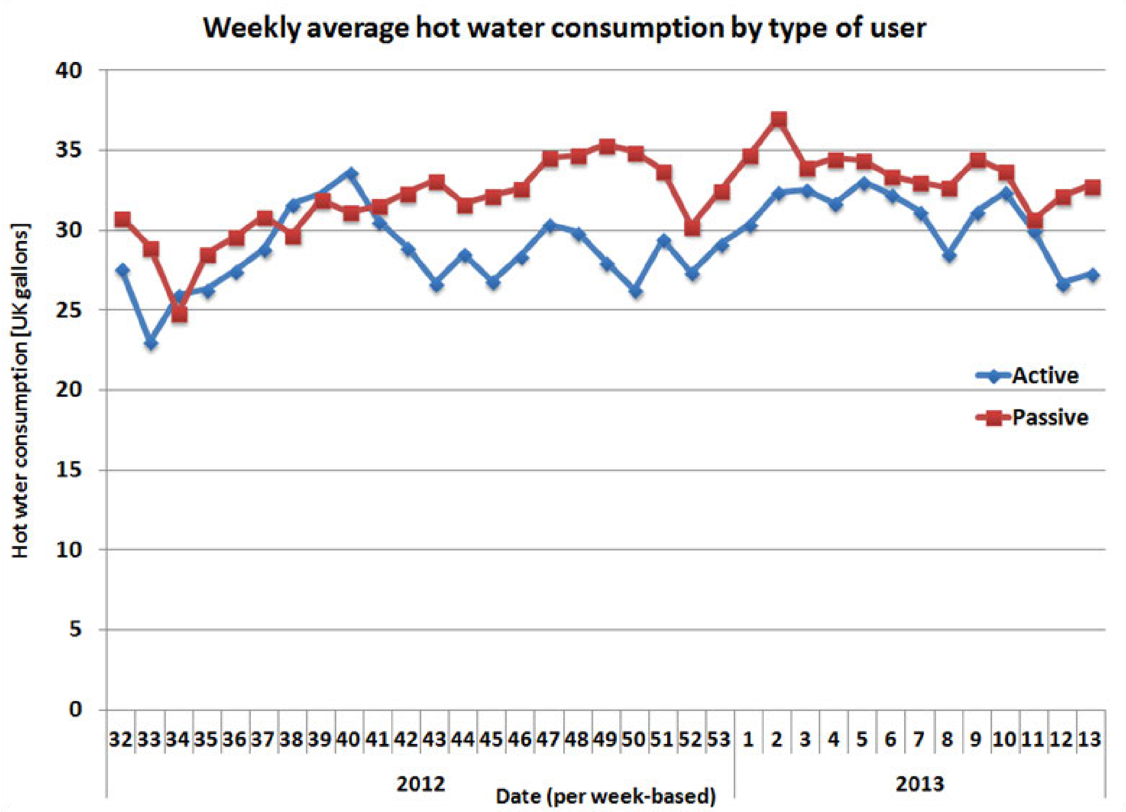
You have reached the end of the questionnaire. Your responses and your data will be kept confidential. In order to partake in the prize draw, please enter your email address below.

Please enter your email address:

Thank you for your participation in this survey and the Albus project!

10.4 Volunteer bias

A hypothesis test was utilized with the aim to identify if a relationship between type of user and consumption exists in the data. The selected tool was an ANOVA with type of user as a factor.
H0: There is no difference on hot water consumption between active and passive users.
Ha: There is a difference in the hot water consumption between active and passive users.
Significance level: 5%



One-way ANOVA: Active_2, Passive_2

```
Source  DF      SS      MS      F      P
Factor   1  162.14  162.14  27.80  0.000
Error   68  396.56    5.83
Total   69  558.70

S = 2.415   R-Sq = 29.02%   R-Sq(adj) = 27.98%


                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level       N    Mean  StDev  --+---------+---------+---------+-------
Active_2   35  29.348  2.481  (------*-----)
Passive_2  35  32.392  2.347                          (------*------)
                              --+---------+---------+---------+-------
                              28.8      30.0      31.2      32.4
```

Based on ANOVA results, p-value is lower than significance level then H0 is false and Ha should be taken. Therefore, active users have a lower consumption than passive users, this suggest a “greener” attitude in active users.

10.5 Impact of a 5-minute shower

This section describes the calculations made to estimate the impact of reducing the shower time to five minutes. Data was obtained from Environment Canada's water usage website [6].

Baseline: 10-minute shower
Assumptions:

1. Clement's Green suites already have a low flow showerhead.
2. According to an Enerpro study, 45% of the required energy for heating water is provided by a geo-exchange field while the remaining 55% is provided by natural gas.
3. Suite occupancy will be estimated through national average for MURBS (2.1 people per suite).
4. Every person takes a daily shower.
5. For heating purposes, water input temperature is 10C and output is 40C ($\Delta T = 30\ K$)
6. According to FortisBC. HHV for natural gas in the Lower Mainland is 38.58 GJ /1000 m3.
7. One GJ of energy from LNG combustion produces 56 kg of CO2 (data from NRCan).

Steps to estimate baseline:

1. Volume of water consumed by a 10-minute shower:

$$Water = time * flow$$
$$Water = 10[min] * 9.5 \frac{litres}{minute} = 95\ litres$$

2. Volume of water in a year for whole building:

$$Water = 95\ litres * 365\ days * 55\ suites * 2.1\ \frac{people}{suite} = 4{,}004{,}962.5\ litres \approx 4{,}000 m^3$$

3. Energy required to heat 4,000 cubic meters of water:

$$E = mass * Cp * \Delta T$$
$$E = 4x10^6 kg * 4.186x10^{-6} \frac{GJ}{kg\ K} * 30\ K = 502.32\ GJ$$

4. LNG combusted (55% energy is from LNG, 45% is from geo-exchange)

$$Energy = 0.55 * 502.32\ GJ = 276.28\ GJ$$
$$Volume = \frac{276.28\ GJ}{38.58x10^{-3}\ \frac{GJ}{m^3}} = 7.161\ m^3$$

5. Cost of energy from LNG:

$$Annual\ Cost = \frac{Basic\ charge}{day} * 365\ days + E * (Delivery + MidStream + Gas\ price)$$
$$Annual\ Cost = \$0.389 * 365\ days + 276.28 * (\$3.691 + \$1.192 + \$2.977)$$
$$Annual\ Cost = \$0.389 * 365\ days + 276.28 * \$7.86 = \$2{,}313.51$$

6. CO2 emissions:

$$Emissions = 276.28\ GJ * 56 \frac{kg}{GJ} = 15.471\ tonnes\ of\ CO2$$

Gains: By observation, the amount of shower time is half of the baseline then, the amount of water is halved. Therefore, the energy requirements and costs are the half of the baseline.

$$Water \approx 4{,}000 m^3 * 0.5 = 2{,}000\ m^3$$
$$Energy = 502.32 GJ * 0.5 = 251.16\ GJ$$
$$Cost = \$2{,}313.51 * 0.5 = \$1{,}156.76$$
$$Emissions = 15.471 tonnes * 0.5 = 7.735\ tonnes\ of\ CO2$$