Do LEED Certified Homes Perform As Expected?

White Paper on
Energy Performance Evaluation of LEED Homes in Manitoba

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Executive Summary

LEED (Leadership in Energy & Environmental Design) and other green standards for homes are intended to help develop buildings that are energy and water efficient, and that offer healthy and environmentally friendly indoor environments for people. That is basically why Manitoba Housing, the largest landlord in Manitoba, made the decision to develop seventy two (72) homes to those standards between 2011 and 2013 in three cities located in Northern and Western Manitoba. The homes were all designed according to green and LEED standards by one architectural firm, ft3 Architecture Landscape Interior Design, while the construction was done by three different contracting firms. Once construction was completed, only few units at each location were selected for and achieved LEED certification. Brandon units were used as affordable housing rentals, in the fall of 2011 while the units in both Thompson and The Pas were used as college students' family housing, in spring of 2013.

In 2014, there was a call from a number of stakeholders to conduct a Post Occupancy Evaluation (POE) for these units to find out how they perform now that all of them were occupied for a year, at least. Work on the POE was divided between two research groups, the first group from Red River College (RRC) led work on assessing the energy performance and lifecycle cost while the second group from the University of Manitoba led work on indoor environmental quality (IEQ) and a functional assessment. While the energy performance assessment; subject of this white paper, is completed; work is still ongoing to complete the other assessments. **Appendix A** includes up-to-date progress work related to lifecycle cost analysis and IEQ assessments.

For the past two years, monthly hydro billing data, provided by Manitoba Hydro, were methodically used to assess the energy performance of those units at the three locations. The energy performance was defined by levels of: 1) deviations of actual consumptions from projections, 2) trends and 3) variability/irregularity in consumptions. The analysis showed that there were no differences in performance between the LEED certified units and the other units. In addition, the analysis showed that trends and variability of monthly consumptions may deserve more attention than the absolute actual consumption values. Most importantly; the efforts made to collect and prepare the data for analysis reinforce the need for better and more precise energy monitoring and measuring systems.

Parallel to analyzing and assessing energy performance, a critical assessment of the LEED rating and certification process was conducted based on reviewing not only project-related documents but the related literature as well. It should first be noted that the initiative undertaken by Manitoba Housing and other stakeholders to provide LEED homes to students and low-income families should be extoled. As a matter of fact; other Manitoba organizations such as "Habitat for Humanity" and the Manitoba Chapter of CaGBC should also be commended for supporting efforts to provide LEED homes to Manitobans. And although there have been mixed results and opinions about the effectiveness of the

standard, it is believed, based on the assessment conducted, that LEED still can offer a viable process in the pursuit of sustainable homes. However, it is also believed that like many other processes, the LEED rating and certification process needs continuous improvements and tweaking in order to enhance the effectiveness of its rating system and hence the intended impacts. The results of the analysis conducted to date in this project provide empirical evidence that support such hypothesis.

Therefore and in addition to the primary goal of evaluating the energy performance of these homes in the three Manitoba cities, this white paper aims to achieve the following objectives:

- Propose a simple and yet effective process for benchmarking and managing energy performance in those and similar buildings in Manitoba
- Critique the effectiveness of the LEED standards and its rating process in achieving set expectations and further offering recommendations for continuous improvements

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1. Introduction & Background

The focus of this paper is on assessing the energy consumption performance of seventy-two (72) housing units that were all designed to LEED standards but only a few were certified: four (4) units in Brandon, six (6) units in each of The Pas and Thompson.

The paper also examines the effectiveness of the LEED rating and certification process adopted to certify the selected homes. The certification process was conducted by teams including third party consultants and according to LEED guidelines. In addition to reviewing the design and construction documents, the process focused on performing air leakage tests and after correcting a number of related deficiencies, the selected units achieved gold ratings. The Brandon units were occupied, as affordable housing rentals, in the fall of 2011 while the units in both Thompson and The Pas were occupied, as college students' family housing, in the spring of 2013.

Figure 1 (below) shows the locations of Thompson, The Pas and Brandon where those units were built.

Thompson is a city in northern Manitoba located 830 km (520 mi) north of the Canada–United States boarder, and 739 km (459 mi) north of the provincial capital of Winnipeg. It has a population of 13,123 residents. Thompson is home to one of the two main campuses of the University College of the North. The new campus was completed in February 2014 and student family housing, designed by ft3 as LEED homes and built by Newton Enterprises Ltd., was completed in 2013. The project is located on a partially grassed area of the North West portion of a Recreational Centre parking lot, just South West of the Wildlife Association building.

The Pas is located approximately 630 km (390 mi) northwest of Winnipeg, and 40 km (25 mi) from the border of Saskatchewan. The population of The Pas in 2011 was 5,513. The town hosts the main campus of the University College of the North. As in Thompson, the new campus was completed in 2014 while student family housing, designed by ft3 as LEED homes and built by Von Ast Construction (2003) Inc., was completed in 2013. The units are located east of the existing University College of the North campus on Seventh Street (Centennial Drive).

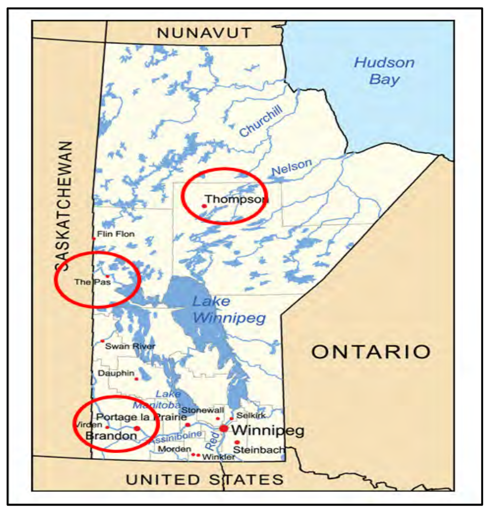


Figure 1: Manitoba Map showing the locations of the three cities.

Brandon is the second-largest city in Manitoba. It is located in the southwestern corner of the province on the banks of the Assiniboine River, approximately 214 km (133 mi) west of Winnipeg, and 120 km (75 mi) east of the Saskatchewan border. Brandon covers an area of 465.16 km2 (176.1 sq mi) and has a population of 53,229. In 2010, Manitoba Housing commissioned ft3 to design 24 units, as part of its efforts to provide subsidized & affordable housing to low income families in Manitoba. The units were designed to LEED standards and their construction was by 036074 WBS Construction and completed in the fall of 2011. The units are located at 15th Street North and Stickney Avenue.

All houses in each location are composed of multiplexes of 2, 4, 6 or 8 units. The designs of individual units were essentially the same except for floor areas. There are basically three sizes of units: 150, 200 and 250 m^2, approximately.

The construction work itself was executed according to the applicable federal, provincial and municipal codes and standards, which is the normal practice. The structures are all of wood frame construction on cast-in-place concrete basements complete with concrete pile foundations. All dwelling units' ground floors include basic visitable design features such as a no step entrance, wider doorways and hallways and an accessible washroom. The one-storey duplex houses accessible units of three bedrooms and four bedrooms for families living with physical disability.

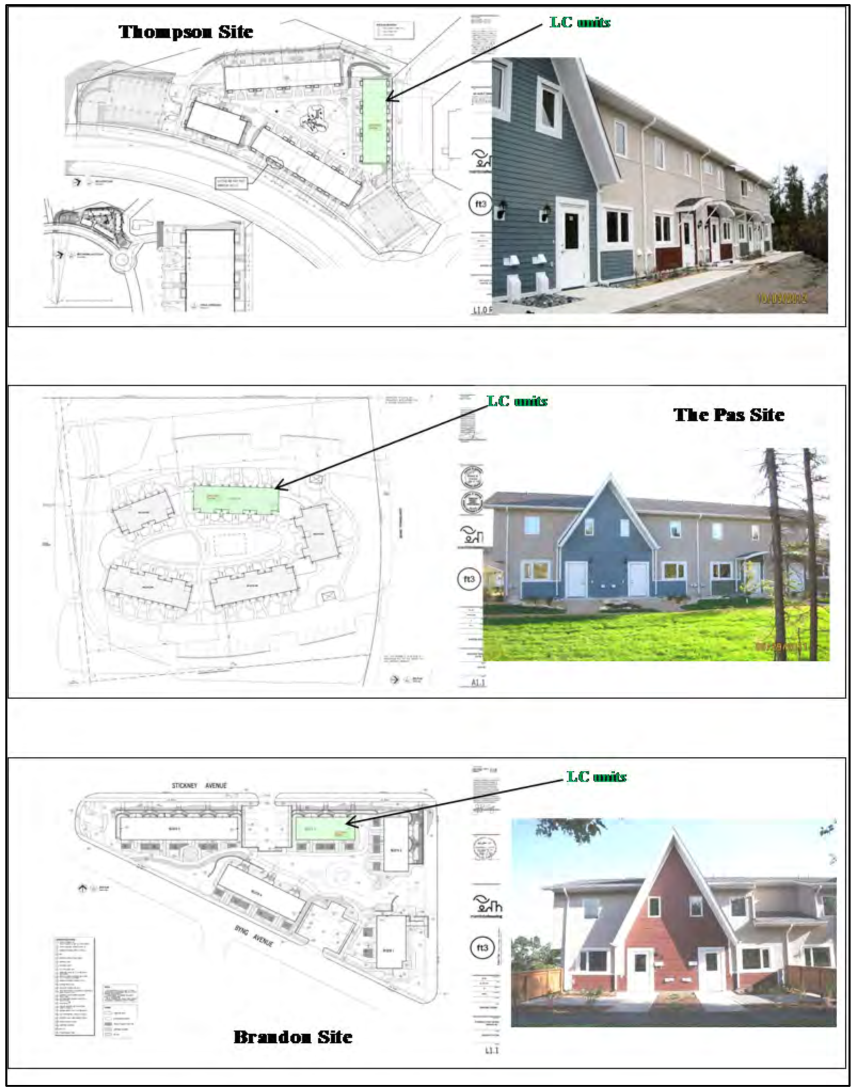


Figure 2: Plan views and front pictures for the developments at the three sites.

Site development included resident and visitor parking stalls, soft and hard landscaping and a play area.

Occupants in both Thompson and The Pas houses are characterized as "students' families" while those in Brandon houses as "low income families".

2. Assessment of LEED Certification and Rating Process

According to the project manuals[1] for all three developments: "The multi-family housing units will meet Manitoba Hydro Power Smart Gold level or exceed the standards of Canada Green Building Council's Leadership in Energy and Environmental Design (LEED) silver designation, with a portion of the total project formally registered with LEED Canada for Homes". Energy consumption levels referred to above were projected during the design stage using Hot2000 software models.

The project documents also outlined the responsibilities of the different stakeholders towards the LEED rating and certification process:

For LEED® Green Rater, to:

- Perform all tests outlined by the LEED® for Homes requirements
- Prepare or approve commissioning forms and construction checklists for each piece of equipment.

- Observe Functional Performance Testing and system start-up procedures, as performed by the installing Contractor.
- Provide completed Balancing Reports to the Commissioning Agent for review.

For Contractors: "All Contractors and related subcontractors shall be responsible for cooperating and coordinating their work with the LEED® Rater and Commissioning Authority. They shall be responsible for carrying out all the physical activities required for the initial installation of components and systems, and for operating the systems as required during the commissioning process as instructed by the LEED® Rater."

Furthermore, the documents included a list of "systems to be commissioned" as well as description of the "AIR TIGHTNESS AND FUNCTIONAL PERFORMANCE TESTING":

- Air tightness tests are to be done before installation of drywall.
- Functional Performance Tests are to be done before installation of drywall and upon completion of home.
- Vent systems must meet CSA F326.
- Testing of Heat Recovery Ventilator to confirm flow and system balance
- Air flow and delivery to each room shall be tested.
- Air volume and temperature to each room are to be measured.
- Maximum duct leakage is to be calculated.
- Maximum heat output will be calculated room by room and must fall within 20% of specified volumes.

Most importantly, the documents outlined the requirements and responsibilities for training as follows:

- Occupant training shall be provided by the Owner.
- Training will continue until the Project Owner is satisfied that adequate training has been provided.
- Training sessions may be videotaped for future reference.
- Training sessions will fulfill all requirements for LEED® for Homes, including:
  - Identification of the general purpose of system
  - Instruction on how to use the O&M Manuals
  - Review of as-built control drawings and schematics
  - Demonstration of start-up/shutdown, occupied/unoccupied modes, modulation of device range of capacity, power failure, alarms, equipment staging, interlocks with other equipment, sensor and actuator calibrations
  - Demonstration of interactions between systems, and optimized methods for energy conservation
  - Identification of health and safety issues
  - A discussion of tenant interactions issues
  - A discussion of how each feature or system is environmentally responsive

2.1 Review of Process Followed in Project

Based on reviewing the documented reports, certifying LEED designated units in the three sites followed a methodical process. This process consisted of two parts; part A: the "site inspections/tests" by the LEED Rater and part B: completing the "LEED Canada for Homes Checklist" based on the LEED team assessments of the eight categories defined by the Canada Green Building Council (CaGBC). It should be noted the LEED team included representations from the owner (Manitoba Housing), the designers (ft3) and the building contractors on each site in addition to a LEED consulting firm (Midscape Innovations) and a LEED Rater (Prairie House performance Inc.).

The following summary describes the work done in both parts of the process and the results ending with the issuance of the LEED certificates for the designated units in the three sites:

Part A: Site Inspections

Generally; inspections of the LEED designated units were conducted by the LEED Rater where the focus was on performing three tasks: air tightness tests, ventilation and heating systems assessments. The Rater documented the results of the inspection in a report and sent it to other LEED team members. Deficiencies noted, whether through tests or visual observations, were then conveyed to the building contractors to correct. Once corrections were made and all observations were addressed by the corresponding building contractor, a follow up site visit was made by the Rater to verify, with the process repeated till all issues and deficiencies were addressed. Finally, the LEED consulting firm issued a final report, based on the Rater's verifications, confirming that all checks were made and the units were ready for certification.

Tables 1 to 3 include results of the tasks conducted by the LEED Rater for the three sites.

Site	Unit #	unit 22	unit 24	unit 26	unit 28	unit 30	unit 32
Thompson	July 25 ACH @ 50 pa	Not tested	Not tested	Not Tested	Not tested	4.14	3.55
	Sept. 19 ACH @ 50 pa	2.37 complies	3.1	2.7	2.79	2.77	2.85
	Oct. 5 ACH @ 50 pa		3.07	2.94	2.73	2.94	2.72
	Oct. 5 NLA @ 10 pa		2.3	2.39	2.26	2.4	1.5 Complies
	Oct 5 NLR @ 50 pa		0.19 Complies	0.18 Complies	0.17 Complies	0.17 Complies	
The Pas	Unit #	unit 6	unit 8	unit 10	unit 12	unit 14	unit 16
	July 21 ACH @ 50 pa	1.67 complies	2.2 complies	2.06 complies	1.97 complies	1.7 complies	1.67 complies
Brandon	Unit #	app 9	app 10	app 11	app 12		
	July 29 ACH @ 50 pa	1.12 complies	1.64 complies	1.57 complies	1.31 complies		

ACH @ 50 pa target = 2.5

NLA @ 10 pa Target = 1.66 cm2/m2

NLR @ 50 pa Target (Energy Star for New Homes 2.5 ACH equivalent) = 0.2 cfm/ft2

Results of air tightness tests at the three sites

Table 1. Results of the air tightness tests at the three sites (red indicates failure- green indicates pass)

Site	Unit #	unit 22	unit 24	unit 26	unit 28	unit 30	unit 32
Thompson	flow	did not meet requirements- deficiencies noted (July 2012) and corrected/verified (January 2013)					
	installation	deficiencies noted (July 2012) and corrected/verified (January 2013)					
	balancing	deficiencies noted (July 2012) and corrected/verified (January 2013)					
The Pas	Unit #	unit 6	unit 8	unit 10	unit 12	unit 14	unit 16
	flow	did not meet requirements- deficiencies noted (July 2011) and corrected/verified (Nov 2011)					
	installation	deficiencies noted (July 2011) and corrected/verified (Nov 2011)					
	balancing	deficiencies noted (July 2011) and corrected/verified (Nov 2011)					
Brandon	Unit #	app 9	app 10	app 11	app 12		
	flow	all met NBC					
	installation	deficiencies noted (July 2011) and corrected/verified (Nov 2011)					
	balancing	all met NBC					

flow has to meet LEED Canada for Homes, F-326 or NBC requirements

Results of ventilation (HRV) assessments at the three sites

Table 2. Results of the ventilation assessments at the three sites

Site	Unit #						
Thompson	Unit #	unit 22	unit 24	unit 26	unit 28	unit 30	unit 32
	flow	low flow noted (Sept 2012) -no records of corrections/verifications					
	installation	deficiencies noted (July 2012) and corrected/verified (Sept 2012)					
The Pas	Unit #	unit 6	unit 8	unit 10	unit 12	unit 14	unit 16
	flow	low flow noted (July 2011) -no records of corrections/verifications					
	installation	deficiencies noted (July 2011) and corrected/verified (Nov 2011)					
Brandon	Unit #	app 9	app 10	app 11	app 12		
	flow	did not meet (July 2011) - no records for corrections/verifications					
	installation	deficiencies noted (July 2011) and corrected/verified (Nov 2011)					

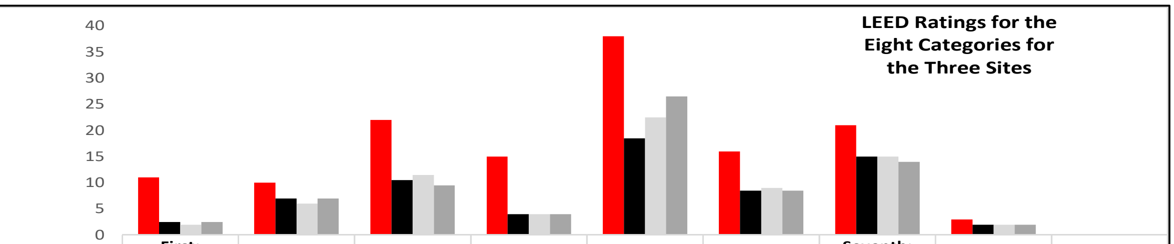
The supply flows in all supply air runs to be measured and adjusted to attempt to meet HOT2000 room by room target flows within 20%.

Results of heating commissioning/assessments at the three sites

Table 3. Results of heating assessments at the three sites

Part B: Completing "LEED Canada for Homes Checklist" and Assigning LEED Rating

The LEED team was tasked with reviewing, assessing and rating the designated units according to the eight categories defined by the CaGBC. Table 4 shows a summary of the checklist for the three sites.



	First: Innovation and Design process	Second: Location & Linkages	Third: Sustainable Sites	Fourth: Water Efficiency	Fifth: Energy & Atmosphere	Sixth: Materials & Resources	Seventh: Indoor Environment al Quality	Eighth: Awareness & Education	Total
Max Points	11	10	22	15	38	16	21	3	136
Thompson	2.5	7	10.5	4	18.5	8.5	15	2	68
The Pas	2	6	11.5	4	22.5	9	15	2	72
Brandon	2.5	7	9.5	4	26.5	8.5	14	2	74

Table 4. Final scores for the eight categories assessed for LEED certifications at the three sites

As shown in the above table, the designated units at the three sites achieved Gold LEED certificates (the threshold for Gold certification was 65 points) although the target was Silver (the threshold for Silver was 50 points).

2.2 Critical Analysis of the LEED Rating & Certification Process

Generally, the LEED design, rating and certification work for the three sites followed standard strict, structured process for these types of developments. The projects' manuals and design drawings included clear construction specifications and guidelines for allocating responsibilities and defining relationships among the various stakeholders. However, reviewing the project documents related to the two parts of the rating process revealed areas in "need for improvements". These areas, described in the comments below, may not necessarily be confined to these three projects but rather can be looked at as opportunities to improve the process in general.

- The site inspections by the LEED Rater began after the buildings were constructed and prior to occupancy. The same observations may also be made to building commissioners. Although this may be the current standard process, earlier involvement of the LEED Rater and commissioners as part of the design and construction team, may have reduced construction deficiencies and corrective actions needed to correct them.

- Although the ventilation and heating installation process was assessed by the Rater, air tightness tests and related corrective work seem to have been the primary focus of the assessment based on available records reviewed. This may have resulted in undermining the operational integrity of these heating and ventilation systems, particularly their long-term efficiencies. Moreover, tightening the envelopes in some of those units did not appear to have achieved the intended target of energy conservation. This is evident from assessing the energy performance of the individual units, as shown later where units attaining higher air tightness values were not generally the ones achieving better energy performance. It is also unclear in the documents why there was a switch to Normalized Leakage Rate (NLR) test standard from the Air Change per Hour (ACH) test standard followed in Thompson's first few rounds of tests. With lack of clarifications, it appears that there was a pressure to pass these units that failed using the ACH methodology.
- Although the manuals outlined the training requirements for occupants, no records of such training exist. This part may have been totally overlooked or dealt with in a superficial manner. As a matter of fact, the eighth category for certifying the units; "Awareness and Education" has the lowest weight according to LEED score card giving an indication of "less importance".
- Reviewing the other categories in the checklist, it appears that the highest rating was associated with "Energy & Atmosphere" while the lowest rating with "Awareness & Education" with other categories in the middle. Even though energy is a significant factor in ensuring sustainability, issues such as the design process, education and water efficiencies may be perceived as unimportant.
- There are no references in the rating process to post occupancy monitoring of parameters such as energy and water performance or indoor air quality. Again, although this may be the standard way of conducting the rating process, monitoring the post occupancy performance of such parameters is essential in achieving the true sustainability intended for the development. The lack of such monitoring capabilities was one of the major challenges for this project (and perhaps for other similar projects) that impeded the performance assessments, as will be discussed later. As a matter of fact; this analysis poses the question of "why not delay the initial LEED rating and certifying process till after reviewing monitored and measured performance for a post occupancy set period?"
- Finally, the cost of LEED certification appears to have been the reason why only a few units on each site were selected to go through the certification process. In either case, the cost issue needs to be considered and assessed.

3. Energy Data Collection and Management

3.1 Weather Data

According to the newly introduced Manitoba Energy Code for Buildings (2014); the three cities are located in the following climate zones:

Location	Climate Zone	HDD
Brandon	ZONE 7A	5760
The Pas	ZONE 7B	6480
Thompson	ZONE 8	7600

On the other hand, actual monthly weather data for the three cities were retrieved from Environment Canada archived site (https://weather.gc.ca/**canada**_e.html). Data collected included the average monthly temperature (C^o) and monthly total heating degree days (HDD). *Figure 3* (below) shows a graphical representation of the actual monthly weather data for the three cities during the analysis periods.

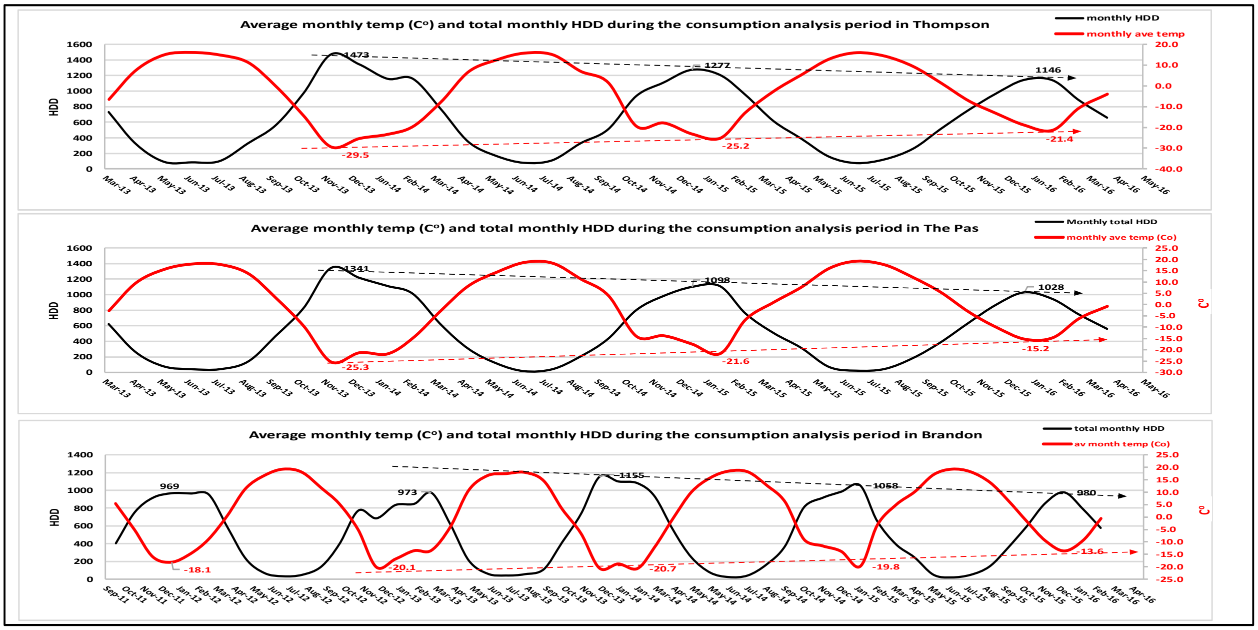


Figure 3: Average monthly temperatures and total monthly heating degree days for the three cities during the analysis periods

The graph shows the cyclic nature of temperature changes throughout the twelve months of the year from the cold winter to the warm summer months. It is interesting to notice that the average monthly temperature rises and the total monthly HDD decreases during the winter months over the past three years in the three cities. Notwithstanding the possible correlation to the proverbial "climate change", this observation played a role in setting the limits for heating seasons, as will be discussed later.

3.2 Hydro Consumption Data

To assess the energy performance of the homes in the three sites, three types of consumption data were collected: reference, projected and actual data. The following sections present these data.

3.2.1 Statistics Canada Consumption Reference Data

There are a variety of sources that may be considered for reference data. However, in this analysis consumption data from Statistics Canada for Manitoba showed that the average annual household energy use, in comparable homes, was 250 kWh/m^2 approximately. The figure is also close to the national average referenced in Canadian Mortgage and Housing Corp (CMHC) and Natural Resources Canada (NRCan) references.

3.2.2 Hot2000 Projected Data

HOT2000™ developed by Natural Resources Canada is a simplified residential heat loss analysis program that is widely used in North America by builders, engineers, architects, researchers, utilities and government agencies. Utilizing current heat loss/gain and system performance models, the program aids in the simulation and design of buildings for thermal effectiveness, passive solar heating and the operation and performance of heating and cooling systems. For this project, HOT2000 was used during the design stage to produce monthly hydro projections for all units designated for LEED certifications as shown in Table 5 on the following page.

The following notes may be made by reviewing the HOT2000 projections shown in the table below:

- The annual average consumption for Thompson, The Pas and Brandon LEED units are: 172,144 and 133 kWh/m^2, respectively. These figures are comparable to or less than that known for R-2000 Home values of 175 kWh/m^2.
- Lower projected values for Brandon LEED units reflect the fact that geothermal system is used for heating and cooling purposes, in addition to the climate effects of course.
- As expected from such modeled projections, the variability in the consumption values of the units for the same months in the same complex are negligible.
- Based on reviewing the consumption values over the winter months versus the warmer months as shown in *Figure 4*, it appears that May and September consumption values can be taken to reflect no or very minimum heating activities in the homes. This led to assuming that the "no-heating" seasons would include these two months in addition to June, July and August.
- During the "no heating" seasons in Thompson and the Pas, it appears that the projected monthly consumption used primarily for lighting, appliances and hot water is 8 kWh/m^2. In Brandon, these projected values for warm weather consumption are 10 kWh/m^2 due to the central cooling feature that does not exist in the other two developments.

		HOT2000 monthly projections for Thompson LEED units in kWh												Annual Total
		january	february	march	april	may	june	july	august	september	october	november	december	kWh
unit 22		3,495	2,751	2,369	1,649	1,297	1,177	1,206	1,199	1,208	1,689	2,451	3,319	23,811
unit 24		3,767	2,921	2,443	1,627	1,339	1,236	1,267	1,260	1,249	1,640	2,478	3,512	24,740
unit 26		3,816	2,961	2,479	1,648	1,345	1,236	1,267	1,260	1,254	1,661	2,514	3,559	25,000
unit 28		3,792	2,951	2,475	1,645	1,345	1,236	1,267	1,260	1,255	1,665	2,507	3,536	24,935
unit 30		4,240	3,286	2,729	1,765	1,384	1,236	1,267	1,260	1,285	1,784	2,754	3,935	26,925
unit 32		4,351	3,395	2,849	1,888	1,476	1,237	1,267	1,260	1,376	1,951	2,910	4,063	28,023
	area(m2)	HOT2000 monthly projections for Thompson LEED units in kWh/m2												kWh/m2
unit 22	150	23	18	16	11	9	8	8	8	8	11	16	22	159
unit 24	148	25	20	17	11	9	8	9	9	8	11	17	24	167
unit 26	148	26	20	17	11	9	8	9	9	8	11	17	24	169
unit 28	148	26	20	17	11	9	8	9	9	8	11	17	24	168
unit 30	148	29	22	18	12	9	8	9	9	9	12	19	27	182
unit 32	150	29	23	19	13	10	8	8	8	9	13	19	27	187
Average		26	20	17	11	9	8	8	8	9	12	18	25	172

		HOT2000 monthly projections for The Pas LEED units in kWh												Annual Total
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh
unit 6		2,978	2,316	1,981	1,413	1,258	1,201	1,232	1,229	1,192	1,437	2,030	2,776	21,043
unit 8		3,067	2,389	2,019	1,384	1,252	1,201	1,232	1,229	1,192	1,425	2,020	2,820	21,230
unit 10		2,996	2,335	1,977	1,369	1,253	1,201	1,232	1,229	1,192	1,410	1,981	2,757	20,931
unit 12		2,961	2,309	1,957	1,362	1,253	1,201	1,232	1,229	1,192	1,403	1,963	2,727	20,788
unit 14		2,943	2,297	1,951	1,361	1,253	1,201	1,232	1,229	1,192	1,403	1,958	2,712	20,732
unit 16		3,608	2,795	2,359	1,603	1,293	1,201	1,232	1,229	1,215	1,641	2,399	3,338	23,912
	area(m2)		HOT2000 monthly projections for The Pas LEED units in kWh/m2											kWh/m2
unit 6	150	20	15	13	9	8	8	8	8	8	10	14	19	140
unit 8	148	21	16	14	9	8	8	8	8	8	10	14	19	143
unit 10	148	20	16	13	9	8	8	8	8	8	10	13	19	141
unit 12	148	20	16	13	9	8	8	8	8	8	9	13	18	140
unit 14	148	20	16	13	9	8	8	8	8	8	9	13	18	140
unit 16	150	24	19	16	11	9	8	8	8	8	11	16	22	159
Average		21	16	14	10	8	8	8	8	8	10	14	19	144

		HOT2000 monthly projections for Brandon LEED units in kWh												Annual Total
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	kWh
APT 9/E		2,039	1,698	1,637	1,355	1,273	1,199	1,229	1,226	1,207	1,355	1,599	1,944	17,761
APT 10		1,822	1,526	1,491	1,278	1,252	1,199	1,229	1,226	1,190	1,282	1,439	1,736	16,671
APT 11		1,787	1,499	1,473	1,272	1,252	1,199	1,229	1,226	1,190	1,277	1,420	1,705	16,529
APT 12/E		1,967	1,643	1,591	1,330	1,270	1,199	1,229	1,226	1,205	1,329	1,549	1,877	17,416
	area	HOT2000 monthly projections for Brandon LEED units in kWh/m2												kWh/m2
APT 9/E	150	15	13	12	11	10	10	10	10	10	11	12	14	137
APT 10	148	14	12	12	10	10	10	10	10	10	10	11	13	131
APT 11	148	14	12	11	10	10	10	10	10	10	10	11	13	130
APT 12/E	150	15	12	12	10	10	10	10	10	10	10	12	14	134
Average		14	12	12	10	10	10	10	10	10	10	12	14	133

Table 5 HOT2000 projections for hydro consumptions for all the LEED units in the 3 sites

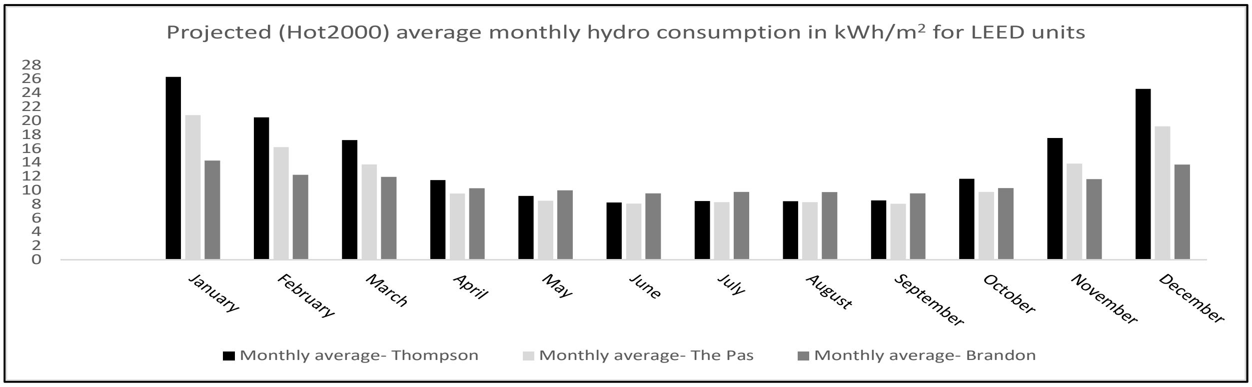


Figure 4: Projected (HOT2000) average monthly hydro consumptions for LEED units

3.2.3 Actual Consumption Data

The hydro meters installed for all the units in the three sites are the regular types of meters, as opposed to smart meters. It became clear at the start of this project that replacing these meters with smart ones or installing other consumption measuring devices (e.g. transducers or commercial types of meters) is a difficult if not impossible task at that time. That left collecting data from existing regular meters the only option for actual consumption information.

The regular meters provided basic consumption values that were read periodically by the utility company or designated personnel and used primarily for billing purpose. The meters were read every second month (sometimes every 3rd month) even though the bills were issued monthly. The consumption values shown on the bills were therefore either "Estimated-E" or "Actual-A". The following shows an example of consumption billing data records as received for one of the units in Thompson.

Premise: 6717375										
Service To Date	**Bill Month**	**Bill Print**	**Read Type**	**Tran Type**	**Rate Code**	**Bill Days**	**Total Usage**	**Usage Revenue**	**Service Revenue**	**Total (no taxes)**
2015/10/15	2015/10	2015/10/19	E		KR01	30	1,262	$96.82	$7.57	$104.39
2015/09/15	2015/09	2015/09/17	A		KR01	29	444	$34.06	$7.57	$41.63
2015/08/17	2015/08	2015/08/19	E		KR01	33	637	$47.98	$7.43	$55.41
2015/07/15	2015/07	2015/07/17	A		KR01	30	327	$24.14	$7.28	$31.42
2015/06/15	2015/06	2015/06/17	E		KR01	31	1,103	$81.41	$7.28	$88.69
2015/05/15	2015/05	2015/05/19	A		KR01	30	2,136	$157.66	$7.28	$164.94
2015/04/15	2015/04	2015/04/17	E		KR01	34	2,441	$180.17	$7.28	$187.45
2015/03/12	2015/03	2015/03/18	A		KR01	28	3,054	$225.42	$7.28	$232.70
2015/02/12	2015/02	2015/02/18	E		KR01	28	3,036	$224.09	$7.28	$231.37
2015/01/15	2015/01	2015/01/19	A		KR01	31	3,998	$295.09	$7.28	$302.37
2014/12/15	2014/12	2014/12/17	E		KR01	31	2,993	$220.91	$7.28	$228.19
2014/11/14	2014/11	2014/11/18	A		KR01	30	2,652	$195.74	$7.28	$203.02

The "as-is" monthly consumption data shown in the example above under "Total Usage" cannot be used accurately to assess consumption performance unless it is re-arranged in a more realistic format. For this analysis, running averages for each two consecutive months were considered to produce more realistic monthly consumption values. *Figure 5* (next page) shows "as-is" vs arranged monthly data for all units at the three sites during the analysis periods.

It should be noted from the figure that:

- The frequent peaks and valleys appearing in the "as-is" graphs reflect the actual (A) and estimated (E) monthly billing values. These patterns disappear with taking the two months running average values.
- The graphs showing the averages follow the normal pattern of consumptions familiar for cold and warm weather months. This normal pattern is not very obvious for the Brandon units due to the geothermal systems for these units that drastically reduces the need for hydro power during the heating or cooling months.

It should also be mentioned that records of vacancies were provided by the building managers at the three sites. However, the billing information did not often reconcile with vacancies records.

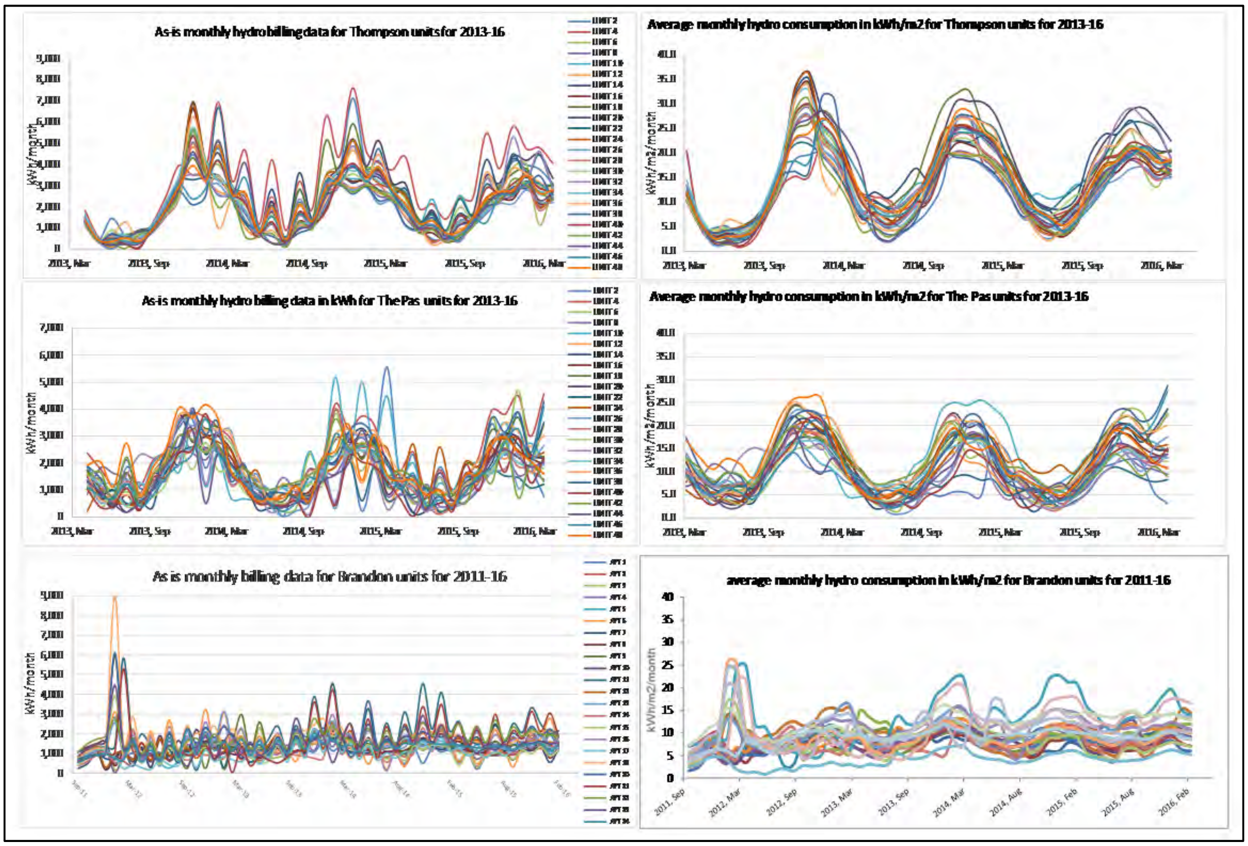


Figure 5: "as-is" vs average monthly consumptions for all units at the three sites during the analysis periods

3.3 The Geothermal System in Brandon

The Brandon site contains a geothermal loop heating system that provides heating and cooling for all 24 residential dwelling units within a total of five separate buildings. Each dwelling unit contains a water-to-air heat pump that uses the geothermal supply water as a heating or cooling sink for its internal refrigerant coil.

The geothermal system water is circulated via a primary loop from the field ground loop around the site to each building. Each of the five buildings contains a secondary loop drawing ground loop water from the primary to circulate within. The primary loop is circulated by main circulating pumps. The secondary loops are circulated with dedicated pumps within each building delivering tempered supply water to each dwelling unit heat pump.

The system was commissioned in September 2012 and was deemed operational as designed. Recommendations were made by the commissioning agent to install operational sensors and to conduct annual checks to ensure performance is maintained. It is not clear from available records whether these monitoring systems were installed.

In order to account for the hydro consumption used by all pumps, primary and secondary, in determining the actual hydro consumption used by each unit, the following assumption was made. The geothermal system is a combination of two parts. The central part that runs the main loops and the local parts that runs the units' furnaces and heat exchanges. The consumption for the central part (5 pumps w a total of 12 HP) is included in the common service hydro account while that for the local parts are included in the units' accounts. This leaves us with determining the consumption of the central part of the system and dividing it among all units. To do so, two sources were examined: Manitoba Housing tests of the central pump and Manitoba Hydro's common service account.

The Engineering Division at Manitoba Housing estimated annual consumption of the central part at 66,000 kWh. This was based on sampling the pumps' operation for about 800 hours and extrapolating the related operational consumption to a year's worth. This would result in a monthly consumption value of 237 kWh/unit, approximately, to be added to the monthly consumption of each unit shown on the bills.

However, reviewing the billing data for the common service account for Brandon over the past four years shows an average value of about 65,000 kWh/year. The common service account at any location such as Brandon's is used for parking plugs, area lighting and other central operations such as that used for the geothermal system.

This means that the Manitoba Housing estimate is on the higher side and may lead to unfairly penalizing Brandon units' hydro consumption. Therefore, a more reasonable estimate was assumed as the share of each unit in running the central geothermal pumps. This estimate was based on assuming values for lights and plugs for each month of the year and then subtracting the sum of these two values from the monthly common service account values. *Figure 6* below shows the monthly values of hydro consumption in kWh/m^2 resulting from running the central geothermal system and to be shared by units during the analysis period.

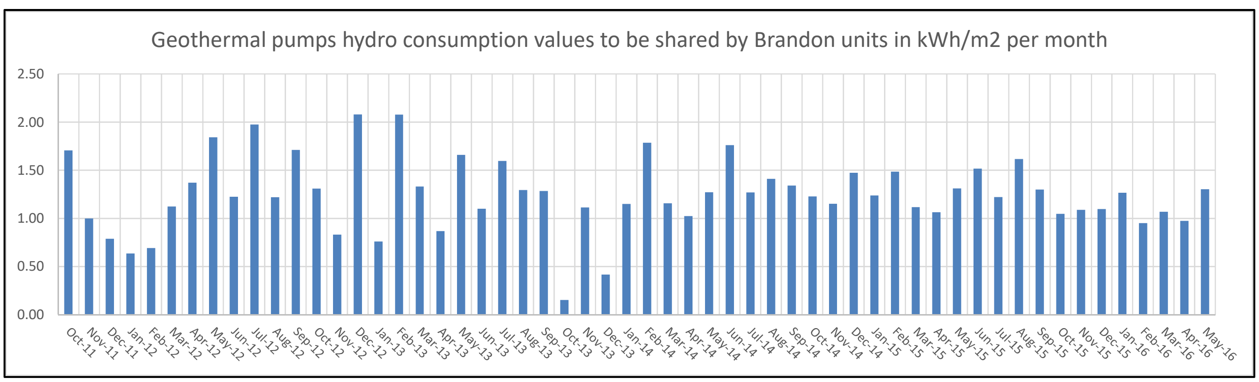


Figure 6: Estimated monthly hydro consumption of the central geothermal system to be added to Brandon's units monthly hydro consumptions

4. Assessment of Energy Performance

4.1 Bases of the Assessment

The primary metric used in describing the energy performance is the hydro consumption per unit area, while the scope of energy performance assessments conducted in this project involved addressing the following main questions:

a) How significant are the deviations of actual consumptions from design projections and other consumption references (e.g. for conventional homes)?
b) Are there any significant trends in actual consumptions noticed post occupancy (over 3 years in Thompson and the Pas and almost 5 years in Brandon)?
c) How significant are the variations/spreads in energy consumption within or between the groups of units or individual units themselves?

With the lack of occupancy data (e.g. number of occupants per unit) and precise means for measuring consumption, answering these questions, should help us investigate how these units are performing with respect to energy consumption and determine possible causes of performance anomalies, if applicable.

Before proceeding with the assessments, it was necessary to group the units within each location into two categories: LEED Certified (LC) vs Non-LEED Certified (NLC) Units. As mentioned before, only 6 units in Thompson, 6 units in the Pas and 4 units in Brandon were LEED certified even though all units were designed according to LEED.

It was also necessary to prepare the monthly consumption data in somewhat normalized form to account for seasonal temperature changes during the year and to recognize the significant difference between summer and winter consumption as well as possible changes in occupancy levels. Particularly for Thompson and The Pas units, where no mechanical cooling system were used, consumption during the warm weather was limited to lighting, water heating and plug loads. While the winter consumption process entails heating and heat recovery ventilation in addition to the other consumption parameters. The consumption processes and in turn consumption levels were significantly different between the two seasons, namely the heating season (HS) and the no-heating season (NHS), as determined by the probability parameter $p < 0.05$ as shown in *Figure 8 (next page)*.

It should be noted that when consumption data analysis began in 2014, the no heating season (NHS) was assumed to include only June, July and August, which reflected the projections produced using HOT2000. However, with more actual data collected up to the spring of 2016, it became clear that May and September may be also added to the no heating seasons. The Rationale for making that assumption may be explained by first reviewing *Figures 3* and *4* (earlier) that show a rise in average monthly winter temperatures and a corresponding decline in heating degree days over the past few years. Secondly, the actual consumption values for both May and September appear to correlate better with the no heating averages than with the heating consumption values, as shown in *Figure 8 (next page)*.

The normalization itself entailed expressing the monthly consumption values in terms of the total monthly heating degree days ($Wh/m^2/HDD$) during the heating seasons (October to April) and leaving them as kWh/m^2 during the no-heating seasons (May to September). In addition to the reasons stated above, this normalization would also allow for accurate comparisons of performance between the three developments in the three cities.

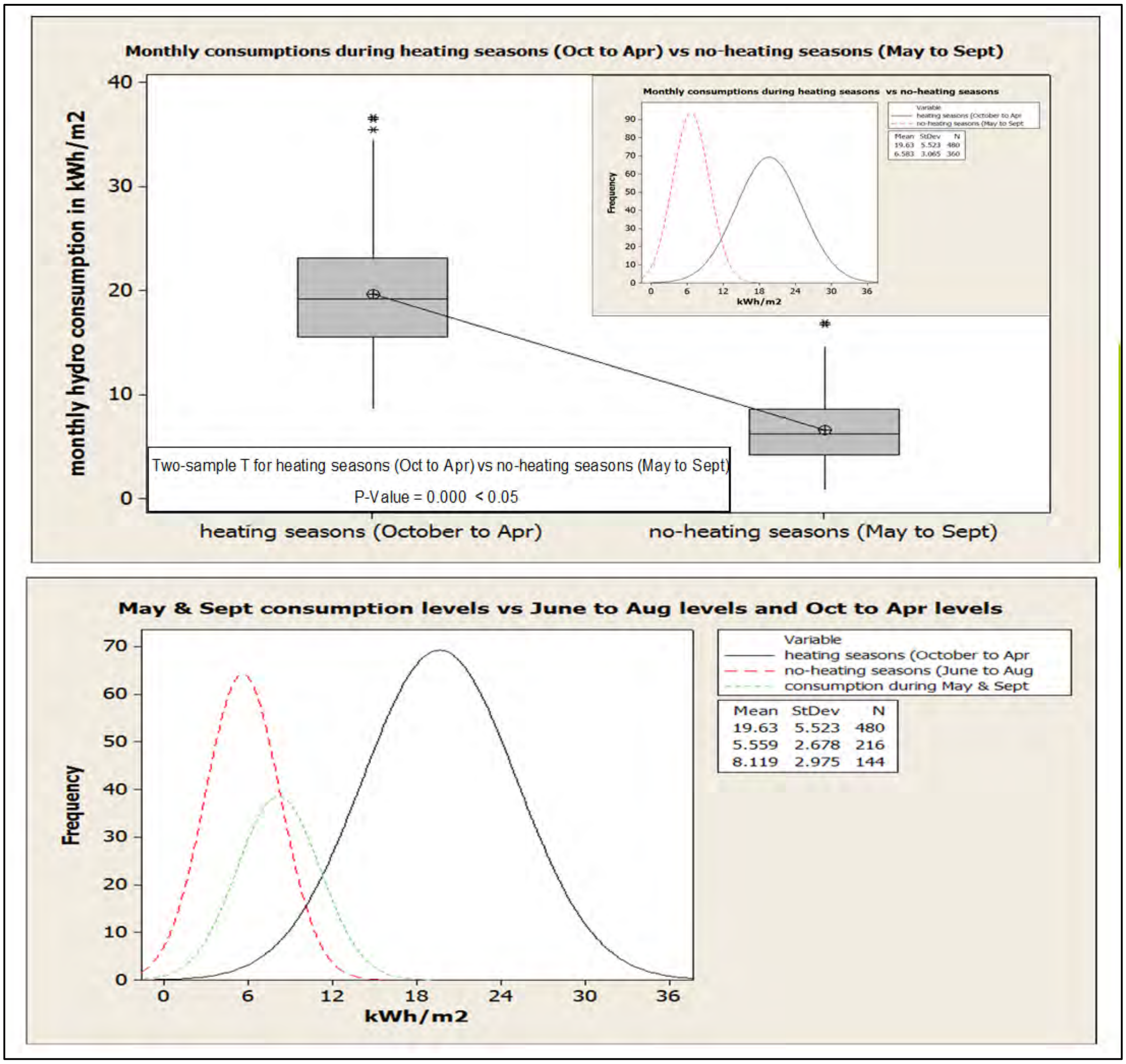


Figure 8: Difference between monthly consumption during HSs and NHSs with and without adding May & September to NHSs months

It should be noted that statistics were used extensively throughout the analysis to minimize anecdotal assessments and substantiate the conclusions. Readers should note the frequent use of the words “significant” or “insignificant” to describe differences between measured parameters based on the use of reliable statistical tests. The statistic that determines such significance is called P-value. P takes any value less than 0.05 if a difference is significant and a value greater than 0.05 if the difference is insignificant. Boxplots and histograms were also used frequently to illustrate the distributions and levels of variability within consumption data.

4.2 Assessing Energy Performance for Thompson, The Pas and Brandon Units

This section presents results of the assessment of the post-occupancy energy performance of the Thompson, The Pas and Brandon units while the next section (4.3.) will include comparisons of the performance across the three sites. The performance assessments, aim to address the three main issues identified earlier: deviations from projections, trends and levels of variability in monthly consumption values.

Figure 9 below shows actual total annual consumption before normalization (in kWh/m²) post occupancy in relation to both HOT2000 projected values and Stats Canada's reference values, for the Thompson, the Pas and Brandon units. It should be noted that the hydro consumption values shown for Brandon units below include their shares of operating the central geothermal system, as explained in section 3.3. The figure also shows the results of the air tightness tests for the LC units at the three sites.

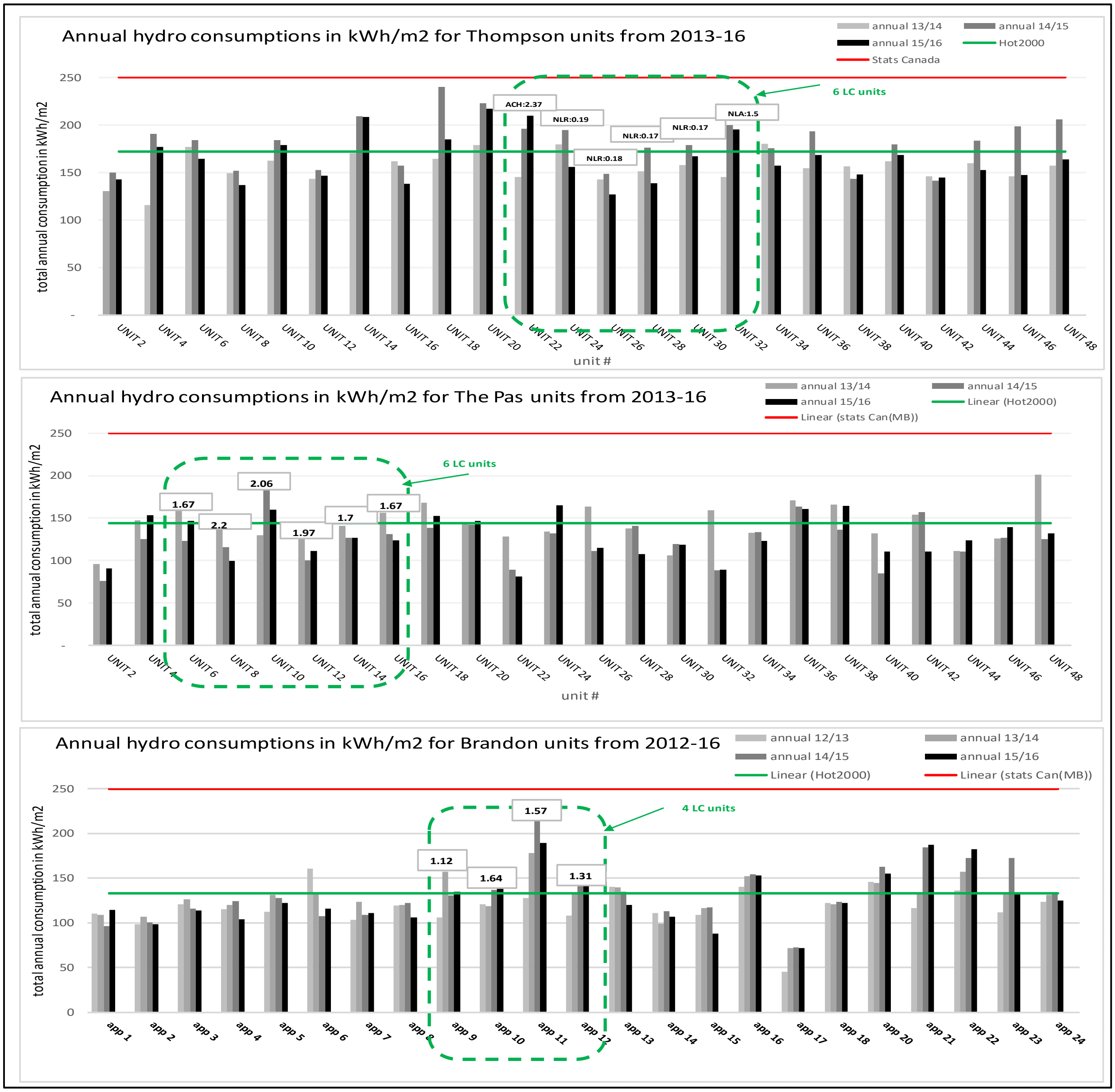


Figure 9: Total annual consumptions for the units at the three sites with respect to projections and reference values

Generally speaking; the average annual hydro consumption values of all units in the three sites were lower than that projected values using HOT2000 and significantly lower than Stats Canada reference consumption values for Manitoba as shown in *Figure 9* (above) and listed in *Table 9* (next page).

	Ave actual total annual hydro consumption (kWh/m^2)	Projected total annual consumption using Hot2000 (kWh/m^2)	Stats Canada referenced total annual consumption (kWh/m^2)
Thompson	168	172	250
The Pas	133	144	
Brandon	127	133	

Table 9: Comparisons between average actual hydro consumption and both projected and referenced values

Figure 9 (above) also shows that there were no significant differences between LC and NLC units particularly in Thompson and The Pas. As a matter of fact, the average annual hydro consumptions are 167.19 kWh/m^2 and 167.06 kWh/m^2, for both Thompson's LC and NLC units. In The Pas, the average annual hydro consumptions for LC units (134 kWh/m^2) is slightly higher than that for NLC units (131 kWh/m^2).

However, in Brandon and although *Figure 9* (above) shows insignificant differences between LC and NLC units, statistical tests reveal otherwise with the average annual hydro consumptions for LC units (145 kWh/m^2) is significantly higher than that for NLC units (123 kWh/m^2). Result of this statistical test is shown in Figure 10 (below). Such significant difference may be attributed to extremely higher consumption for one of the LC units (app #11) as well as the noticeably lower consumptions of some NLC units (apps # 17, 1, 2).

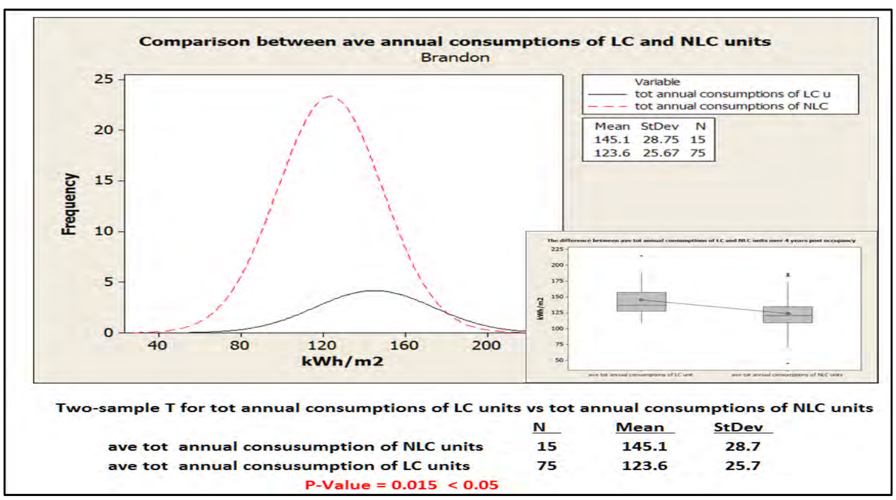


Figure 10. Significant difference between LC and NLC annual consumptions in Brandon

Another general and yet interesting observation from *Figure 9* (previous page) and *Table 1* (shown earlier) is the lack of correlation between the air tightness tests and annual hydro consumptions of the units. It appears that the majority of the units, in any of the three sites, had been performing as well or even better than the units that passed the air tightness tests, for LEED certification purposes. Even within the LC units, there are no clear correlations between energy performance and air tightness tests results. For example, conventional wisdom (based on air tightness test in ACH @ 50 pa in this case) would suggest that units #6 and #16 in The Pas should be performing better than units #8, #12 and #14 but the opposite is true.

To put this observation into perspective, we may try to ponder the following questions: did the investments made to bring the LC units within the allowable limits improve related hydro consumption?

Of course one may argue that “performance could have been much worse if these units were left as built” or that “air leakage is not the only factor affecting performance” or that “those units showing better performance may have been constructed better or tighter than others”, or that the “NLR standard should not be used in air tightness tests in the case of Thompson”… All arguments can be made and some may even be true.

After normalizing consumption data and dividing it into the HS and NHS groups, the analysis showed for the units at Thompson and The Pas that while there was no significant difference between the monthly actual averages and Hot2000 projected consumptions during HSs, a significant difference existed between actual and projected consumption during NHSs, as shown in *Figures 11* and *12* below. This may be attributed to the nature of occupants at both sites. Some, if not the majority of student families may vacate units during the summer (i.e. no school) times. However, this may also be due to over projections.

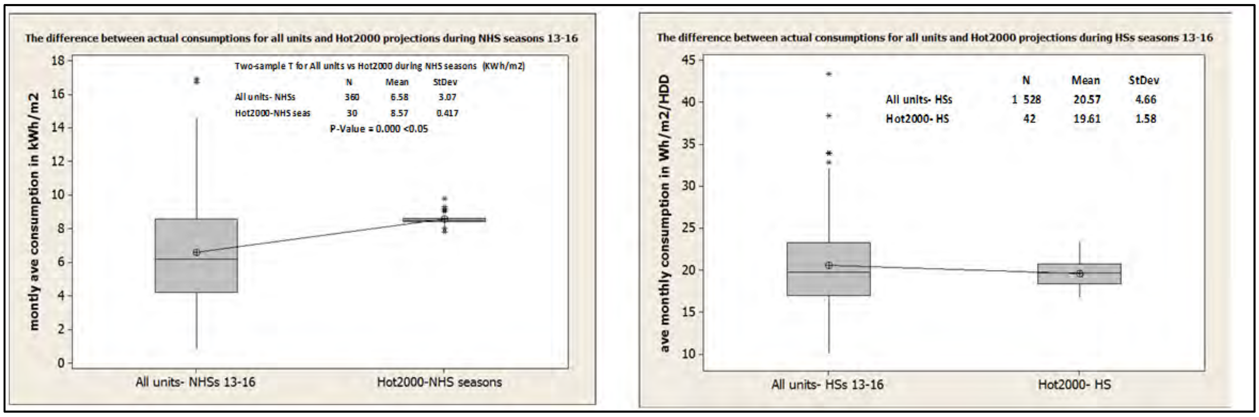


Figure 11: Difference between actual and projected monthly consumptions during HSs and NHSs for Thompson units

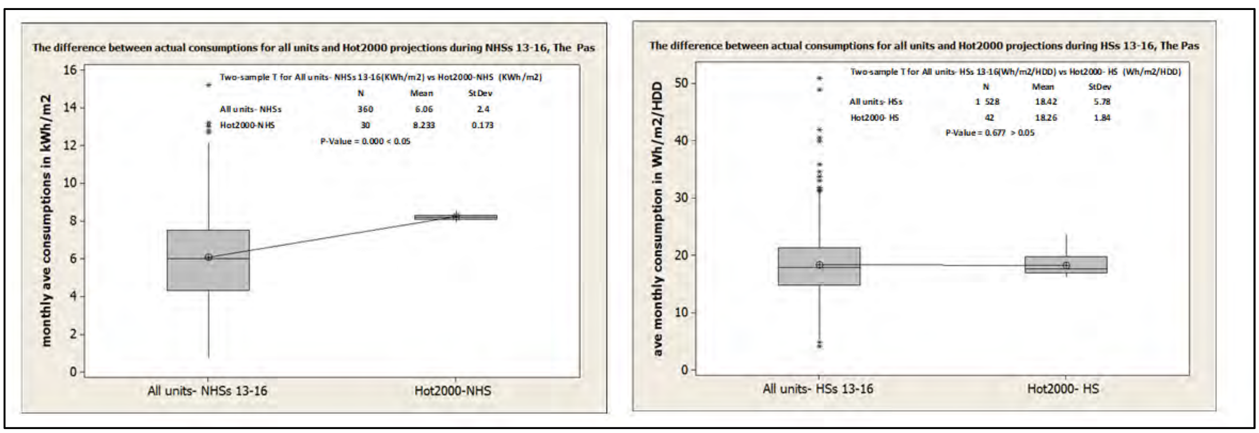
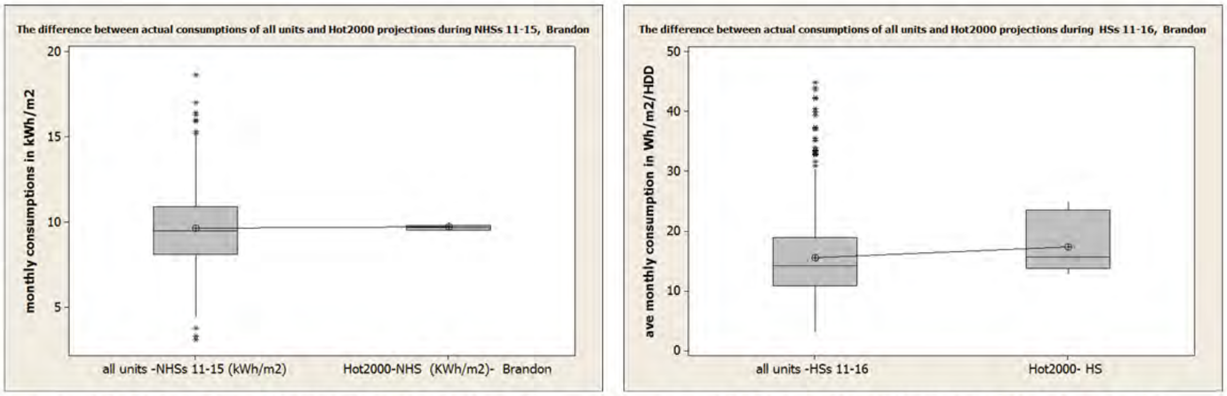


Figure 12: Difference between actual and projected monthly consumptions during HSs and NHSs for The Pas units

As for Brandon, for consistency with the other two locations, consumption data was also normalized and divided into the HS and NHS groups even though the geothermal system in Brandon was used for heating and cooling purposes. No significant difference between the monthly actual averages and Hot2000 projected consumptions during either HSs or NHSs was observed, as shown in *Figure 13 (below)*. Unlike the units for Thompson and the Pas, the insignificant difference during the NHS in Brandon may be attributed to the existence of the geothermal systems.



Two-sample T for all units vs Hot2000 during NHSs 12-15 in Brandon

	N	Mean	StDev
all units act monthly consumptions-NHSs	439	9.63	2.43
Hot2000 projections during NHS	20	9.715	0.181

P-Value = 0.487 > 0.05

Two-sample T for all units vs Hot2000 during HSs 11-16 in Brandon

	N	Mean	StDev
all units act monthly consumptions-HSs	1 774	15.58	6.83
Hot2000 projections during HS	28	17.39	4.53

P-Value = 0.051 > 0.05

Figure 13. Difference between actual and projected monthly consumptions during HSs and NHSs for Brandon units

As was noted with annual consumptions before normalization, there were no significant differences in performance between LC and NLC units during the HSs or NHSs, both at Thompson and The Pas sites. *Figures 14* (below) and *15* (next page) show the close similarity in overall average monthly consumptions between the LC and NLC units during three HSs and NHSs. From the figures, we can see that not only the overall averages are almost identical, but that also the variability in monthly consumptions was very similar, as expressed in the standard deviations for both groups over the same periods.

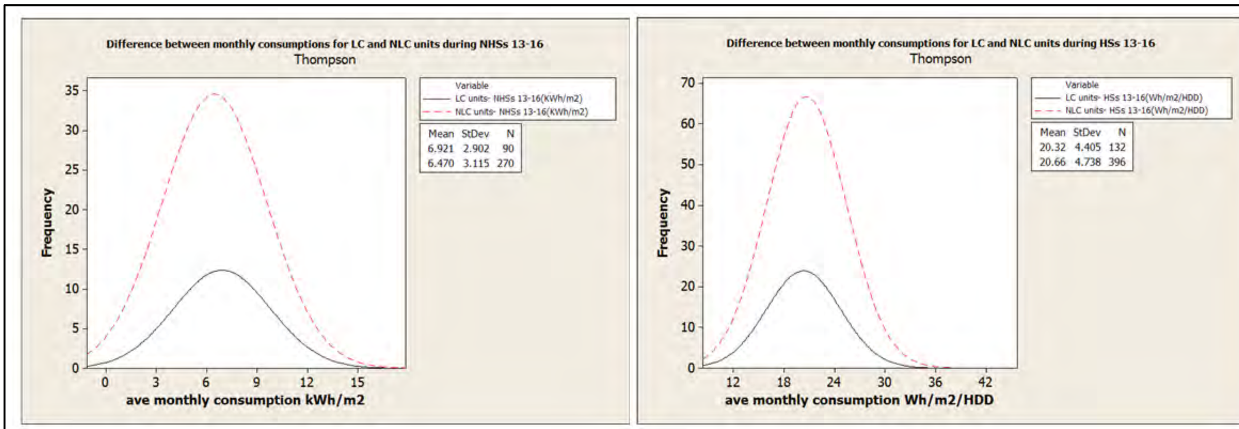


Figure 14: Difference between actual ave monthly consumptions for LC and NLC units during HSs and NHSs for Thompson units

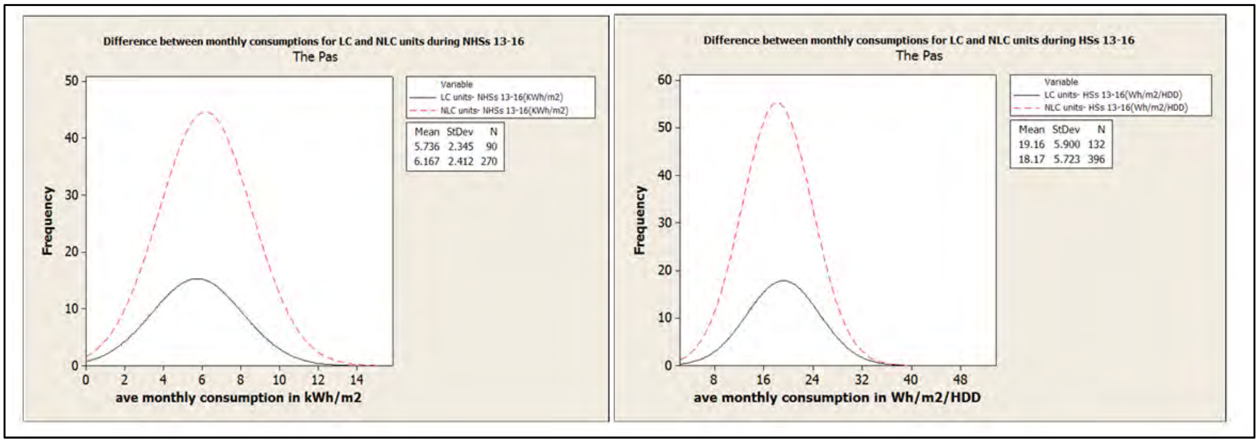
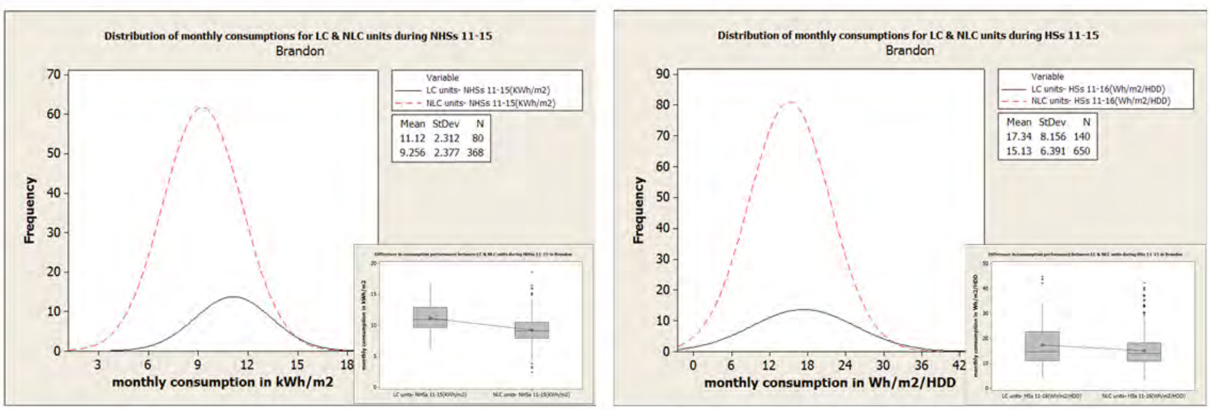


Figure 15: Difference between actual ave monthly consumptions for LC and NLC units during HSs and NHSs for The Pas units

For Brandon and as noticed before when analyzing total annual consumptions prior to normalization, there was a statistically significant difference in the monthly consumption between the LC and NLC units during both the HSs and NHSs, as shown in *Figure 16* (below). However, and as suspected before, this difference resulted from the significantly higher consumption of one particular LC unit (app #11) as well as the noticeably lower consumptions of a couple of NLC units (apps # 17, 1, 2).



Two-sample T for LC vs NLC units- NHSs 11-15(KWh/m2)

	N	Mean	StDev
LC units- NHSs	80	11.12	2.31
NLC units- NHSs	368	9.26	2.38

P-Value = 0.000 < 0.05

Two-sample T for LC vs NLC units- HSs 11-16 (Wh/m2/HDD)

	N	Mean	StDev
LC units- HSs	140	17.34	8.16
NLC units- HS	650	15.13	6.39

P-Value = 0.003 < 0.05

Figure 16: Difference between actual ave monthly consumptions for LC and NLC units during HSs and NHSs for Brandon units

In order to address the trending question; *Figures 17* (following page) shows three years' monthly consumption for all units in Thompson before and after normalization. While the actual monthly consumption in kWh/m^2 generally decreased during heating season (HS), the normalized consumptions in $Wh/m^2/HDD$ showed a slight upward trend.

Some of the possible reasons for the trend are: "heating systems are not maintained properly", or "more leaks are developing through deteriorating windows or door seals", or "the relatively low consumption values at first year compared to second and third years makes the linear trend appears more significantly upward than it actually is", or "rate of reductions in HDD are not correlated with reduction rates of consumption"...etc. However, occupancy is unlikely to be the cause of such trend due to the nature of occupants. For student families, turnover is quite normal, which may affect the variability in consumption but unlikely to cause a trend.

Nonetheless, although not significant, but if normalized consumption, expressed in Wh/m^2/HDD is considered a measure of efficiency, then that slight trend should continue to be monitored and efforts should be made to better understand the causes and mitigate the problems, if existing.

Figure 17 (below) shows the same insignificant upward trend for consumption during no heating seasons (NHSs) in Thompson.

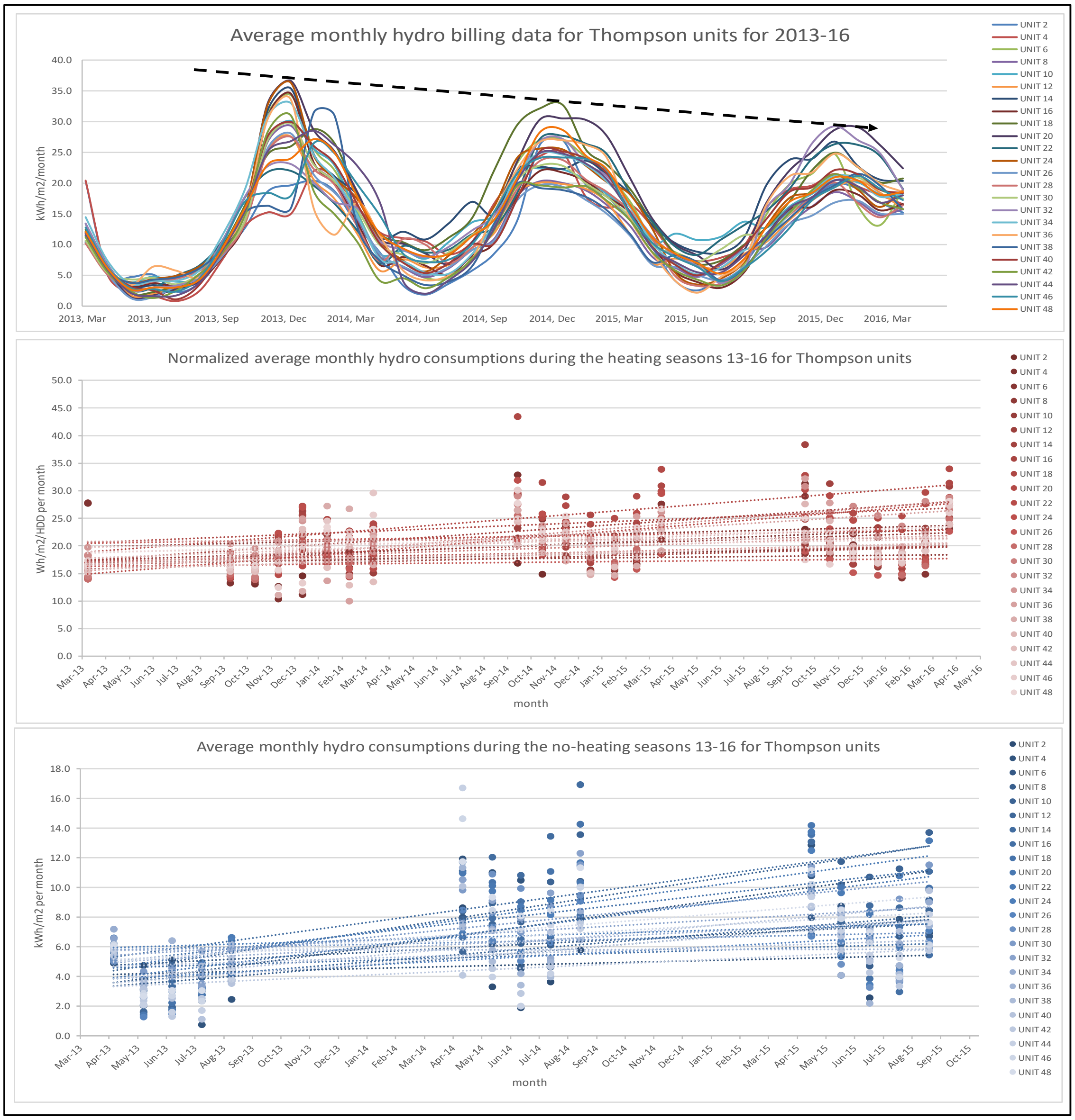


Figure 17: Monthly average consumptions before and after normalization for Thompson units throughout the analysis periods

Figure 18 (next page), on the other hand, shows the boxplots displaying the distribution and averages consumption for both LC and NLC units at each year during the HS and NHS.

Figure 18 shows the same conclusion as before; that no significant difference between LC and NLC units' monthly consumption or performance in any of the three years of analysis exists. However, we also notice evidence of the trends observed earlier in *Figure 17* (above) where both LC and NLC units experienced a rise in average monthly consumptions over the past three years, particularly during the HSs.

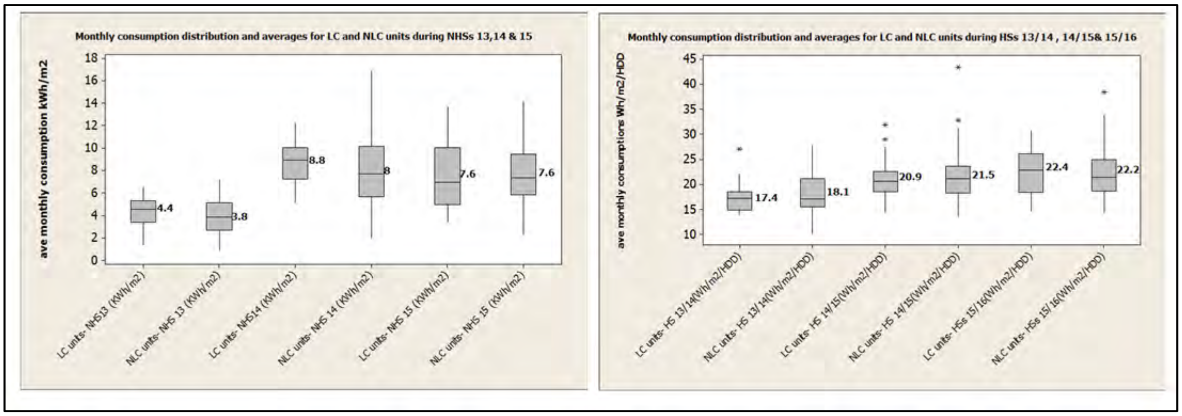


Figure 18: Differences between ave monthly consumptions for LC and NLC units in Thompson during each of the past three years

Similarly, and in order to address the trending question for The Pas units; *Figure 19* (below) shows three years' monthly consumptions for all units before and after normalization. The figure shows that unlike Thompson's consumption pattern, the general trends are subtle in actual monthly consumptions for the Pas units, particularly during HSs.

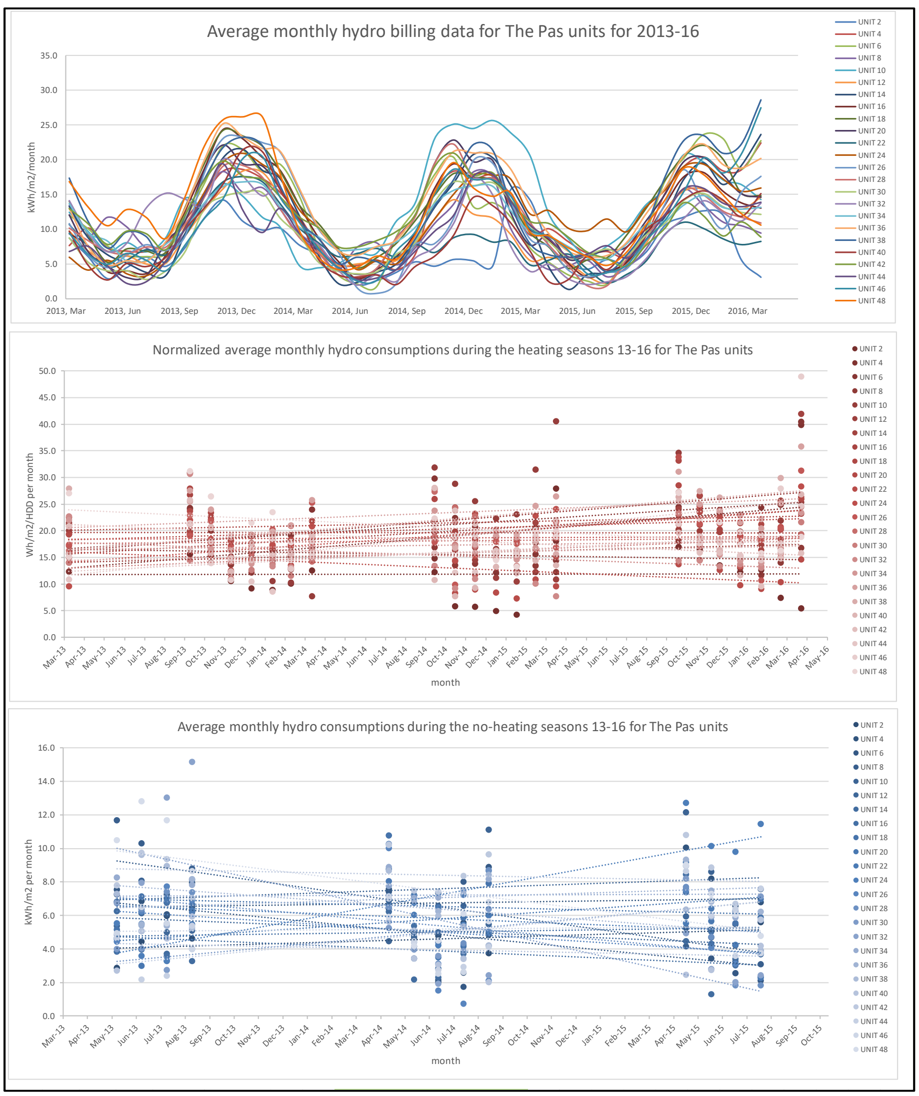


Figure 19: Monthly average consumptions before and after normalization for The Pas units throughout the analysis periods

Figure 20 (below), on the other hand, shows the boxplots displaying the distribution and consumption averages for both the LC and NLC units for each year during the HSs and NHSs. From reviewing the figure, we notice that although slight differences existed between the LC and NLC monthly consumption, no significant differences could be observed. Moreover, LC units showed a slight decrease in monthly consumption between NHS 13 to 15 (6.8, 5.4, 5.0 kWh/m^2 respectively). While the same LC units showed a slight increase in monthly consumption between the HSs 13/14 to 15/16 (17.4, 18.5, 21.3 Wh/m^2/HDD respectively), these trends were not significant. NLC units did not show similar trends.

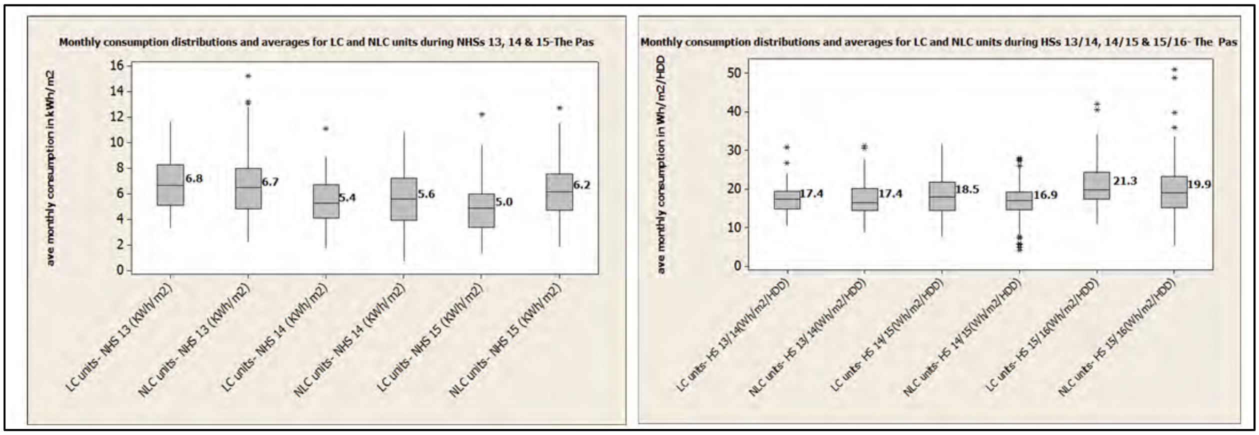


Figure 20. Differences between average monthly consumptions for LC and NLC units in The Pas during each of the past three years

As for Brandon, in order to address the trending question; *Figure 21* (following page) shows five years' monthly consumption for all units before and after normalization. The figure shows that there may be slight trends in consumptions before and after normalization.

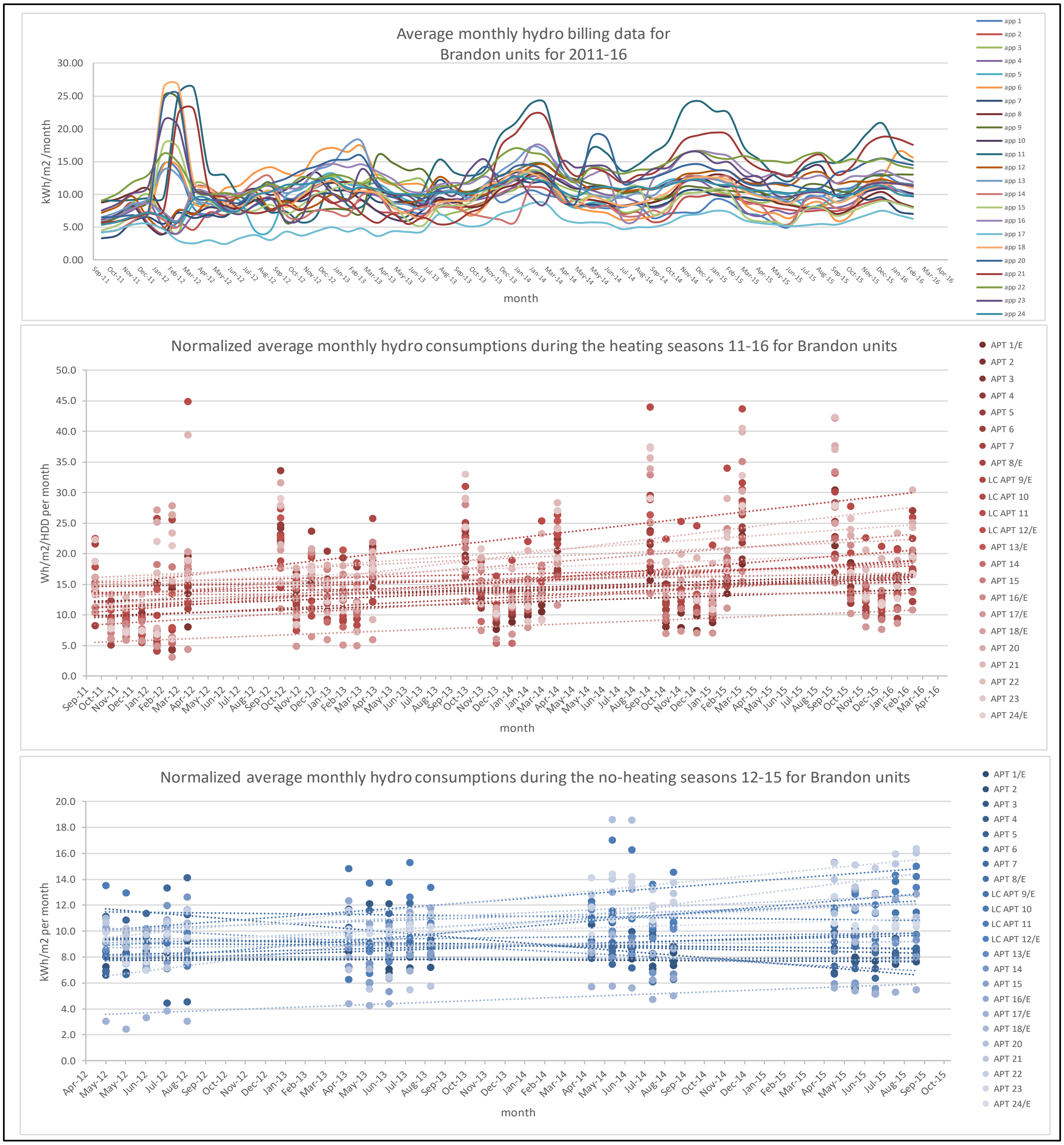


Figure 21. Monthly average consumptions before and after normalization for Brandon units throughout the analysis periods

Figure 22 (next page), on the other hand, shows the boxplots displaying the distribution and consumption averages of consumptions for both the LC and NLC units for each year during the HSs and NHSs.

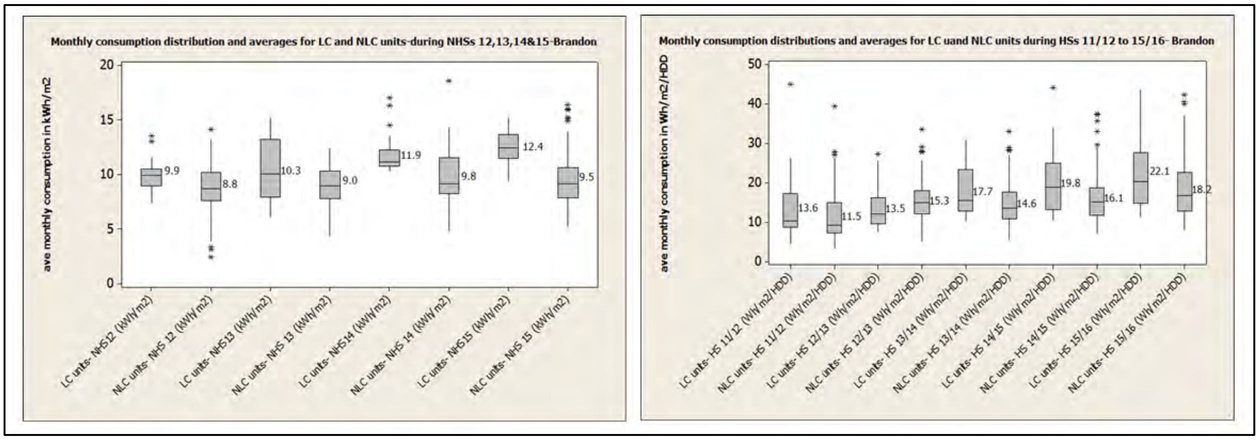


Figure 22: Differences between ave monthly consumptions for LC and NLC units in Brandon during each of the past five years

Figure 22 (above) shows consumption & consumption efficiency trends for both LC and NLC units during both HSs and NHSs, at varying degrees. The figure also shows the significant differences between LC and NLC units' monthly consumption averages. As mentioned before, this may be attributed to the significantly higher consumption of one LC unit and significantly lower consumptions of some NCL units.

The variability in monthly consumption values, on the other hand, deserves some attention **IF** consistent consumption performance is important for sustaining energy. To understand the causes and effects of energy consumption variability, one may compare between the "spread" of projected (HOT2000) and actual monthly consumptions data, shown in *Figures 23 to 25* for the three sites.

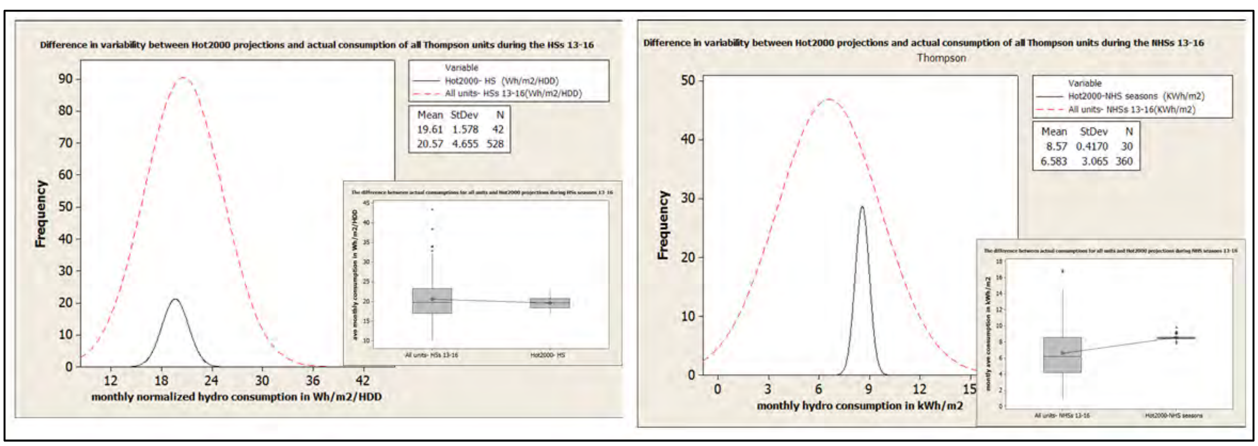


Figure 23: Difference in the variability/spread between projected and actual hydro consumption values for Thompson units

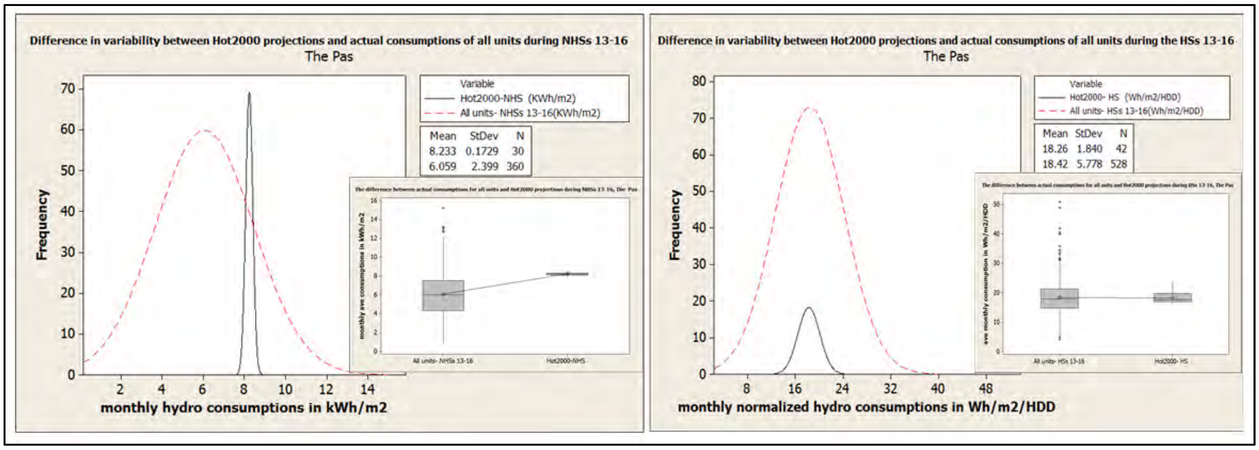


Figure 24: Difference in the variability/spread between projected and actual hydro consumption values for The Pas units

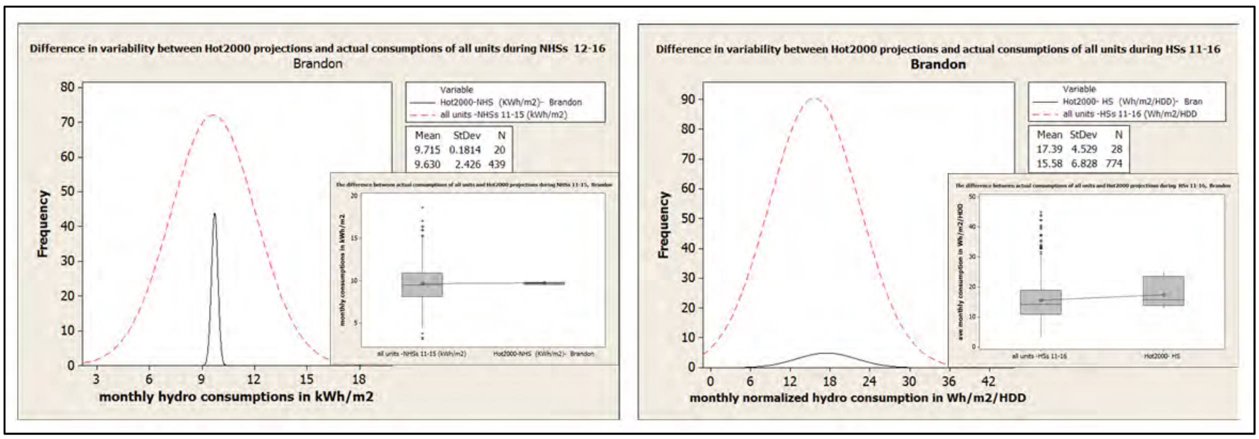


Figure 25: Difference in the variability/spread between projected and actual hydro consumption values for Brandon units

Notwithstanding the frequencies (i.e. number of data points), the figures above show the spread in actual consumption compared with the spread of projected Hot2000 monthly consumption values. During HSs, while the average normalized monthly consumption values in both were close, the spread (i.e. variability) of actual monthly consumptions was multiple times as that for projected values, as expressed by the difference in standard deviations and in the widths of the distribution curves and depths of the boxplots (note: during the NHSs, such variability difference is even higher).

This may be explained by the fact that projected values generated using tools such as Hot2000 are based on a set of inputs and assumptions, some of which are ideal, such as rates of air changes, envelope insulated R-values and occupancy levels per unit. Actual values, on the other hand, reflect "real world" conditions which influence consumption. These conditions include: overlooked design and/or construction defects, HVAC systems' deficiencies, environmental changing conditions, and most importantly occupants' effects (e.g. #, habits and behavior). The conditions may even include imprecisions in monitoring and recording consumption data.

While it is unrealistic to assume that we should target such tight consistency shown for projected consumption, we should strive to reduce the variability in actual consumption. The effects of understanding the causes of and in turn reducing such variability and improving the consumption consistency have a number of benefits. First, large variability in any process indicates the existence of defects, as mentioned above, that may result in wasting energy. Therefore, identifying leaky windows for example or clogged furnace filters or missing wall insulation would definitely lead to correcting problems and conserving energy. Second, in the long run, consistent energy consumption would be a reflection of changes in occupants' behavior and would also allow utility companies to supply less expensive energy and better plan for it, the consumption of which would be more predictable (less variable).

One way of realizing such target may exist with "better" management and control of consumption. Smart meters and emerging smart home technologies (Appendix B) would help inform occupants in real time how much they are losing by raising a thermostat's dial unnecessarily, or by leaving windows ajar in the middle of winter, or by not maintaining their furnaces, hot water tanks and heat recovery systems. Another way is through using benchmarks and baseline consumption values that integrate dynamic control mechanisms; such as those proposed in later sections.

It should be noted that although variations exist among all unit's consumptions; there were no significant differences between the two groups; LC and NLC units, except for the Brandon units.

4.3 Comparing Energy Performance Among the Three Sites

In order to compare energy performance across the three sites, all consumption data during the heating seasons (HSs) had to be normalized and expressed in terms of heating degree days ($Wh/m^2/HDD$). Consumption data during the five months of no heating seasons (NHSs) on the other hand, were left in as is in kWh/m^2. It should also be noted that:

- The following comparative analysis was only focused on hydro consumption with respect to local weather conditions and units' areas. Unit occupants on each site may affect performance but they were not addressed in this analysis.
- These units' construction was completed by three different building contractors and therefore it is expected that local materials, labour and general construction conditions may vary and have different effects on the final products. However, the hypothesis is: if basic designs of all units were the same for the three developments, then no significant differences were to be expected for energy consumption performance and specifically its efficiency ($Wh/m^2/HDD$).
- Although consumption data for the Brandon units included their share of running the geothermal system, there were inherent differences in the consumption processes and in turn consumption values compared with those for the The Pas and Thompson units.

Taking the above notes into account, *Figure 26* (next page) shows the differences in monthly consumption averages and variability across the three sites both during heating and no heating seasons. The figure shows that Thompson had the highest monthly average (mean) consumption during all HSs at 20.6 $Wh/m^2/HDD$ followed by The Pas units with an average of 18.4 $Wh/m^2/HDD$ and the Brandon units with an average of 15.6 $Wh/m^2/HDD$.

During the NHSs and as expected and shown in the figure, Brandon units' had the highest monthly average at 9.6 kWh/m^2 followed by Thompson and The Pas units' averages of 6.6 and 6.1 kWh/m^2, respectively.

Statistical tests, the results of which shown in *Figure 27* were also conducted to assess the significance of the difference between monthly consumption values at the three sites. The figure shows significant differences among consumptions levels at the three sites, both during the HSs and NHSs. It should be noted that the term "significant" refers to the statistical hypothesis suggesting that the differences in monthly average consumption were not likely due to chance but rather an inherent or natural difference across the sites. This significance level is reflected in the probability value P (< 0.05).

The variability in monthly consumption average values, on the other hand and as shown in *Figure 26* (next page), was the lowest in Thompson during the HSs with standard deviation (σ) of 4.7 $Wh/m^2/HDD$

followed by The Pas and then Brandon units' σ's at 5.8 and 6.8 $Wh/m^2/HDD$, respectively. However, during the NHSs, Thompson units showed the highest variability with σ at 3.1 kWh/m^2 followed by that for The Pas and Brandon units (2.4 kWh/m^2).

The differences in variability (or consistency) of monthly consumptions may also be noticed in the number of "outliers" values appearing in the boxplots for The Pas and Brandon compared to those for Thompson as depicted in *Figures 26* (below) and *27 (next page)*. Such higher number of outliers could result from computational errors or be due to occupancy levels at the different locations during these seasons or issues within the consumption process that result in skewing the data towards one side and therefore needs to be addressed. The later reason is believed to be the likely one.

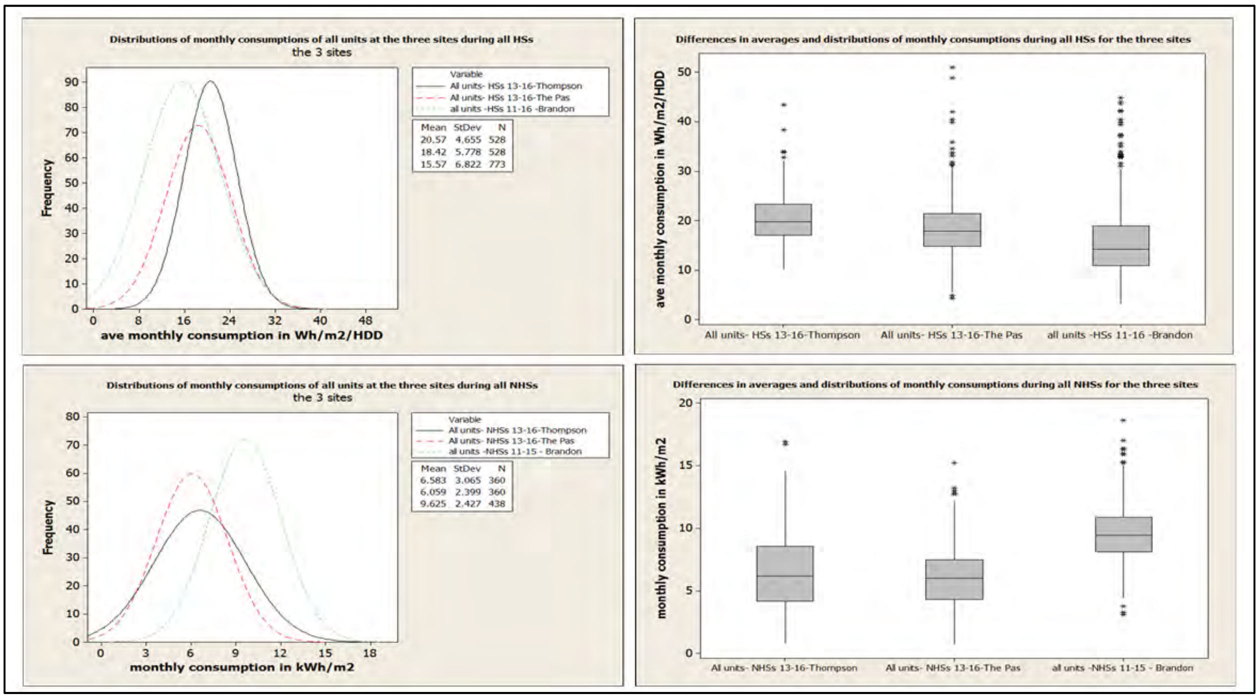


Figure 26: Distribution and variation of monthly consumptions for the three sites

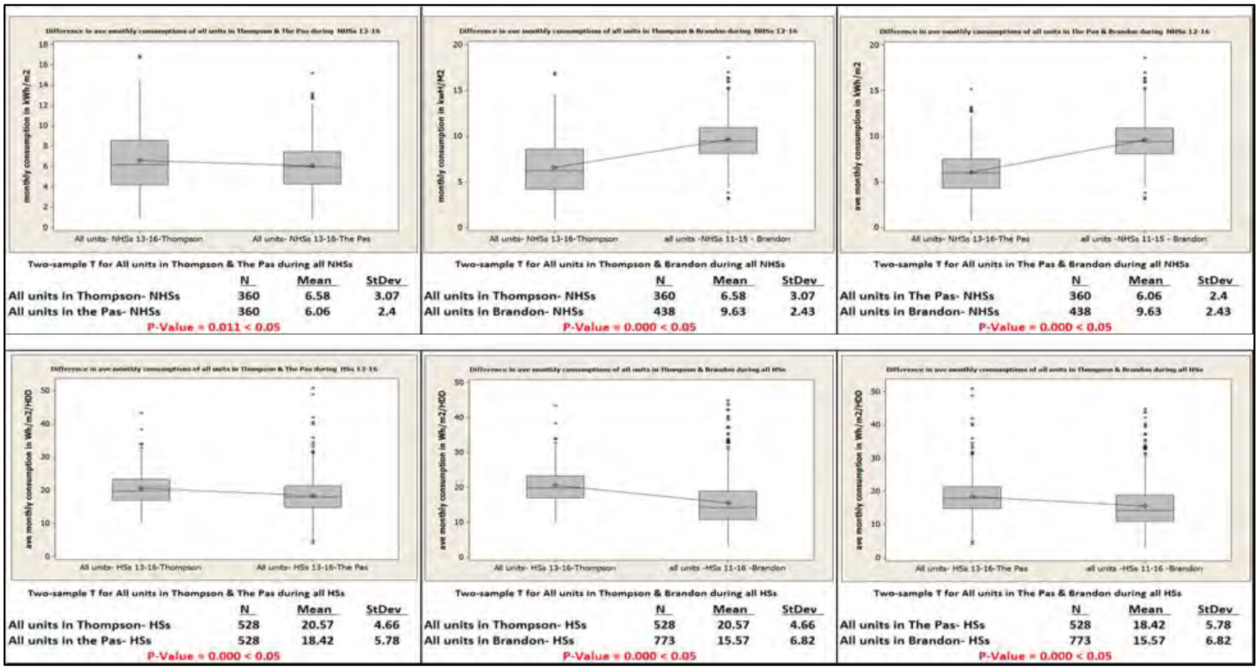


Figure 27: Results of testing the significant differences between monthly consumptions at the three sites

5. Proposed Benchmarking Process

The above assessment of energy consumption performance at the three sites has so far shown that:

- Consumption performance differ significantly among the three sites
- Consumption performance differ significantly between the HSs and NHSs, particularly in The Pas & Thompson
- There are no significant differences between projected (Hot2000) and actual average monthly consumption during the HSs but significant differences during the NHSs
- There are no significant differences between consumption performance of LC and NLC units
- Consumption variability and trends could be more important parameters to focus on than deviations from projections

Therefore, the proposed benchmarking process is based on those analytical assessments listed above and is intended to establish a monitoring and managing process that targets “best practice” to continuously improve and control energy consumption in those and similar residential homes.

The process entails:

1. Developing a simple model for projecting average monthly consumption based on the historical data from each site.
2. Using a simple visual tool that relates actual to projected consumption and helps identify significant differences not only in consumption values but also in consumption variability and trends in a timely manner.

In order to develop the consumption prediction model, a review is first conducted of monthly consumption for all units post occupancy during the HSs and NHSs, as that shown in *Figure 28* (next page) for the Thompson units.

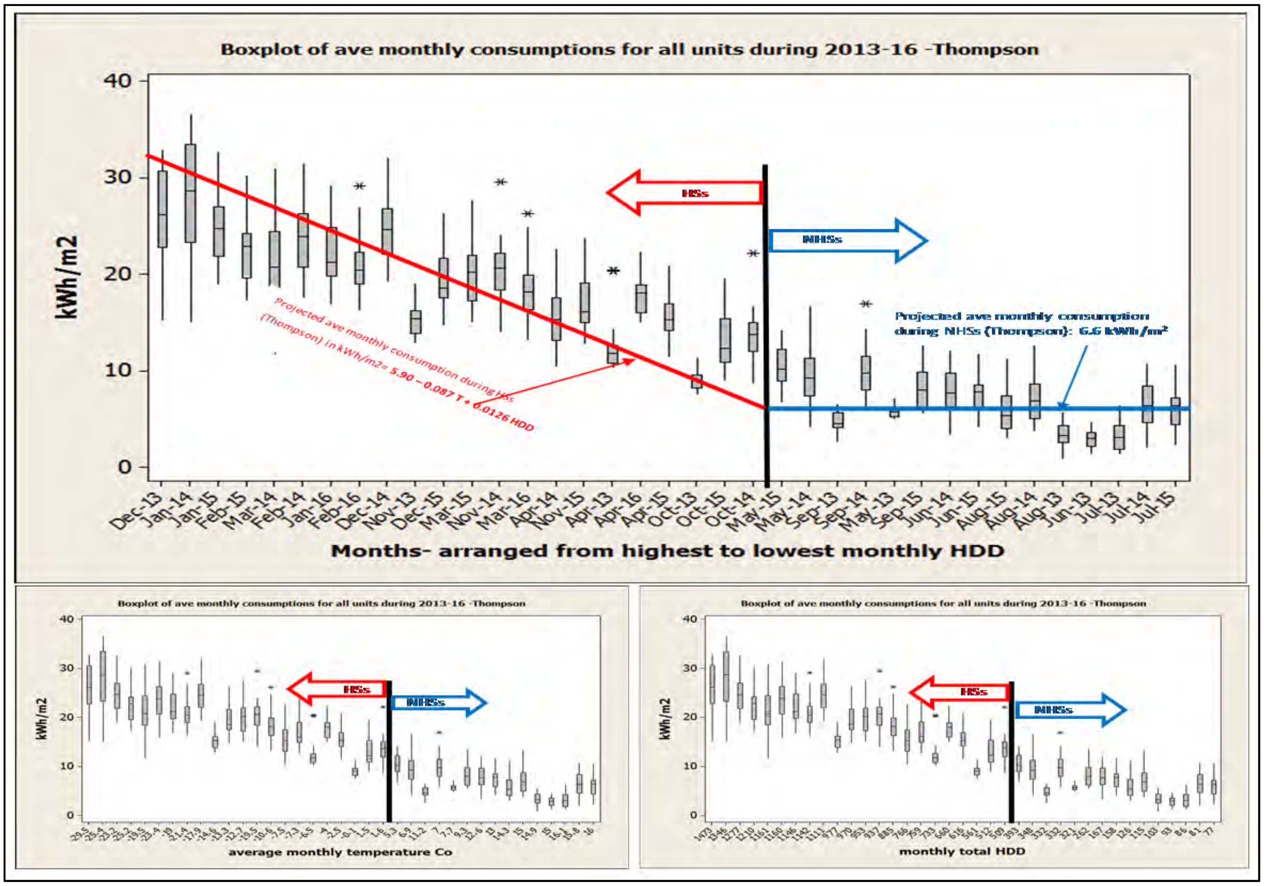


Figure 28: Development of the consumption projection model using historical average monthly consumption values for all units in Thompson

The figure shows that when average monthly consumptions values were correlated to total monthly HDD, the resulting divide between heating seasons (October to April) and no-heating seasons (May to September) existed at HDD of 400 and average monthly temperature of 5 C^o, approximately.

Based on this dividing line, the projected average consumption value during the NHSs is assumed to be equal to the average historical values of 6.58 kWh/m2 (refer to *Figures 8* and *11*). The projected average consumption values during the HSs, on the other hand, are established from regression analysis. The linear regression analysis performed between historical average monthly consumptions and both HDD and monthly average temperatures yielded the following relationship:

$$\mathbf{PAMC_{Thompson} = 5.90 - 0.087\, T_{Thompson} + 0.0126\, HDD_{Thompson}} \qquad \text{-1-}$$

Where:

PAMC = Projected Average Monthly Consumption in kWh/m^2

T = average monthly temperature in C^o

HDD = total monthly heating degree days

The second step in the process of benchmarking is using a control chart that is based on the deviations of actual from projected monthly consumptions. In general, the control chart is a graph used to monitor how a process changes over time with relevant measurements plotted in time order. A control chart always has a central line for some sort of an average and for this proposed chart, the average line corresponds to “0”; that is the hypothetical difference between actual and projected consumption for a perfect and stable process. The chart also has upper and a lower control limits. These limits are based on historical data and contain over 95% of all measurements; **IF** the process is in control. The measurements falling inside the limits; called noises, represent the normal variation and trends within the process. However; if the process gets out of control at any time; more measurements start to fall outside these limits, highlighting the need for managers or operators of the process to start working on finding the cause of such signals/problems.

To adapt this powerful tool, two statistical tests were performed; first to ensure that the values representing the deviations of actual from projected consumption were normally distributed and second, to determine if there was a significant difference between those values representing HSs and NHSs deviations. The results of these tests, as shown in *Figure 29* (below), confirmed that indeed these values were normally distributed and that there was no significant difference between the two sets of deviations (P-value > 0.05).

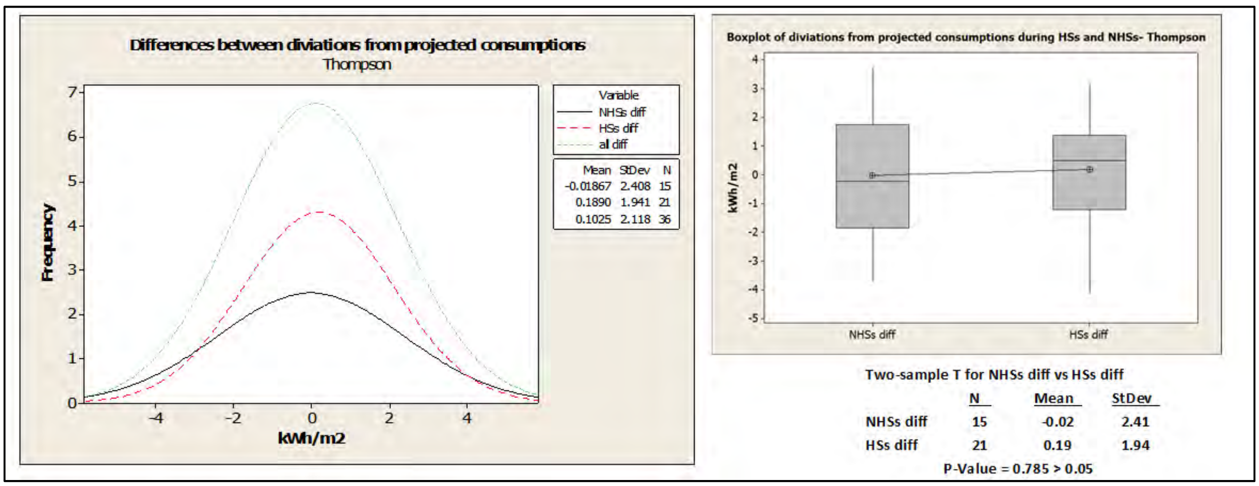


Figure 29: Differences between deviations from projections for both HSs & NHSs

The importance of these tests is that we could now use one control chart for both sets of deviations even though the actual or projected values themselves were significantly different.

In developing the control chart, the overall average actual and historical monthly consumptions were first determined from actual/historical monthly consumption of all individual Thompson units. Projected monthly averages, on the other hand, were then calculated using the total monthly HDD and average monthly temperature for HSs values (according to relation 1. above) or assigned the average value of 6.6 kWh/m^2 for the NHSs months. *Figure 30* (following page) shows part of calculating the limits of the proposed chart and an illustration, using the histogram of the deviations from *Figure 29* (below), of how the chart can be constructed and used for plotting the monthly deviations.

Thompson	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Mar-16	Apr-16	
Total Monthly HDD	733.40	320.60	93.40	86.30	103.20	331.90	560.60	976.60	1473.30	1346.30	1160.00	1161.00	885.00	660.00	
Average Monthly Temperature Co	-6.50	7.70	15.00	16.10	14.90	11.20	-0.10	-14.60	-29.50	-25.40	-23.40	-19.50	-10.60	-4.00	
Overall Monthly Historical Average kWh/m^2	12.43	5.72	2.86	3.19	3.33	4.76	9.07	15.33	25.80	27.80	23.81	21.00	18.46	17.77	
Monthly Target Consumption kWh/m^2	15.71	6.60	6.60	6.60	6.60	6.60	12.97	19.48	27.03	25.07	22.55	22.23	17.97	14.56	
Deviation from Target	-3.28	-0.88	-3.74	-3.41	-3.27	-1.84	-3.90	-4.15	-1.23	2.73	1.26	-1.23	0.49	3.20	
Control Chart Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Moving Range		2.40	2.86	0.33	0.14	1.43	2.07	0.25	2.91	3.96	1.47	2.49	1.91	2.72	1.65
LCL (lower control limit)	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	-4.38	
UCL (upper control limit)	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	4.38	

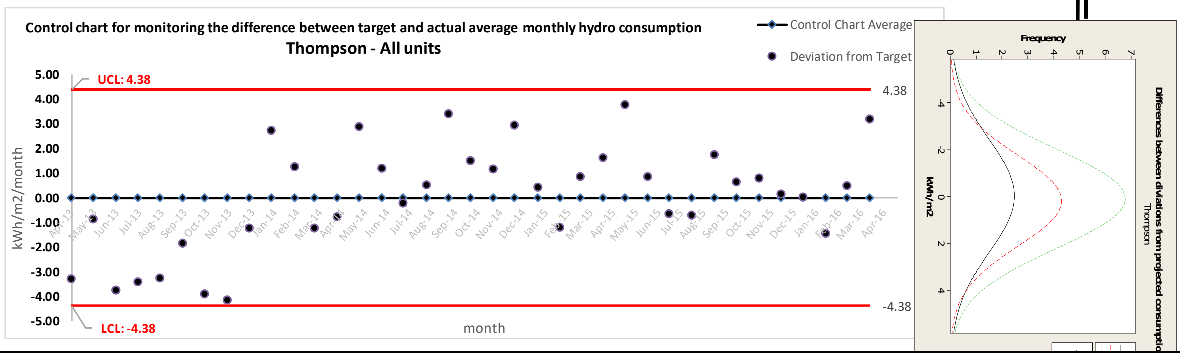


Figure 30: Illustration of how the control chart is constructed and used

It should be noted that the upper and lower limits shown in *Figure 30* (above) were calculated as 2.66 times the average moving range (1.65). Alternative upper and lower limits in the chart may be calculated as +/- 3 standard deviations of the differences between actual and projected values.

To further illustrate the usefulness of these charts, let us assume that those limits set above were used to monitor and manage consumption levels for individual units. *Figure 31* (below) shows the control charts for units #20 and #42. The graph shows that the number of signals (i.e. the red dots for measurements falling outside the control limits) were much higher for unit #20 compared with those for unit #42. Month to month plotting of those deviations could definitely raise flags for owners or managers to inspect the units and perhaps to address any maintenance or repair problem instead of waiting to inspect annual consumption levels (top part of the figure).

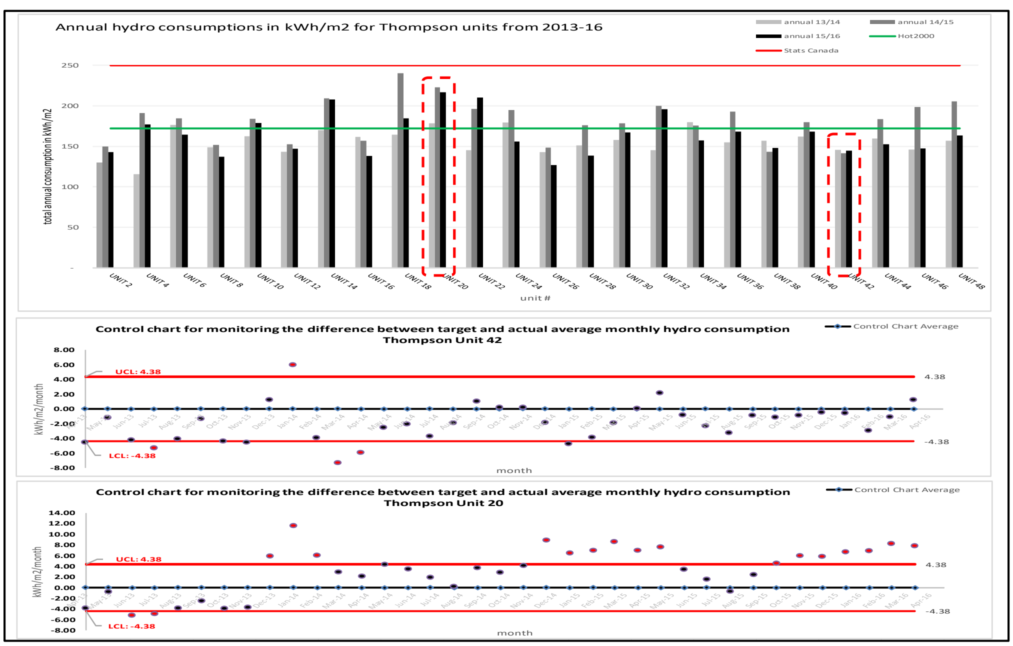


Figure 31: Illustration of using the control chart for monitoring and managing consumptions for individual units

The benchmarking process for both The Pas and Brandon units follow the same steps as those followed for Thompson. Relationships 2 and 3 show the regressions models for the projected average monthly consumptions (PAMC) in The Pas and Brandon, respectively, as functions of average monthly temperatures (T) and total monthly HDD.

$$\mathbf{PAMC_{\text{the Pas}} = 3.35 - 0.124\ T_{\text{the Pas}} + 0.015\ HDD_{\text{the Pas}}} \qquad \text{-2-}$$

$$\mathbf{PAMC_{\text{Brandon}} = 7.46 - 0.0166\ T_{\text{Brandon}} + 0.0046\ HDD_{\text{Brandon}}} \qquad \text{-3-}$$

Figures 32 (below) and *33* (next page) show the development of the monthly consumption prediction models for both sites. It should be noted that the regression models for both Thompson and The Pas were better representations of the data (monthly temperatures and HDD) than the Brandon data. This is manifested in the values of best fit parameters (R-squared) of the models for Thompson and The Pas at 87% compared to 36% for Brandon model. This is attributed to the already established fact that monthly consumption values for Brandon units were less dependent on weather changes due to the existence of the geothermal system as well as the significant variability and number of anomalies inherent in these values compared with Thompson's and The Pas's values (*Figure 25*).

It should also be noted that the line dividing HSs from NHSs in the Pas exists at the average monthly temperature of 7C^{o} and HDD of 350 approximately while that for Brandon exist at the monthly temperature value of 10 C^{o} and HDD of 250 approximately.

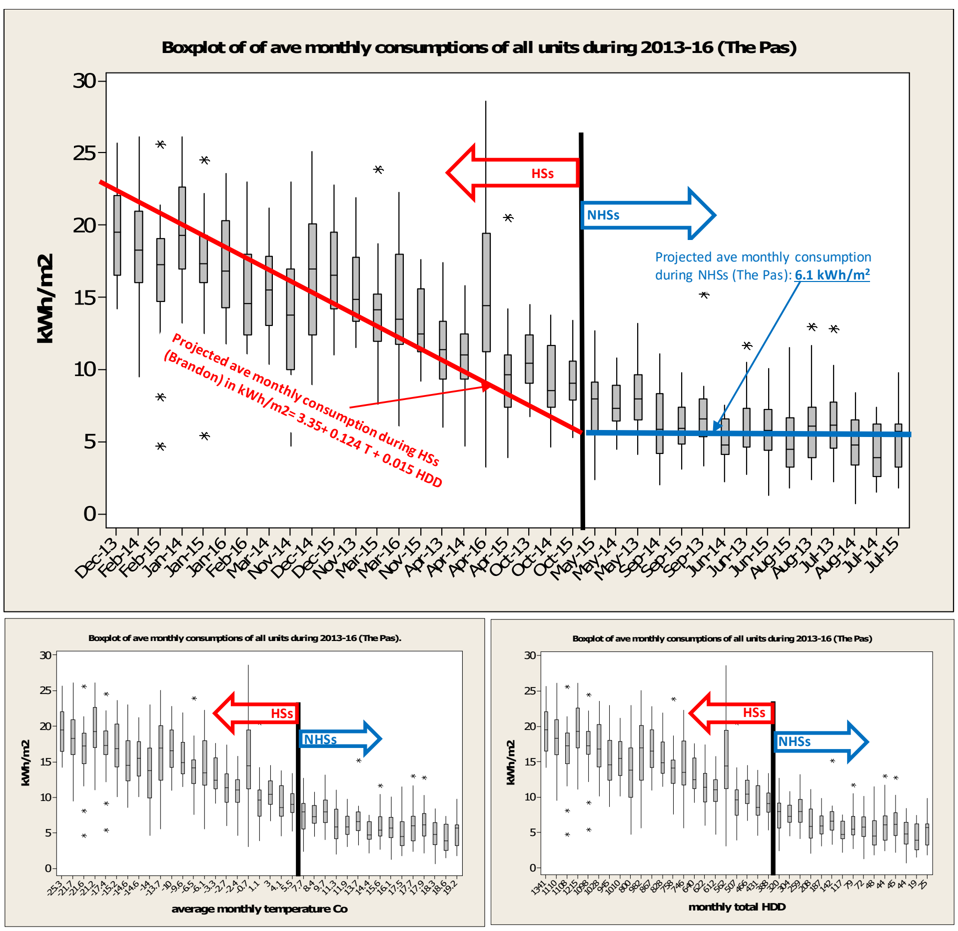


Figure 32: Development of the consumption projection model using historical average monthly consumption values for all units in The Pas

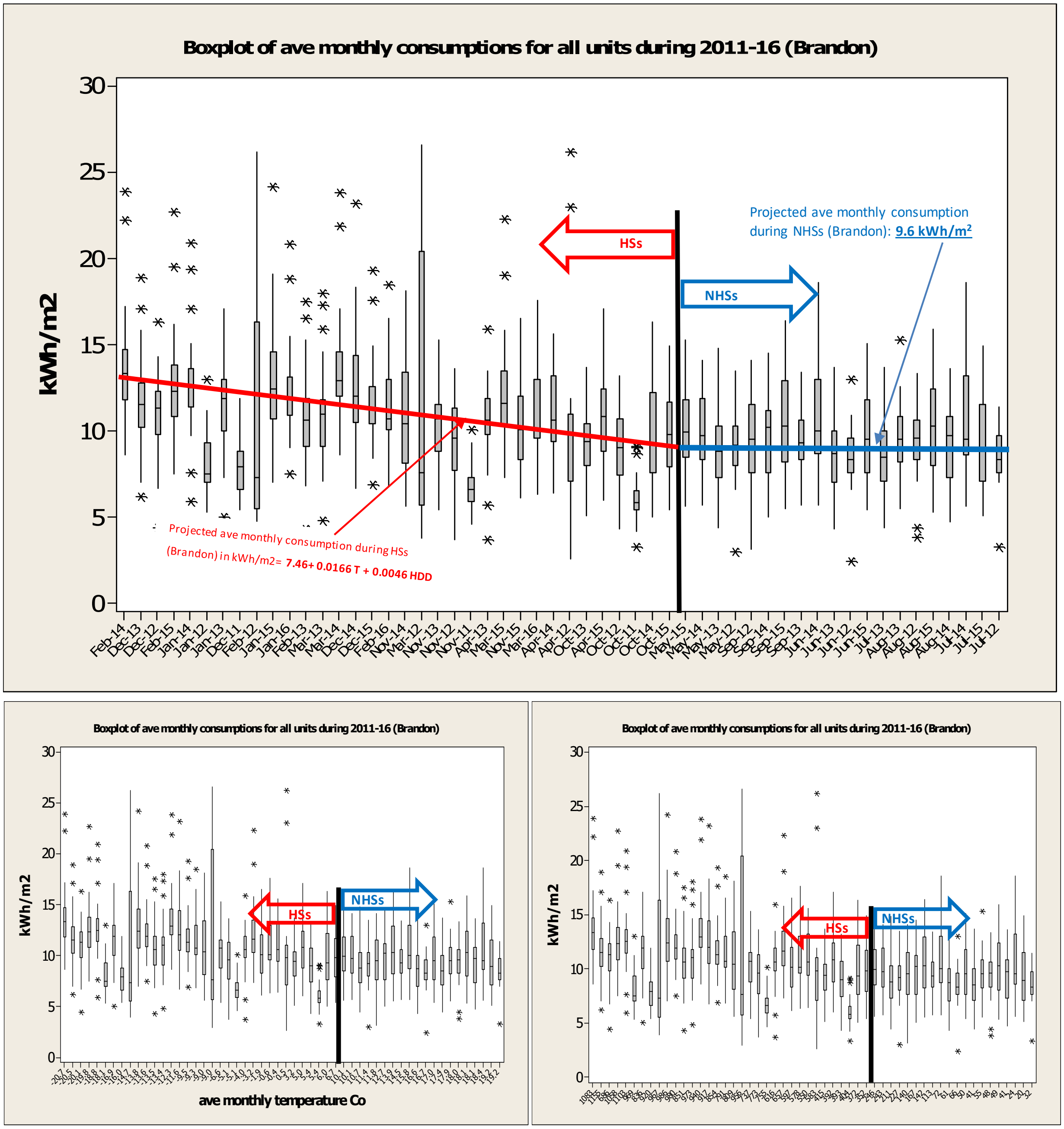


Figure 33: Development of the consumption projection model using historical average monthly consumption values for all units in Brandon

Based on the consumption projection models, the control charts can also be developed for both The Pas and Brandon, in the same way described before for Thompson's units. *Figures 34* and *35* (next page) show the calculations for establishing these charts and illustrations of applying them in monitoring average monthly consumptions of all units.

The Pas	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-16	
Total Monthly HDD	622	259	79	45	44	142	466	828	1341	1215	1110	1010	562	
Average Monthly Temperature C°	-2.7	9.7	15.6	17.9	17.7	13.7	3.0	-9.6	-25.3	-21.2	-21.7	-14.6	-0.7	
Overall Monthly Historical Average kWh/m²	11.4	8.2	6.0	6.3	6.2	6.7	10.7	15.5	19.5	19.3	18.0	15.5	15.4	
Monthly Target Consumption kWh/m²	13.0	6.1	6.1	6.1	6.1	6.1	10.0	17.0	26.6	24.2	22.7	20.3	11.9	
Deviation from Target	-1.7	2.1	-0.1	0.2	0.1	0.6	0.7	-1.5	-7.1	-5.0	-4.7	-4.8	3.5	
Control Chart Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Moving Range		3.72	2.13	0.30	0.08	0.49	0.09	2.18	5.63	2.13	0.25	0.09	4.53	1.68
LCL (lower control limit)	-4.46	-4.46	-4.46	-4.46	-4.46	-4.46	-4.46	-4.46	-4.46	-4.46	-4.46	-4.46	-4.46	
UCL (upper control limit)	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	4.46	

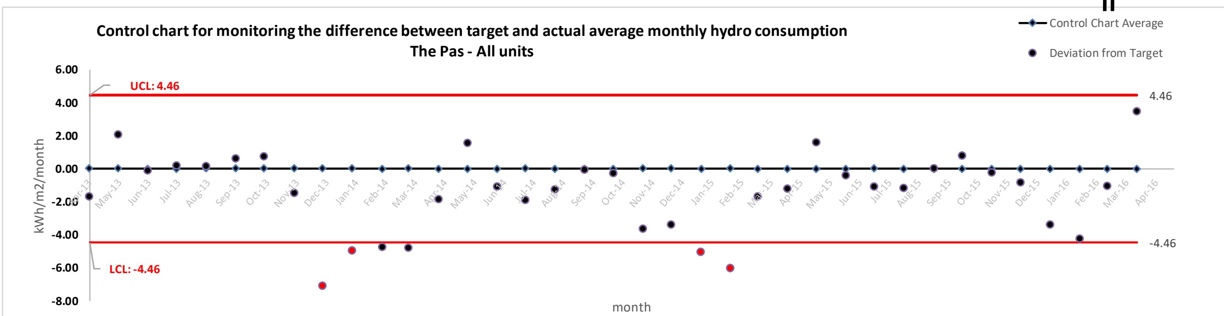


Figure 34: Illustration of how the control chart is constructed and used for the Pas units

Brandon	2011, Oct	2011, Nov	2011, Dec	2012, Jan	2012, Feb	2012, Mar	2012, Apr	2012, May	2012, Jun	2012, Jul	2012, Aug	2012, Sep	2012, Oct	2012, Nov	2012, Dec	2013, Jan	2013, Feb	2013, Mar	2016, Mar	
Total Monthly HDD	404	755	920	969	967	956	583	227	66	32	48	140	393	773	686	836	851	973	578	
Average Monthly Temperature C°	5.4	-5.1	-16.0	-18.1	-14.7	-9.0	0.5	11.4	16.7	19.2	18.0	11.8	5.4	-5.1	-20.1	-16.9	-13.5	-13.4	-0.6	
Overall Monthly Historical Average kWh/m²	6.1	6.7	7.9	8.2	11.2	12.4	10.2	9.0	8.5	8.5	9.3	9.4	9.0	9.4	11.0	11.4	10.8	11.2	11.0	
Monthly Target Consumption kWh/m²	9.2	11.0	12.0	12.2	12.2	12.0	10.1	9.6	9.6	9.6	9.6	9.6	9.2	11.1	10.9	11.6	11.6	12.2	10.1	
Deviation from Target	-3.2	-4.3	-4.0	-4.0	-0.9	0.3	0.1	-0.6	-1.1	-1.1	-0.3	-0.2	-0.2	-1.7	0.0	-0.2	-0.8	-1.0	0.9	
Control Chart Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Moving Range		1.15	0.26	0.02	3.12	1.25	0.26	0.64	0.53	0.03	0.77	0.10	0.03	1.47	1.68	0.18	0.63	0.20	0.54	0.67
LCL (lower control limit)	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	-1.78	
UCL (upper control limit)	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	

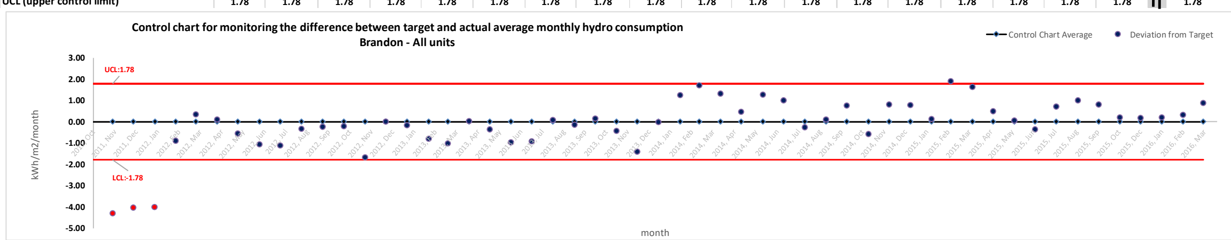


Figure 35: Illustration of how the control chart is constructed and used for Brandon units

6. Summary, Conclusions & Recommendations

The project began in early 2014 in response to a call to conduct a post occupancy evaluation (POE) for a seventy-two LEED homes; twenty-four of which are located in each of three Manitoba cities: Thompson, The Pas and Brandon. The framework proposed to conduct the POE entailed assessing the functional, technical and economic aspects of those units. Two teams of researchers; one from Red River College (RRC) and the second from University of Manitoba (UOM) became involved in the project. The RRC team led energy performance and lifecycle cost assessments while the UOM team led the indoor environmental qualities (IEQ) and functional assessments. While the energy performance assessment; subject of this white paper, is completed; work is still on going to complete other assessments. Appendix A includes up-to-date progress work related to lifecycle cost analysis and IEQ assessments.

To conduct the assessments for energy performance, hydro monthly billing data were re-arranged and normalized to transform them into more reliable and representative data for analytical purpose. The twelve months of a year were then divided into heating season (HS) and no-heating season (NHS) due to the significant differences in related energy consumption and their monthly consumption values. HSs months included October to April and NHSs months included May to September. The primary energy performance metrics were selected as monthly consumption in Wh/m^2/HDD and kWh/m^2 for both HSs and NHSs months, respectively. Units in each location were divided into LEED Certified (LC) and Non-LEED Certified (NLC) units.

The performance assessments of energy consumption for the units at each location were based on three main attributes: deviations from projections/reference values; trends and levels of variability of average actual monthly consumption values for both LC and NLC units.

Generally, and for all three sites, the energy performance analysis showed that the annual average actual consumption values were lower than projected and reference values.

Although differences exist between the performances of the Thompson and the Pas units; analysis of monthly average consumptions showed that they both shared the following results:

- There was no significant difference between the LC and NLC units
- There was no significant difference between the monthly average actual and projected consumption during the HSs
- A significant difference existed between the monthly average actual and projected consumption during the NHSs
- While un-normalized actual monthly consumption in kWh/m^2 generally decreased over the last three years; the normalized consumptions in $Wh/m^2/HDD$ during HSs showed a slight upward trend.
- Significant variability existed in the monthly average actual consumptions; whether during HSs or NHSs, compared with the consistent and “tight” pattern of consumptions for projected consumptions

As for Brandon and due to the use of geothermal system to supply heating and cooling loads during HSs and NHSs; the energy consumption process and in turn performance were significantly different than in Thompson and The Pas. The analysis showed:

- There was no significant difference between the monthly actual averages and Hot2000 projected consumptions during either HSs or NHSs
- There is statistically significant difference in the monthly consumptions between LC and NLC units during both HSs and NHSs
- There may be slight trends (upward) in consumptions before and after data normalization.
- Variability in monthly consumptions was very significant in Brandon and there was also a significant number of anomalies (outliers) that add to such irregularity

To address the consumption related issues identified during the analysis, an energy visual management process was proposed that targets continuous improvements of energy consumption, particularly controlling excessive variability and reduction in consumption efficiencies. The proposed process consisted of:

1. A simple model for projecting average monthly consumption based on the historical data from each site
2. A simple visual tool that correlated actual to projected consumptions and helped identify significant differences not only in consumption values but also in consumption variability and trends in a timely manner.

However; in order to ensure that the proposed process achieves its objectives; parallel improvements of the current LEED rating and certification process must be implemented. The following recommendations are based on assessing the LEED process documented and reviewed for this project:

- Early involvement of the LEED Rater and commissioners in the design and construction stages, would result in reducing construction deficiencies and subsequent re-work to correct them.
- More emphasis should be placed on assessing ventilation and heating installations and processes.

- Less emphasis may be placed on air tightness tests as currently conducted and efforts may be made to streamline the test procedures or totally replace it with a more cost-effective alternative
- Training for the occupants must follow standardized, credible and transparent procedures and the rating for the “Awareness and Education” category in the LEED score card must be reviewed and increased relative to other categories.
- The rating process must include references to post occupancy monitoring of parameters such as energy and water efficiencies and indoor air quality. The process may consider delay certifying units till after occupancy.
- Finally, the cost of certifying needs to be assessed with the aim to reduce it.

Appendix A

First: Summary of Up-to-Date Work on Lifecycle Cost of LEED Homes

As part of performing the POE; a lifecycle cost analysis (LCCA) of LEED homes in the three locations should be thoroughly conducted. The main purpose of undertaking this LLC analysis is to address the question of whether LEED homes would cost more or less to develop, maintain and operate in comparison to conventional homes throughout their life spans.

LCCA properly weights money spent today versus money spent in the future. All costs are converted to current dollars and then summed to develop a total cost in present dollars for alternative homes. This quantity is referred to as the net present value or the total cost in today's dollars.

Currently, and due to limited data available, only an example of lifecycle cost analysis is presented in this report. More detailed analysis will be completed and published in future reports once all related cost data are acquired

In addition to the available capital (initial) costs, the example analysis will demonstrate how typical operational & maintenance costs are all calculated and included in an economic model that may be used to establish a projection for life cycle cost. The work will also use some of the measurements (e.g. energy consumption), in developing the LLC projection model. Some assumptions such as: 50 years for whole building's useful life, steady inflation rates, and current known material prices, are made to help in the demonstration and will be presented below.

The basic formula used is as follows:

$LCC = C + PV_{RECURRING} – PV_{RESIDUAL\text{-}VALUE}$

Where:

LCC is the life cycle cost

C is the Year 0 construction/initial cost (hard and soft costs)

$PV_{RECURRING}$ is the present value of all recurring costs (utilities, maintenance, replacements, service, etc.)

$PV_{RESIDUAL\text{-}VALUE}$ is the present value of the residual value at the end of the study life

The present value (PV) equation is as follows:

$PV = F_Y / (1 + DISC)_Y$

Where:

PV is the present value (in Year 0 dollars)
F_Y is the value in the future (in Year Y dollars)
DISC is the discount rate
Y is the number of years in the future

The following present the values and assumptions used in the example.

First: Initial Costs (C)

The initial cost figures available and shown in Table A-1 are essentially the construction prices charged by the building contractors at each location. The figures do not include property costs, design fees, LEED certification charges or the geothermal system (for Brandon).

	contractor	total$	# units	$/unit	ave m2/unit	$/m2	$/ft2
Thompson	Newton Enterprise	$6,950,706	24	$289,612.75	155	$1,868	$174
The Pas	Von Ast Construction	$6,745,269	24	$281,052.88	155	$1,813	$168
Brandon	WBS Construction	$6,343,628	24	$264,317.83	155	$1,705	$158

Table A-1: Total construction (hard) costs for developing the housing units and sites at the three locations

It should be noted that Manitoba Housing has provided the following figures (*Table A-2*) for conventional homes built during the same period (2010-2011) for comparison purposes

2010 - 15 Units, Hard costs of 244/sq ft and total cost (consulting, etc) of 286/sq ft. – includes geothermal
2010 – 14 Units, Hard costs of 153/sq ft and total costs of 168/sq ft
2011 – 26 Units, Hard costs of 215 / sq ft and total cost of 264/sq ft – includes geothermal

Table A-2: Reference hard and total costs of conventional homes

For purpose of illustration, a total cost of $350,000 per unit is assumed ($2,260/m2 or $210/ft2) for all three sites.

Second: Re-Occurring Costs

Table A-3 shows the matrix for calculating the present values of the initial, operation and maintenance cost over a 50-year life span of the LEED homes.

In the table, the following assumptions are made:

- Unit average area: 155 m^2
- Average annual hydro consumption: 150 $kWh/m^2/yr$
- Average hydro unit cost: $0.07/kWh
- Life span: 50 years
- Escalation rate: 1%
- Discount rate adjusted for inflation: 4%
- Discount rate: 0.50%
- Maintenance & renovations include labour and material for: siding, internal & external painting, roofing, refrigerator, sump pump, water heater, range, dishwasher, clothes washer and dryer, lights, vinyl and carpet flooring, widows, HVAC, heat recovery, geothermal, plumbing & fixtures

Prices and frequencies of work are assumed based on current Manitoba market and as shown in *Table A-3* (below).

unit area		ave hydro consumption & unit cost	assumptions for calculating PV (present value)				first cost	energy	maint&reno
155	m2	150 kwh/m2/yr	life span	50 yrs	disc't rate adjusted for inflation	4%	$2,258	$247	$1,290
		0.07 $/kwh	escalation rate	1%	disc't rate	0.50%			

yr	first cost	pv energy	energy cost	pv m&r	tot m&	wages	cleanir	garbag	incedent
	$350,000								
0	$2,258	$247	$11	$1,290	$35	$15	$5	$5	$10
	$210 ft2								
1		$10	$11	$34	$35	$15	$5	$5	$10
2		$10	$11	$33	$35	$15	$5	$5	$10
3		$9	$11	$32	$35	$15	$5	$5	$10
4		$9	$11	$69	$79	$15	$5	$5	$10
5		$9	$11	$29	$35	$15	$5	$5	$10
6		$9	$11	$29	$35	$15	$5	$5	$10
7		$8	$11	$28	$35	$15	$5	$5	$10
8		$8	$11	$30	$39	$15	$5	$5	$10
9		$8	$11	$26	$35	$15	$5	$5	$10
10		$7	$11	$66	$93	$15	$5	$5	$10
11		$7	$11	$24	$35	$15	$5	$5	$10
12		$7	$11	$52	$79	$15	$5	$5	$10
13		$7	$11	$22	$35	$15	$5	$5	$10
14		$7	$11	$22	$35	$15	$5	$5	$10
15		$6	$11	$38	$63	$15	$5	$5	$10
16		$6	$11	$23	$39	$15	$5	$5	$10
17		$6	$11	$20	$35	$15	$5	$5	$10
18		$6	$11	$19	$35	$15	$5	$5	$10
19		$5	$11	$18	$35	$15	$5	$5	$10
20		$5	$11	$137	$271	$15	$5	$5	$10
21		$5	$11	$17	$35	$15	$5	$5	$10
22		$5	$11	$16	$35	$15	$5	$5	$10
23		$5	$11	$16	$35	$15	$5	$5	$10
24		$5	$11	$17	$39	$15	$5	$5	$10
25		$4	$11	$74	$175	$15	$5	$5	$10
26		$4	$11	$14	$35	$15	$5	$5	$10
27		$4	$11	$14	$35	$15	$5	$5	$10
28		$4	$11	$30	$79	$15	$5	$5	$10
29		$4	$11	$13	$35	$15	$5	$5	$10
30		$4	$11	$43	$121	$15	$5	$5	$10
31		$4	$11	$12	$35	$15	$5	$5	$10
32		$4	$11	$13	$39	$15	$5	$5	$10
33		$3	$11	$11	$35	$15	$5	$5	$10
34		$3	$11	$11	$35	$15	$5	$5	$10
35		$3	$11	$11	$35	$15	$5	$5	$10
36		$3	$11	$23	$79	$15	$5	$5	$10
37		$3	$11	$10	$35	$15	$5	$5	$10
38		$3	$11	$10	$35	$15	$5	$5	$10
39		$3	$11	$9	$35	$15	$5	$5	$10
40		$3	$11	$59	$231	$15	$5	$5	$10
41		$3	$11	$9	$35	$15	$5	$5	$10
42		$2	$11	$8	$35	$15	$5	$5	$10
43		$2	$11	$8	$35	$15	$5	$5	$10
44		$2	$11	$18	$79	$15	$5	$5	$10
45		$2	$11	$13	$63	$15	$5	$5	$10
46		$2	$11	$7	$35	$15	$5	$5	$10
47		$2	$11	$7	$35	$15	$5	$5	$10
48		$2	$11	$8	$39	$15	$5	$5	$10
49		$2	$11	$7	$35	$15	$5	$5	$10
50		$2	$11	$33	$183	$15	$5	$5	$10

yr	inside walls & door	internal re-paining	exterior re-paining	siding	roofing	refriger ator	sump pump	water heater	range	dishwa ter	cloths washer	cloths dryer	kitchen & bathrm	lights	vinyl flooring	carpet	windows	hvac(fu rnace & duct	heat recove ry	geother mal system	plumbi ng fixtures
0	$20	$20	$8	$30	$50	$4	$4	$8	$4	$4	$4	$4	$30	$4	$20	$40	$30	$30	$40	$30	$20
	25	10,20,30,	10,20,30	25	20,40	15,30,45	15,30,45	15,30,45	15,30,45	20,40	15,30,45	15,30,45	25	every 4	20,40	very 8 yr	25 yrs	25	20,40	10,20,30,	20,40
1																					
2																					
3																					
4														$4		$40					
5																					
6																					
7																					
8														$4							
9																					
10		$20	$8																	$30	
11																					
12														$4		$40					
13																					
14																					
15						$4	$4	$8	$4		$4	$4									
16														$4							
17																					
18																					
19																					
20		$20	$8		$50					$4				$4	$20	$40			$40	$30	$20
21																					
22																					
23																					
24														$4							
25	$20			$30									$30				$30	$30			
26																					
27																					
28														$4		$40					
29																					
30		$20	$8			$4	$4	$8	$4		$4	$4								$30	
31																					
32														$4							
33																					
34																					
35																					
36														$4		$40					
37																					
38																					
39																					
40		$20	$8		$50					$4				$4	$20				$40	$30	$20
41																					
42																					
43																					
44														$4		$40					
45						$4	$4	$8	$4		$4	$4									
46																					
47																					
48														$4							
49																					
50		$20	$8										$30				$30	$30		$30	

Table A-3: Example illustrating how different maintenance, operation and energy costs are calculated over home's life span

Assuming a residual cost of zero ($0), *Figure A-1* shows the distribution of those costs, as listed in the table above, for a typical LEED home in Manitoba.

As stated before, more detailed analysis will be completed and published in a future report once all related cost data are acquired.

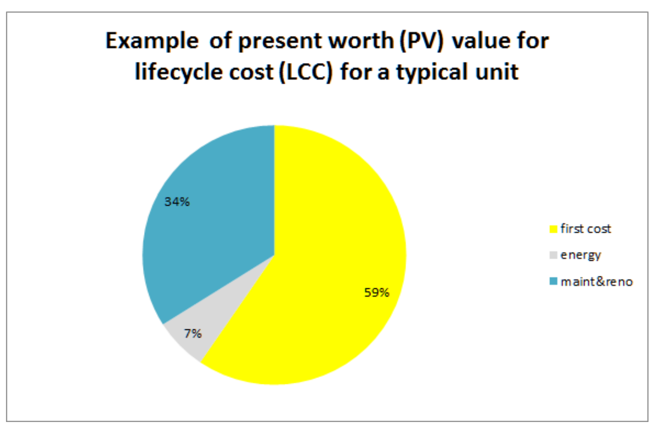


Figure A-1: Distributions of different costs for a typical LEED home in Manitoba

About the Authors

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PhD PEng

A civil engineer with a B.Sc. from Cairo University (Egypt) and M.Eng. and Ph.D., from the University of Manitoba (Winnipeg, Canada).

Shokry began his career as a project manager for commercial, industrial, and residential buildings. He has since held a number of research positions focusing on improving the efficiency and productivity of the construction industry. His research positions include: the Director of Research with the Prairie Masonry Research Institute (PMRI) in Edmonton, Alberta; Senior Research Engineer at the Construction Engineering Department at the University of Alberta; Research Manager with the National Research Council (NRC) in London, Ontario; and Construction Research Chair at Red River College (RRC) in Winnipeg, Manitoba. He also held Adjunct Professorship posts and taught at the University of Alberta and the University of Western Ontario.

Shokry is a Professional Engineer in Alberta and Manitoba and holds a Six Sigma black belt. He authored over fifty publications, holds three patents, and presented in numerous events on construction and environmental related issues.

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Marten's diverse portfolio reflects a career informed by international experience and an unparalleled commitment to sustainability. Working in the Netherlands, United States, and Canada, his areas of specialization include housing developments plus a wide range of experience in academic and healthcare facilities, and institutional landmarks.

A LEED® Accredited Professional since 2008, he is both the Chair of the Manitoba Chapter and a National Director of the Canada Green Building Council. Committed to sustainability as a consideration from the earliest stages of design and throughout the life of a project, his projects include the International Peace Gardens Interpretive Centre (LEED Silver Certified), the ft3 offices at The Strand on Waterfront Drive (LEED CI Gold Certified), in addition to a City of Winnipeg Accessibility Special Recognition Award in 2010. He has pursued a career informed by the belief that green buildings are affordable, durable and functional.