HOUSING RESEARCH REPORT

Inuvik Northern Sustainable House Energy Consumption Monitoring

Canada

CMHC SCHL

CMHC helps Canadians meet their housing needs.

Canada Mortgage and Housing Corporation (CMHC) has been helping Canadians meet their housing needs for more than 70 years. As Canada's authority on housing, we contribute to the stability of the housing market and financial system, provide support for Canadians in housing need, and offer unbiased housing research and advice to Canadian governments, consumers and the housing industry. Prudent risk management, strong corporate governance and transparency are cornerstones of our operations.

For more information, visit our website at **www.cmhc.ca** or follow us on **Twitter**, **LinkedIn**, **Facebook** and **YouTube**.

You can also reach us by phone at 1-800-668-2642 or by fax at 1-800-245-9274. Outside Canada call 613-748-2003 or fax to 613-748-2016.

Canada Mortgage and Housing Corporation supports the Government of Canada policy on access to information for people with disabilities. If you wish to obtain this publication in alternative formats, call 1-800-668-2642.

ARCTIC ENERGY ALLIANCE

INUVIK NORTHERN SUSTAINABLE HOUSE ENERGY CONSUMPTION MONITORING

NWTHC
CMHC

Year 1 & 2 Results

This report presents the results of two years of energy monitoring of the Northern Sustainable House in Inuvik, Northwest Territories. The first year of energy performance and indoor air quality monitoring compared the results with a similar conventional duplex and HOT2000 modeled results. Between years 1 and 2, modifications were made to the house to get it closer to the original design intent. The second year monitored the energy use only of the Northern Sustainable House to compare the results after the upgrades.

EXECUTIVE SUMMARY

The Inuvik Northern Sustainable House (NSH) was built in 2009 as part of a joint project between the Canada Mortgage and Housing Corporation (CMHC) and the Northwest Territories Housing Corporation (NWTHC) and signed over to the Inuvik Housing Authority (IHA). CMHC's Design and Construction of the Inuvik NSH (Canada Mortgage and Housing Corporation, 2013) details the design process, the key design features, the modeling of the duplex, the construction process and some of the challenges and lessons learned from the project.

The house was monitored for 2 separate years (September 2012 - August 2013 and November 2014 – October 2015). There were several house deficiencies discovered during the first year of monitoring and during the commissioning process that were rectified prior to the second year of monitoring.

The Inuvik NSH had a design goal set to reduce the annual energy consumption of the house to 50% that which was built to the Model National Energy Code for Houses (MNECH). In addition the NWTHC set a second goal to achieve an EnerGuide for Houses (EGH) rating of 85 or higher. The as-designed house was modeled to exceed the EGH rating to an estimated EGH 89, and was expected to consume 42% less than the MNECH, or in other words, 58% of the energy consumption of a house built to MNECH. The as-built house was modeled to exceed the EGH rating to an estimated EGH 88 if solar hot water (SHW) is included. In reality without the SHW, the as-built house is modeled to an estimated EGH rating of 87, and was expected to consume 31% less energy than a house built to MNECH, or 69% of the MNECH's energy.

To confirm the actual performance levels of the Inuvik NSH duplex unit, NWTHC and CMHC organized a project to measure energy performance and the indoor air quality of the NSH duplex units and a similar conventional house built by NWTHC. The monitoring was conducted for 2 years, before and after the final house upgrades. In year 1, before the extra attic insulation was added and before there was work done on the heat recovery ventilation (HRV) controls, the 'A' unit of the duplex consumed 15% less energy when looking at billed data, and 36% less energy when looking at monitored data, compared with the MNECH model. The 'B' unit consumed 27% less (billed) and 54% less (monitored). In year 2, after the upgrades, but with the SHW non-functional, the 'A' unit consumed 16% less energy (billed) and 33% less energy (monitored), while the 'B' unit consumed 32% less energy (billed) and 49% less energy (monitored) when compared with the MNECH model. Compared with the conventional unit, the houses consumed 11 to 41% less, depending on the unit and whether billing or monitored data was analyzed; the conventional unit was not reassessed during year 2.

The challenge in comparing modeled results with actual results has been discussed in depth with previous similar projects. Comparing heating results is much less dependent on occupant behavior than comparing personal electricity results, although lifestyle choices will still affect both. One unit of the NSH uses much more electricity than the other unit. If the MNECH model were based on the same occupancy behavior, the comparative results would be much different. The Inuvik NSH consumed nearly 50% less gas for space and water heating compared with the conventional unit in year 1, even though the winter indoor temperatures were kept warmer in the Inuvik NSH.

The Inuvik NSH units each have a 1.7 kW solar photovoltaic (PV) array and the produced about 1360 kWh and 1130kWh per year in each of the monitored years to offset some of their personal electricity usage. The 4-panel solar domestic hot water system offset about one third of the hot water requirements in year 1 but unfortunately was non-functional during year 2 due to lack of maintenance.

The payback on the upgrades compared with a standard construction do not in themselves speak to the importance of a tight and efficient building envelope and mechanical system as there was a steep learning curve on this project. It is anticipated that the future builds, using these techniques would yield much lower incremental construction costs.

There were several big lessons learned from and during the monitoring of the NSH.

1. A good envelope provides a potential for huge energy savings as is evident with the nearly 50% less gas used for heating and water heating from the NSH compared with a conventional duplex.
2. A single SHW system on a remote Northern housing location with minimal hot water loads may not payback the initial capital costs due to the recurring maintenance and glycol costs associated
3. The controls on the HRV preheat are not necessarily straightforward and in the case of the NSH there have been many issues with different contractors setting them up correctly. In addition, the mechanical room in the NSH was warm and created a large buffering effect on the air entering the HRV. The sensors for measuring the air entering the HRV should be placed as closely to the point of entry as possible and not outdoors if a buffering effect is expected. The important temperature to avoid freezing of the HRV core is the temperature entering the HRV, not the outdoor temperature and they may be significantly different and may result in more preheat than is actually required. In extreme cases this results in losing heat through the HRV by heating the exhaust air.
4. There are in some cases quite large differences in monitored and billing data which indicate that either there are inaccuracies in the monitoring, or it is not capturing all of the information or that there are inaccuracies in the utility metering, or a combination of both. If at all possible, monitoring not only on an equipment level but also on a whole system level (in this case the gas entering the house) would be useful to determine where the inaccuracies lie.
5. The level of information required should dictate the amount of monitoring done on a house. In this case there was significant individual equipment monitoring done which has resulted in many lessons. However, this may not be appropriate in every case as it takes a lot of time and money and effort. Simple billing monitoring may be sufficient in many cases depending on the information desired. A lot of information can be extracted from extensive monitoring but should be incorporated in the project design and installed during construction.

RÉSUMÉ

La Maison durable construite pour le Nord (MDN) à Inuvik a été érigée en 2009 dans le cadre d'un projet conjoint entre la Société canadienne d'hypothèques et de logement (SCHL) et la Société d'habitation des Territoires du Nord-Ouest (SHTNO) au bénéfice de l'Inuvik Housing Authority (IHA). Le document de la SCHL sur la conception et la construction de la Maison durable construite pour le Nord à Inuvik (Société canadienne d'hypothèques et de logement 2013) décrit en détail le processus de conception, les principales caractéristiques de conception, la modélisation du duplex, le processus de construction et quelques défis et leçons issus du projet.

La maison a fait l'objet d'un contrôle sur deux années distinctes (de septembre 2012 à août 2013 et de novembre 2014 à octobre 2015). Plusieurs problèmes qui ont été relevés dans la maison au cours de la première année de contrôle et de la période de mise en service ont été rectifiés avant la deuxième année de contrôle.

La MDN d'Inuvik a été conçue avec comme objectif de réduire la consommation d'énergie annuelle de la maison de 50 % par rapport aux maisons construites selon le Code modèle national de l'énergie pour les habitations (CMNEH). En outre, la SHTNO avait fixé un deuxième objectif, celui d'atteindre une cote ÉnerGuide pour les maisons (EGH) d'au moins 85. Telle que conçue, la maison devait dépasser la cote EGH pour atteindre une cote de 89 et consommer 42 % moins d'énergie que les maisons construites selon le CMNEH; en d'autres mots, elle devait consommer 58 % de l'énergie consommée par une maison construite selon le CMNEH. En outre, telle que construite, la maison devait dépasser la cote EGH pour atteindre une cote de 88, si l'on inclut le chauffe-eau solaire. En réalité, sans le chauffe-eau solaire, la maison, telle que construite, devrait dépasser une cote EGH prévue de 87 et consommer 31 % moins d'énergie qu'une maison construite selon le CMNEH, ou 69 % de l'énergie d'une maison construite selon le CMNEH.

Pour confirmer les niveaux de rendement réels du duplex MDN d'Inuvik, la SHTNO et la SCHL ont mis sur pied un projet visant à mesurer le rendement énergétique et la qualité de l'air intérieur du duplex MDN et à comparer les données à celles d'une maison traditionnelle similaire construite par la SHTNO. Le contrôle a eu lieu sur deux ans, avant et après les dernières améliorations apportées à la maison. Dans la première année, avant l'ajout d'isolant supplémentaire dans les combles et avant que les contrôles du ventilateur récupérateur de chaleur (VRC) aient été rectifiés, l'unité «□A□» du duplex a consommé 15 % moins d'énergie selon les données de facturation et 36 % moins d'énergie selon les données contrôlées, si l'on compare au modèle fondé sur le CMNEH. L'unité «□B□» a consommé 27 % moins d'énergie selon la facturation et 54 % de moins selon le contrôle. Dans la deuxième année, après les améliorations, mais sans le chauffe-eau solaire qui n'était pas fonctionnel, l'unité «□A□» a consommé 16 % moins d'énergie selon la facturation et 33 % moins d'énergie selon le contrôle, tandis que l'unité «□B□» a consommé 32 % moins d'énergie selon la facturation et 49 % moins d'énergie selon le contrôle, si l'on compare au modèle fondé sur le CMNEH. Comparées à l'unité traditionnelle, les maisons ont consommé 11 % et 41 % en moins, selon l'unité et les données analysées (facturation ou contrôle); l'unité traditionnelle n'a pas été réévaluée au cours de la deuxième année.

Le défi de comparer des résultats de modélisation et des résultats réels a fait l'objet de discussions approfondies lors de projets semblables antérieurs. La comparaison de résultats liés au chauffage repose beaucoup moins sur le comportement de l'occupant que si l'on compare la consommation personnelle d'électricité, bien que les styles de vie aient quand même une influence dans les deux cas. Un des logements de la MDN a utilisé beaucoup moins d'électricité que l'autre. Si l'analyse du modèle construit selon le CMNEH était fondée sur les mêmes comportements d'occupation, les résultats comparatifs auraient été très différents. La MDN d'Inuvik a consommé près de 50 % moins d'énergie pour le chauffage des lieux et de l'eau

comparativement à l'unité traditionnelle dans la première année, même si les températures intérieures hivernales ont été maintenues à un niveau plus élevé dans la MDN d'Inuvik.

Les unités de la MDN d'Inuvik étaient chacune dotées d'un champ de modules photovoltaïques de 1,7 kW qui a produit environ 1360 kWh et 1130 kWh par année, respectivement. Le système de chauffe-eau domestique solaire à quatre modules a permis de combler le tiers des besoins en eau chaude au cours de la première année, mais il ne fonctionnait pas dans la deuxième année à cause d'un problème d'entretien.

Les frais récupérés comme suite aux améliorations, si l'on compare à une construction traditionnelle, ne soutiennent pas à eux seuls l'importance d'une enveloppe de bâtiment très étanche et d'un système mécanique très efficace, étant donné la courbe d'apprentissage abrupte dans le cas de ce projet. On s'attend à ce que les autres bâtiments construits au moyen de ces techniques entraînent beaucoup moins de coûts de construction supplémentaires.

De nombreuses leçons ont été tirées du contrôle de la MDN.

1. Une bonne enveloppe pourrait permettre de réaliser d'importantes économies d'énergie, compte tenu de la réduction de 50 % du gaz utilisé pour le chauffage des lieux et de l'eau de la MDN comparativement à un duplex traditionnel.
2. Un seul système de chauffe-eau solaire installé dans le Nord où les charges d'eau chaude sont minimes pourrait ne pas permettre la récupération de l'investissement initial, à cause des coûts récurrents liés à l'entretien et au glycol.
3. Les contrôles de préchauffage du VRC ne sont pas nécessairement simples et dans le cas de la MDN, il y a eu de nombreux problèmes avec différents entrepreneurs qui n'installaient pas les systèmes correctement. En outre, la température dans le local technique de la MDN était assez élevée et créait un important effet tampon sur l'air qui pénétrait dans le VRC. Les détecteurs qui mesurent l'air qui pénètre dans le VRC devraient être situés le plus près possible du point d'entrée et non à l'extérieur, si l'on s'attend à ce qu'il y ait un effet tampon. La température qui importe pour éviter le noyau du VRC gèle est la température qui pénètre dans le VRC et non la température extérieure, car celles-ci pourraient différer grandement et entraîner un préchauffage plus important que nécessaire. Dans les cas extrêmes, le chauffage de l'air d'extraction entraîne une perte de chaleur par le VRC.
4. Dans certains cas, les différences entre les données contrôlées et les données de la facturation sont très grandes, ce qui laisse entendre qu'il existe des inexactitudes dans le contrôle, soit que l'on ne saisit pas toute l'information, soit que le compteur des services publics est imprécis, ou une combinaison des deux. Si possible, le contrôle devrait se faire au niveau du matériel, mais également de l'ensemble du système (dans ce cas le gaz qui entre dans la maison), car cela pourrait aider à déterminer où les imprécisions se situent.
5. Le niveau d'information requis devrait dicter le niveau de contrôle effectué. Dans ce cas, beaucoup de contrôles ont été effectués au niveau des différents appareils, et l'on en a tiré de nombreuses conclusions. Toutefois, cela pourrait ne pas se prêter à chaque situation, car il faut y consacrer beaucoup de temps, d'argent et d'efforts. Un simple contrôle de la facturation pourrait suffire dans bien des cas, selon l'information recherchée. Beaucoup d'information peut être extraite d'un contrôle exhaustif, mais le processus devrait être conçu dès le départ et mis en place pendant la construction.

CMHC SCHL

National Office
700 Montreal Road
Ottawa ON K1A 0P7
Telephone: (613) 748-2000

Bureau national
700 chemin de Montréal
Ottawa ON K1A 0P7
Téléphone : (613) 748-2000

Puisqu'on prévoit une demande restreinte pour ce document de recherche, seul le résumé a été traduit.

La SCHL fera traduire le document si la demande le justifie.

Pour nous aider à déterminer si la demande justifie que ce rapport soit traduit en français, veuillez remplir la partie ci-dessous et la retourner à l'adresse suivante :

Centre canadien de documentation sur l'habitation
Société canadienne d'hypothèques et de logement
700, chemin Montréal, bureau C1-200
Ottawa (Ontario)
K1A 0P7

Titre du rapport: ____

____

Je préférerais que ce rapport soit disponible en français.

NOM ____

ADRESSE____
rue App.

____
ville province Code postal

No de téléphone ( ) _____________

Table of Contents

1 BACKGROUND

February of 2009, Canada Mortgage and Housing Corporation (CMHC) approached the Northwest Territories Housing Corporation (NWTHC) and expressed interest in supporting the design and construction of a Northern Sustainable Housing (NSH) project for the Northwest Territories (NWT), similar in scope to other NSH initiatives by CMHC in Dawson City, Yukon and Arviat, Nunavut. As the NWTHC had concerns with climate change and rising energy costs, it saw an opportunity to explore and improve new housing designs for the future through this project and partnership.

The Inuvik NSH is a one-storey 247 m^2 (2,656 ft^2) duplex with two 119 m^2 (1,277 ft^2) suites and a 9.5 m^2 (102 ft^2) mechanical room. The duplex has a highly insulated building envelope, one high-efficiency condensing boiler which serves both units, a heat recovery ventilator for each unit, hot water which is run off of glazed flat-plate solar collectors and topped up with the boiler, as well as a 3.6 kW solar photovoltaic system. CMHC's Design and Construction Report of the Inuvik NSH (Canada Mortgage and Housing Corporation, 2013) details the design process, the key design features, the modeling of the duplex, the construction process and some of the challenges and lessons learned.

To confirm the actual performance levels of the NSH duplex unit, NWTHC and CMHC organized a project to measure energy performance and the indoor air quality of the NSH duplex units and a similar conventional house built by NWTHC. A contract was awarded to the Arctic Energy Alliance (AEA) in April 2012 with full monitoring commencing September 2012.

In October 2013 a second year of monitoring was commissioned. At this time the house was undergoing some upgrades to the mechanical systems and insulation levels to meet the initial design intent. These upgrades were completed in the fall of 2014 and the second year of monitoring commenced. The two deficiencies were brought to design standards were the following: a) the attic insulation was upgraded to design levels of R80 from the existing R40, and b) the HRV preheat controls were changed to meet required control temperatures and properly connected. The solar hot water was functional during the first year of monitoring but not during the second due to a lack of maintenance.

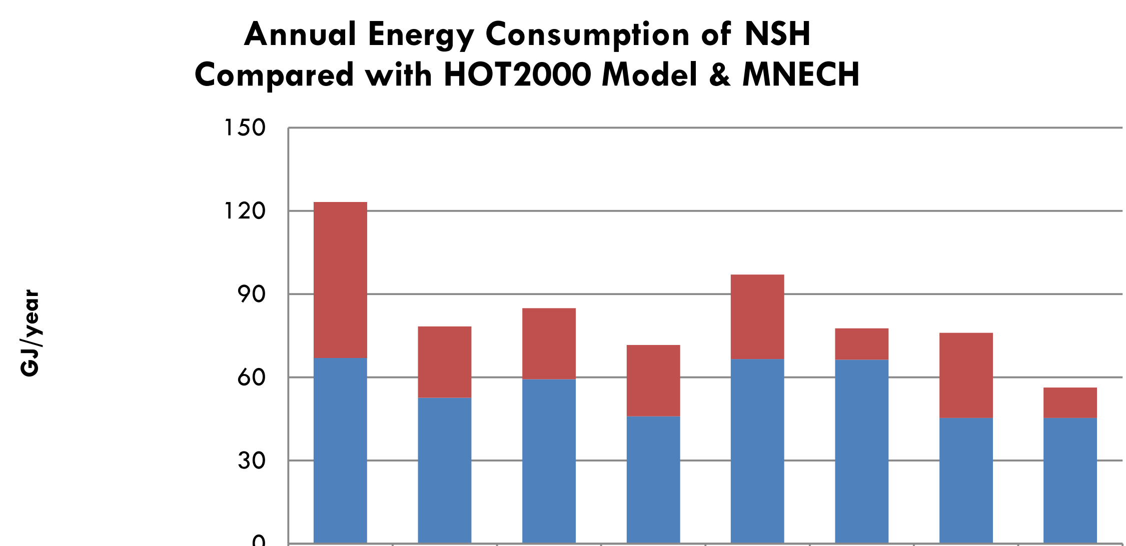
The first year of monitoring included Indoor Air Quality monitoring and an energy-use comparison with a conventional house, whereas the second year of monitoring did not include these two elements.

2 TOTAL ANNUAL ENERGY

2.1 NSH compared with HOT2000 model and MNECH

During the planning and design stage, the proposed design was evaluated using HOT2000 residential energy modelling software in accordance with Natural Resources Canada procedures for its Energy Rating Service (ERS) for new houses (Natural Resources Canada, 2011). An as-built HOT2000 model was completed after the house was built to accommodate for any modifications made during construction that deviated from the original plan. Two modifications to the model were made to the original plan model (ERS P file) to reflect the actual as-built construction of the house (ERS N file): the actual tested ACH were used (see section 3.2), and the SHW was removed from the model as it is non-functional (see section 7.2).

In addition to the energy target based on an EGH rating, the project also considered a comparable baseline of energy performance based on a similar house constructed to the standard of the Model National Energy Code for Houses (MNECH) 1997, a benchmark for energy efficiency at the time the project was designed (National Research Council , 1997).[1]



	MNECH	Year 1 as-built HOT2000 model (functional SHW, ACH actual = 2.4, R40 attic)	Year 2 as-built HOT2000 model (non-functional SHW, ACH actual = 2.4, R80 attic)	HOT2000 as-designed model (functional SHW, ACH = 1.5, R80 attic)	Actual usage (billed) NSH A Year 2	Actual usage (billed) NSH B Year 2	Actual usage (monitored) NSH A Year 2	Actual usage (monitored) NSH B Year 2
Total House Consumption	123	78	85	72	103	84	83	63
Net Electricity (Total Electricity Used - PV)	56	26	26	26	30	11	31	11
Total Gas Usage	67	53	59	46	66	66	45	45
% Difference overall MNECH		-36%	-31%	-42%	-16%	-32%	-33%	-49%
% Difference to HOT2000 as-built overall					21%	-1%	-3%	-26%

FIGURE 2-1: ANNUAL ENERGY CONSUMPTION OF NSH COMPARED WITH MNECH

[1] The 1997 MNECH has been superseded by the new energy efficiency provisions added to the National Building Code in 2012.

The details of the HOT2000 modelling assumptions can be found in the Design and Construction of the Inuvik NSH Report (Canada Mortgage and Housing Corporation, 2013). The simulation results are based on built-in assumptions in HOT2000, at an average load by two adults and two children at 50% occupancy. Typical assumptions include a hot water requirement of 240 litres per day per unit, average electric appliances at 17 kWh/day and lighting at 3 kWh/day, as well as 4 kWh/day of average exterior electricity use. Actual occupancy for NSH A was 3 adults, 1 at 100% occupancy and 1 at approximately 75% occupancy and 1 at 50% occupancy. Occupancy for NSH B is 3 adults and 1 child, all at approximately 50% occupancy.

The MNECH focuses on insulation (RSI value) and air tightness, and sets requirements for a large variety of other building elements, including building envelope, lighting and HVAC. It allows flexible compliance that can be achieved through a prescriptive, performance, or tradeoff path to meet efficiency requirements. The code is intended to help designers and builders choose the level of energy efficiency that is appropriate for specific climates and fuel types. The Design & Construction of the Inuvik NSH (Canada Mortgage and Housing Corporation, 2013) details the modeling assumptions in accordance with the regional requirements of MNECH for Inuvik; taking into consideration the construction and energy costs available for the locality.

2.2 NSH compared with conventional NWTHC house

The total annual energy performance of the individual units of the NSH was calculated in year 1 and 2 and for the conventional unit in year 1. Figure 2-2 shows the comparison of both units of the NSH and the conventional using the collected bills and

Figure 2-3 shows the comparison using the monitored data. The household electricity bills come in separately for each unit but the gas bills and the mechanical room electricity bills are for the entire duplex. The comparison using the bills was done assuming that both units of the duplex are using 50% of the gas being billed, which may not be an accurate depiction if one unit is using more gas than the other unit for heating or hot water.

2.2.1 Billed data

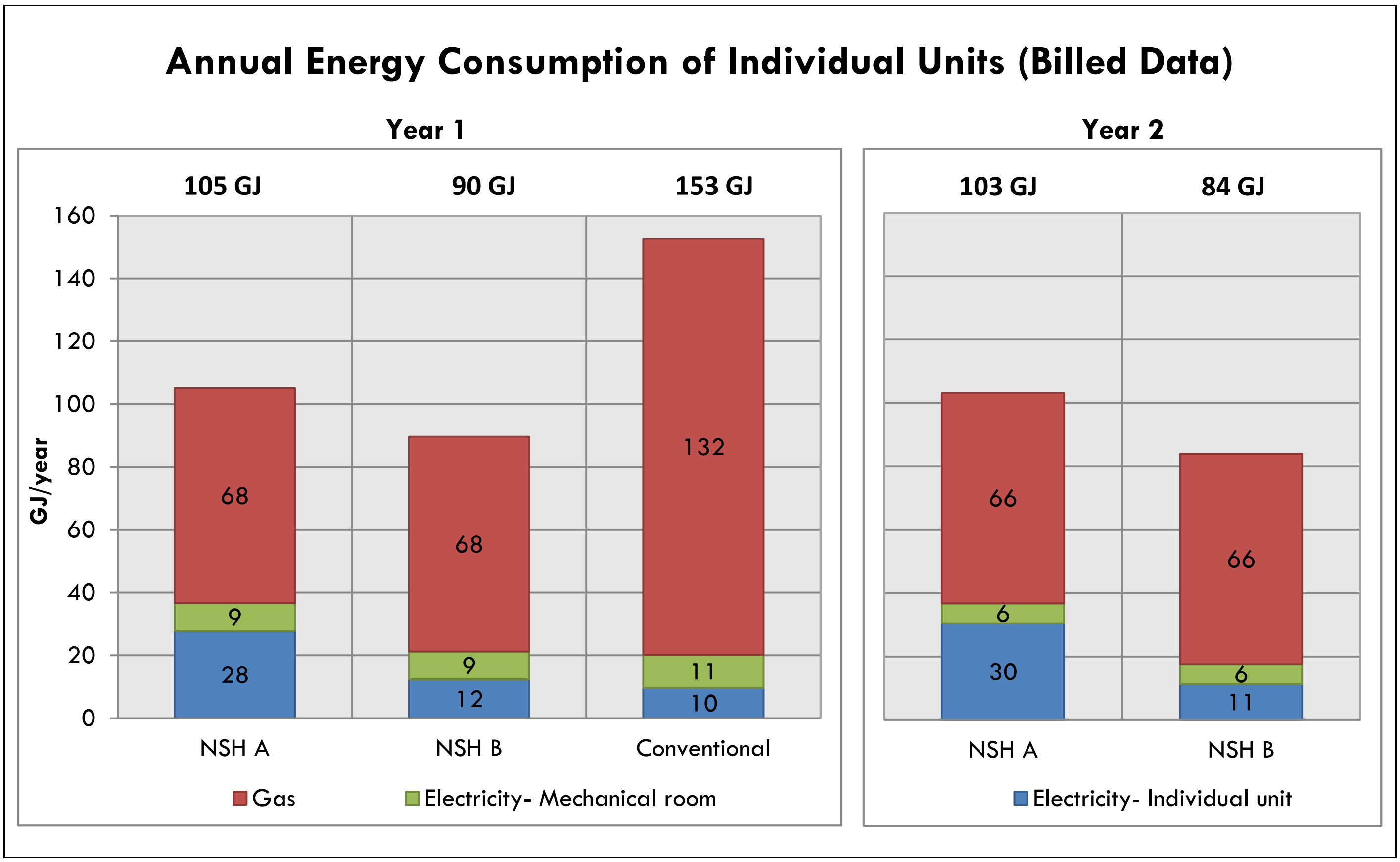


FIGURE 2-2: COMPARISON OF ANNUAL ENERGY CONSUMPTION USING BILLED DATA

Based on billed data, in year 1 the NSH unit used 31 – 41% less energy than the conventional NWTHC unit. The NSH duplex uses 48% less gas than the conventional duplex based on billed data. The results were similar in year 1 and 2.

The occupancy in both units of the NSH remained the same for the two years of monitoring. The heating degree days (18°C) for year 1 was 9653 versus year 2 which was 8638.

2.2.2 Monitored data

The monitored data includes the electricity measured in each individual unit, less the electricity produced by the photovoltaics (in the case of the NSH), 50% of the electricity measured in the mechanical room, the gas used for heating, hot water and the preheat for the heat recovery ventilation (NSH only), less the energy produced by the solar hot water if applicable (NSH only). For simplicity sake, the efficiency of the boiler is assumed constant for the entire year. As the gas bills are for both unit of the duplex and only one unit of the conventional duplex were monitored, some discrepancy was expected. Additional losses in the mechanical room are significant and the assumption of a constant boiler efficiency throughout the year are all contributing to the discrepancy in gas use.

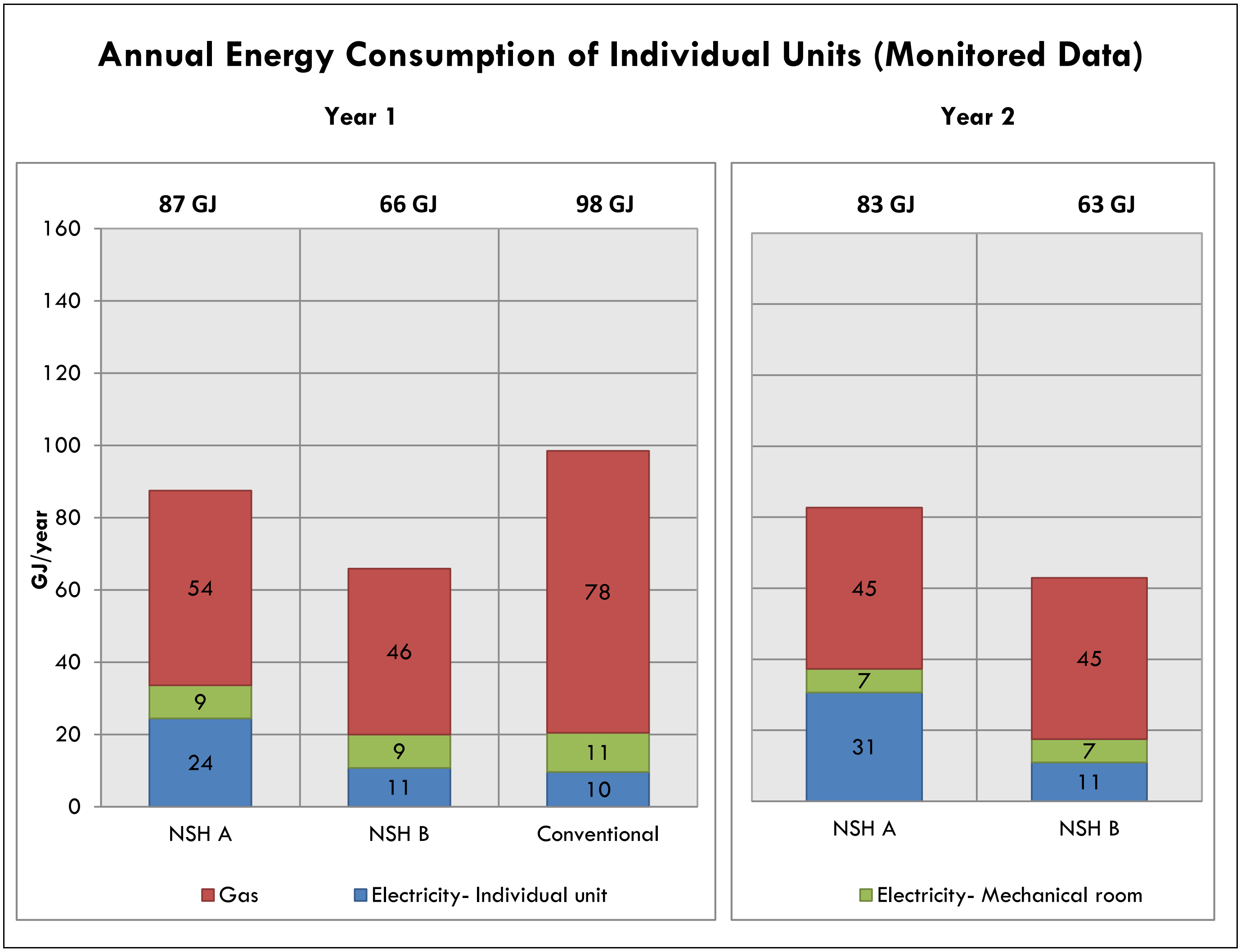
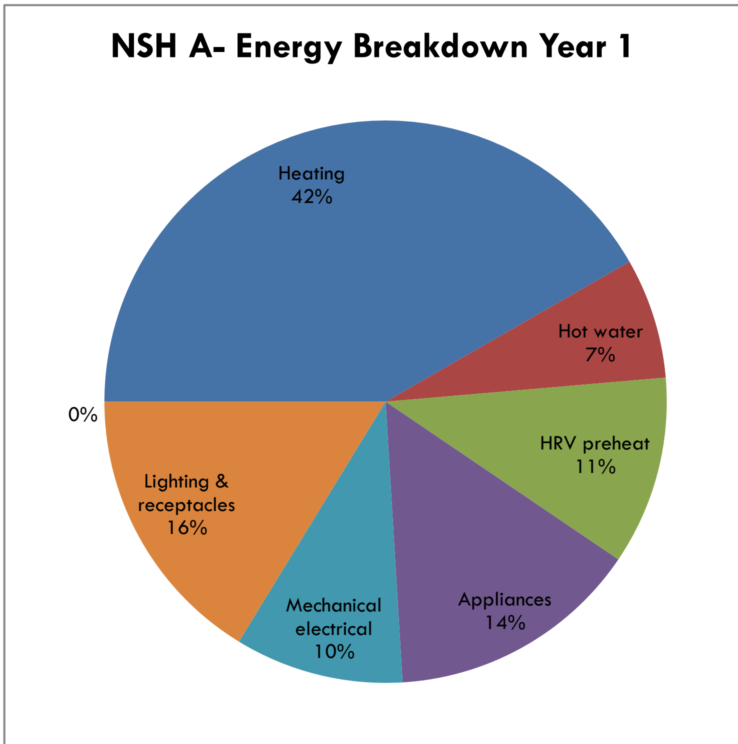


FIGURE 2-3: COMPARISON OF ANNUAL ENERGY CONSUMPTION USING MONITORED DATA

The following figure shows that the energy breakdown is quite different for the NSH units and the conventional units. The conventional unit has a much higher percentage of its energy use deriving from heating whereas the NSH units have a higher percentage from electricity use in lighting and appliances as well as the preheat energy for the heat recovery ventilator (HRV). This is also a function of different occupant behavior. Year 1 and year 2 breakdowns are not significantly different.



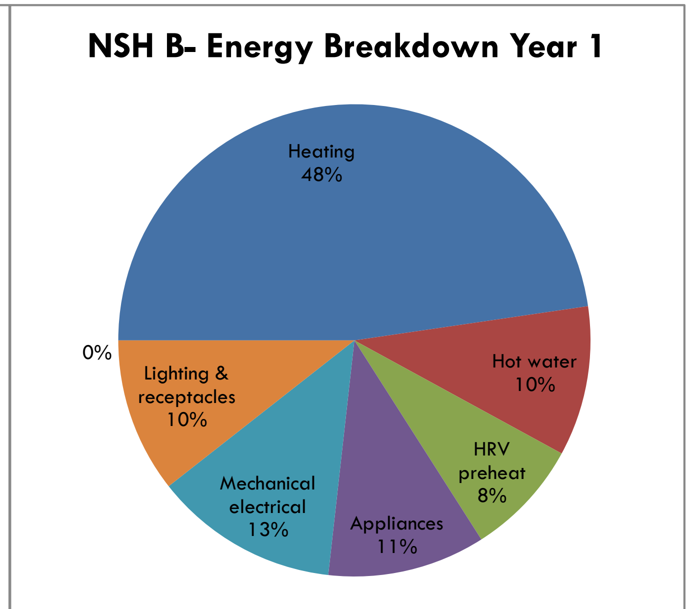
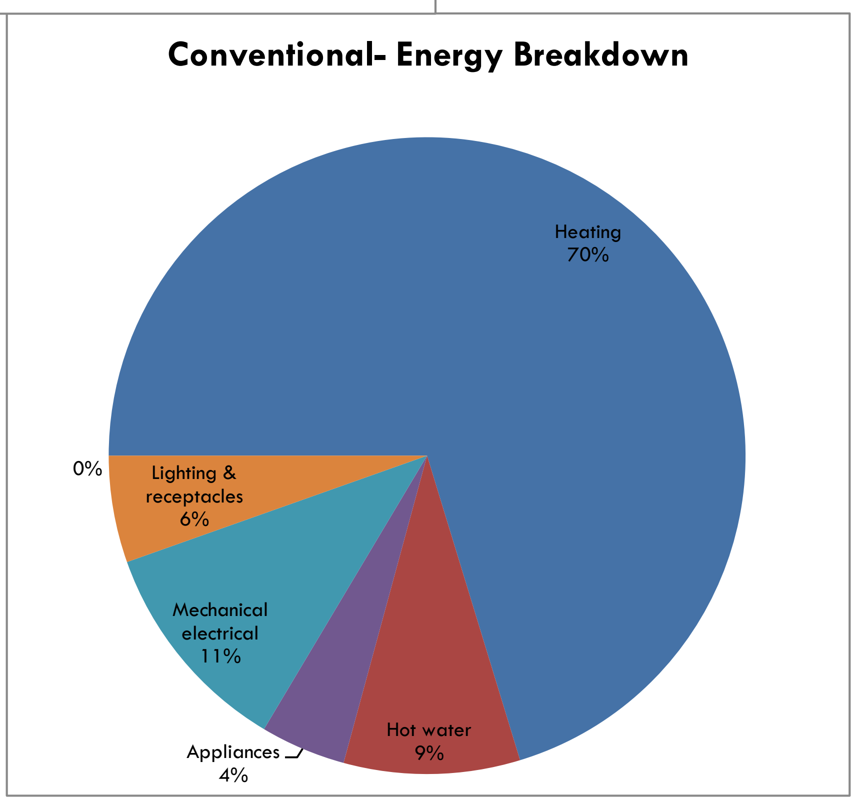


FIGURE 2-4: ENERGY BREAKDOWN OF INDIVIDUAL UNITS BASED ON MONITORED DATA



2.3 Monitored compared with billed data

2.3.1 Electricity use of individual units

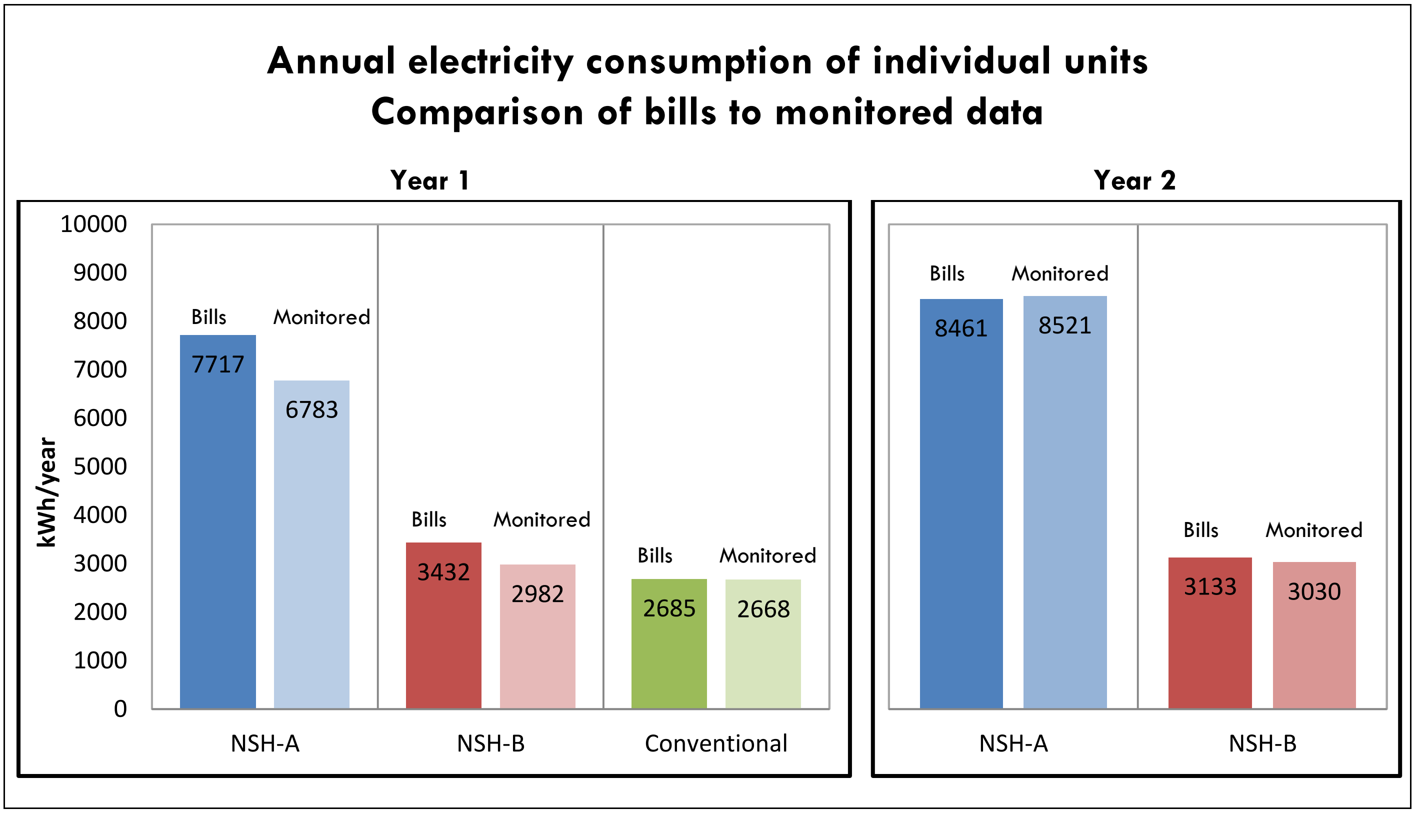


FIGURE 2-5: ANNUAL ELECTRICITY CONSUMPTION OF INDIVIDUAL UNITS COMPARISON OF BILLS TO MONITORED DATA

The electricity use in the two units of the NSH differs between the monitored results and the bills by about 10% in year 1 and by less than 3% in year 2. The conventional unit doesn't differ at all.

There is some discrepancy between the monitored results and the bills in the NSH in year 1 but hardly any discrepancy in year 2. In year 2 an automatic system was set-up so that it was possible to match the monitoring data with the exact dates used for the billing. There was also less data missing in year 2 compared with year 1 due to improvements in the data collection reliability set-up, including internet reliability and improved understanding of the equipment by the team. The monitored results are calculated by summing the annual use of the individual circuits and subtracting the PV production for each unit. There was significant data missing from NSH A in year 1which was estimated which may account for the larger discrepancy between monitored and billed data. See section 7.1.2 for a description of how the PV feeds into the duplex and grid.

2.3.2 Electricity use of mechanical rooms

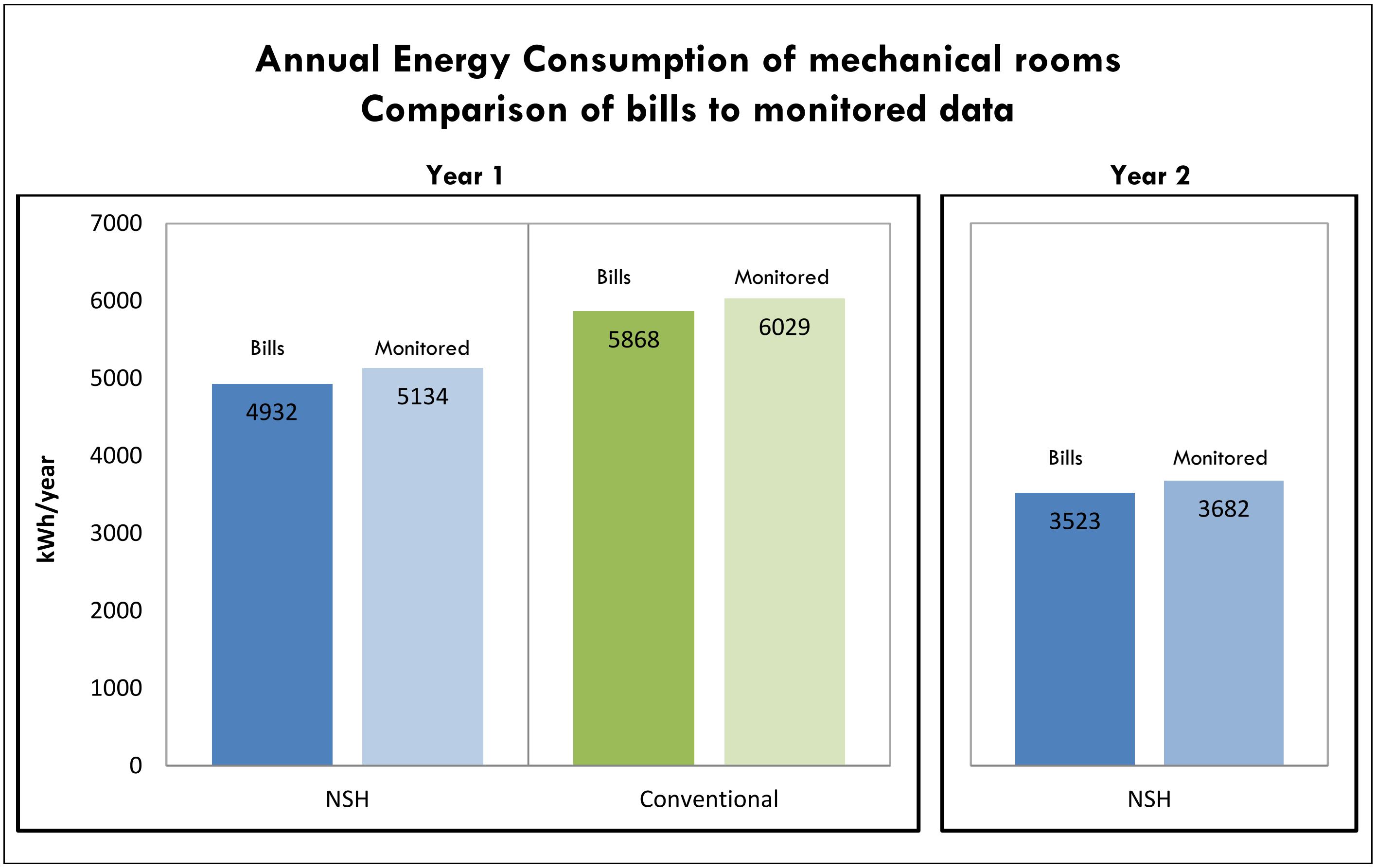


FIGURE 2-6: ANNUAL ELECTRICITY CONSUMPTION OF MECHANICAL ROOMS COMPARISON OF BILLS TO MONITORED DATA

The electricity use in both mechanical rooms is within 5% from bills to monitored data for years 1 and 2. The mechanical room electricity usage in the NSH is nearly 30% lower in year 2 compared with year 1. The mechanical room usage in the conventional house is 40% higher than the NSH (in year 2).

2.3.3 Gas consumption

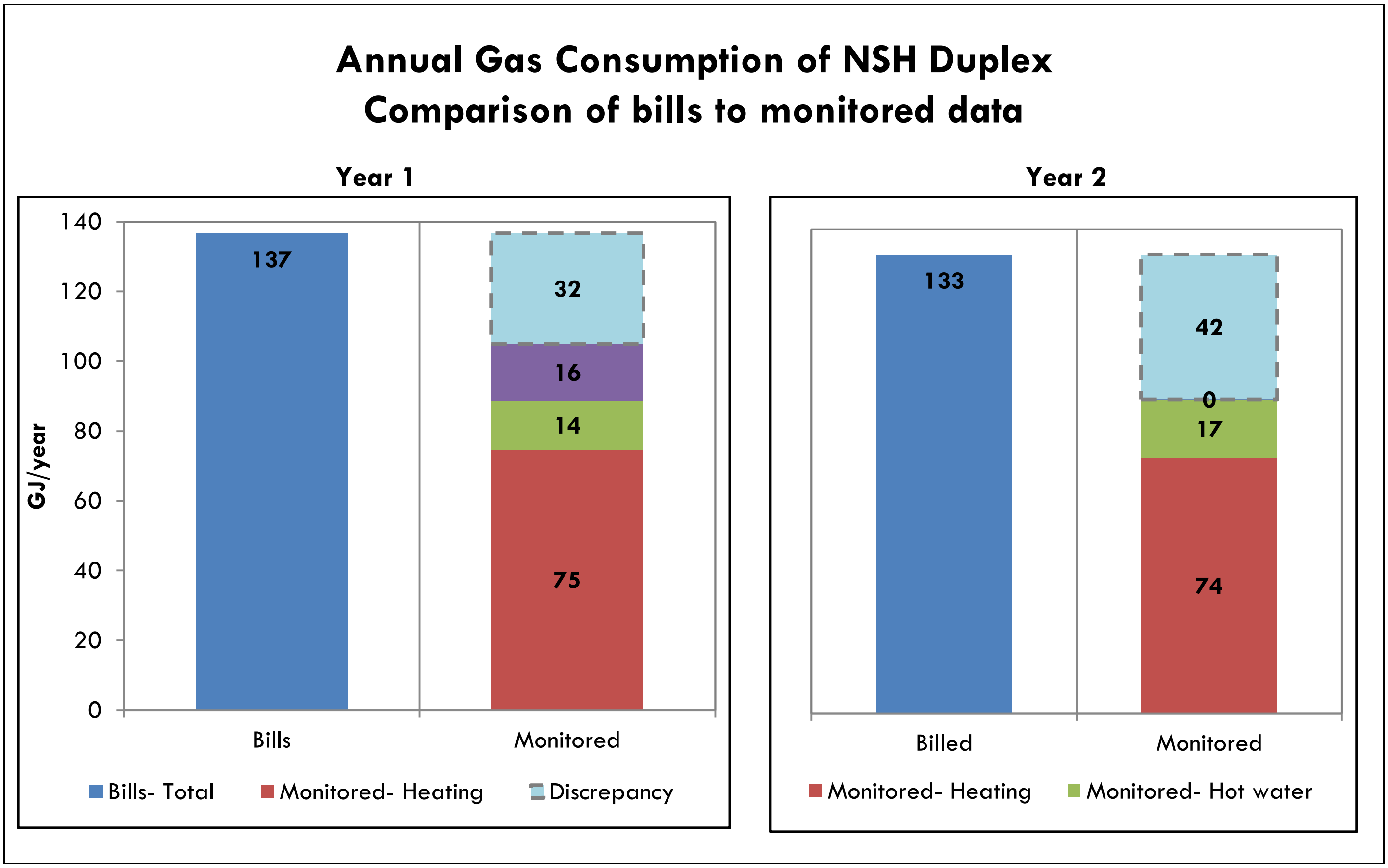


FIGURE 2-7: ANNUAL GAS CONSUMPTION OF NSH DUPLEX (A + B) COMPARISON OF BILLS TO MONITORED DATA

Based on the temperature graphs of the HRV there was some preheat in year 2 but it was not captured in the monitoring due to unknown reasons. See section 8 for more information on the HRV preheat and monitoring.

The estimated gas consumption for the NSH duplex differs by about 30% compared with the bills in year 1 and 40% in year 2.

The monitoring is conducted on the hydronic lines themselves (flow, supply and return temperatures) and not of the gas entering the duplex. Some of the discrepancy is attributed to system losses and accuracies in monitoring equipment, and some is attributed to the calculations using a fixed year-round boiler efficiency. As there is no measurement of the gas itself, some of the discrepancy could also be due to the metering equipment at the utility level.

3 EGH EVALUATIONS AND AIR TIGHTNESS TESTING

3.1 EGH Evaluations

The energy performance goal of the Inuvik NSH was established based on the EnerGuide for houses (EGH) rating system. An EGH rating shows a standard measure of a home's energy performance on a scale of 0 to 100, calculated based on standard operation assumptions (Natural Resources Canada, 2011). A target of **EGH rating 85 or higher** was set by the NWTHC for this project, which meets or exceeds the requirement of a *Highly energy-efficient new house* as defined by NRCAN. Note that for all new construction after 2010, the NWTHC has mandated an EGH 80 minimum rating to promote the concepts demonstrated by the NSH.

	Estimated EGH Rating	Net Electricity (kWh)	Natural Gas (GJ)	Annual Energy Use (GJ)
MNECH baseline	**76**	15600	67	123
Conventional house (single unit) used for comparison	**74**	9130	115	148
NSH As-Built (N Evaluation) Year 1 (single unit) (R40 attic insulation, with SHW, ACH actual = 2.4)	**87**	7140	53	78
NSH As-Built modified Year 2 (single unit) (R80 attic insulation, ACH actual = 2.4) With SHW Without SHW (current set-up)	**88**	7120	48	74
	87	7120	59	85
NSH As-designed (P Evaluation) (single unit) (R80 attic insulation, ACH = 1.5, functional SHW)	**89**	7150	46	72

FIGURE 3-1: ESTIMATED EGH RATINGS AND ANNUAL ENERGY USE FOR MODELLED NSH HOUSES

Note that a P Evaluation (plan) is done before construction based on the submitted house plans and an N Evaluation (new) is based on the actual house after construction.

Each unit of the NSH duplex would achieve an estimated EnerGuide rating of 87 in years 1 and years 2, compared with a house built to MNECH which would achieve an estimated EGH rating of 76. The conventional house, used as a comparison, achieved an estimated EGH rating of 74.

This rating would put these units in the same category as some of the most energy-efficient new houses currently on the Canadian market and fulfills the goal of EGH 85 as part of NWTHC's design objective.

The post-construction HOT2000 model (N Evaluation) takes into consideration a few changes pertaining to the actual duplex construction. With all other conditions being the same as the P Evaluation, three important adjustments were made to reflect the as-built conditions:

- Air leakage according to post-drywall blower door tests (but prior to additional attic insulation)
  - 2.37 ACH @ 50 Pa for unit A; 2.67 ACH @ 50 Pa for unit B;
  - 1.5 ACH @ 50 Pa was originally assumed for both units;
- Roof effective insulation
  - Equivalent of RSI-7 (R40) for year 1 (a deficiency that was corrected in year 2);
  - Equivalent of RSI-14.1 (R80) was originally targeted in the P Evaluation;
- Solar hot water
  - The solar hot water was functioning during year 1 monitoring but not during year 2

If the NSH were built to the designed air tightness and had a functioning SHW system, it would have achieved an estimated EGH rating of 89 and an estimated annual energy use of 72 GJ.

3.2 Air tightness testing

3.2.1 NSH A & B

NSH A	NSH B
Interior Temp: 22°C	Interior Temp: 24°C
Exterior Temp: 8°C	Exterior Temp: 8°C
ACH: 2.37	ACH: 2.67
ELA: 221.79cm^2	ELA: 280.9 cm^2

The air tightness of NSH A is 2.37 ACH @ 50 Pa and of NSH B is 2.67 ACH @ 50 Pa.

3.2.2 Conventional

Conventional
Interior Temp: 20°C
Exterior Temp: -16°C
ACH: 3.70
ELA: 358.8 cm^2

The air tightness of the conventional unit is 3.70 ACH @ 50 Pa.

FIGURE 3-2: ESTIMATED HEAT LOSS* FOR THE CONVENTIONAL UNIT FORM HOT2000 OUTPUT FILE

4 GAS USE

4.1 Gas use

Both the conventional duplex and the NSH duplex use gas for heating, delivered via the town gas line. The gas piped to the duplex was originally natural gas, but due to a shortage of natural gas the town has since switched to a propane air-mix with a very similar heating value to natural gas. The price paid by the local housing authority increased from $19.30/GJ to $41.00/GJ +GST in November 2012. The occupant does not pay for gas use.

Gas is used for space heating, water heating, and in the case of the NSH, preheat on the HRV. The occupants of the conventional unit keep their indoor temperatures lower than the occupants of the NSH. The NSH receives one gas bill for both sides of the duplex; this is the same for the conventional unit as well. Figure 4-1 compares the total gas consumption of the NSH and conventional duplexes.

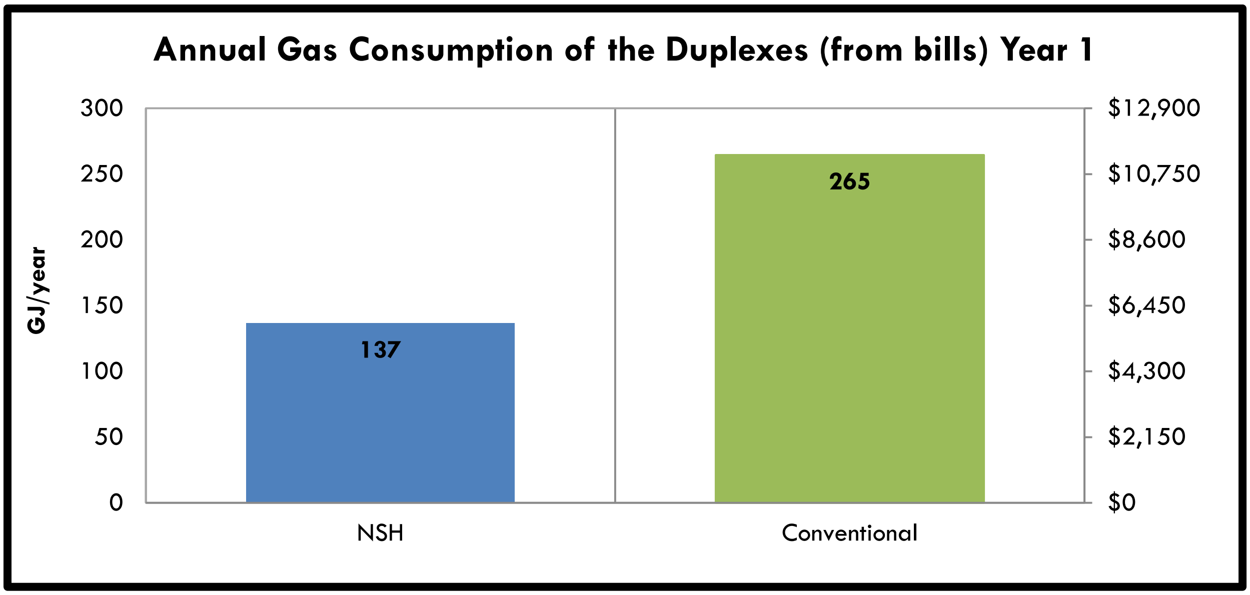


FIGURE 4-1: ANNUAL GAS CONSUMPTION OF NSH COMPARED WITH CONVENTIONAL DUPLEX BASED ON BILLS, YEAR 1

The annual amount of gas consumed by the entire conventional duplex is double that of the entire NSH duplex.

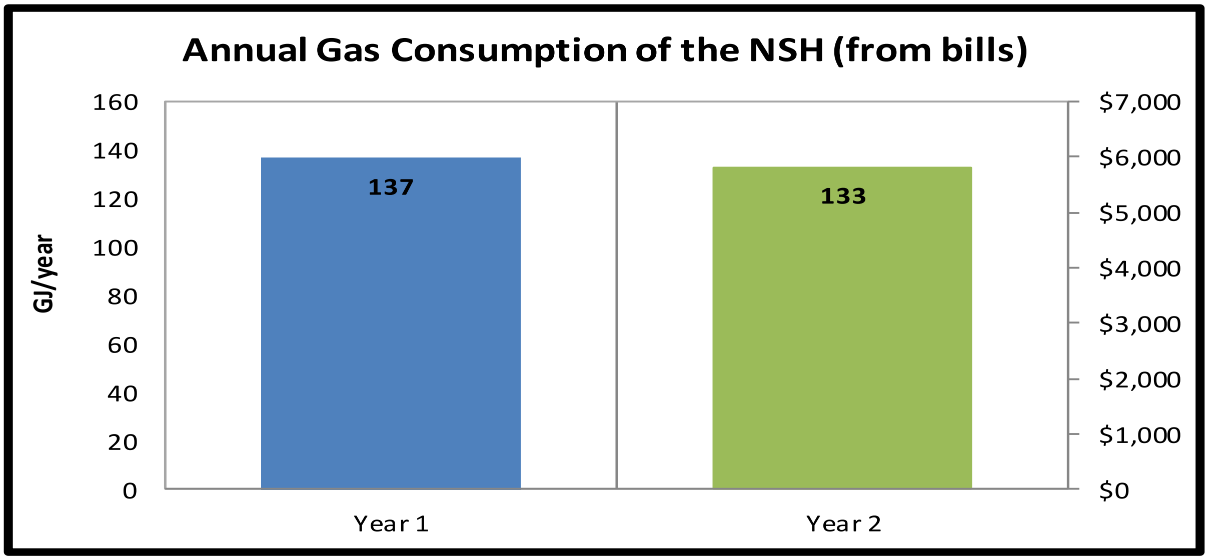


FIGURE 4-2: ANNUAL GAS CONSUMPTION OF NSH YEAR 1 AND YEAR 2 BASED ON BILLS

The annual amount of gas consumed by both sides of the NSH was compared over two years. The heating load drops during the second year, but not significantly. During the second year the SHW system was not working, meaning that the gas used for hot water heating would have been increased, however the HRV preheat was turned off for one unit during the second year, decreasing the gas consumption.

The occupancy in both units of the NSH remained the same for the two years of monitoring. The heating degree days (18°C) for year 1 was 9653 versus year 2 which was 8638.

4.2 Heating

The NSH has one high-efficiency condensing modulating natural gas boiler which meets the space heating needs and some of the domestic hot water demand of both units. One pump-controlled heating loop passes through each housing unit. The boiler controller regulates the demand temperature of the boiler based on outdoor temperature. The boiler is an IBC VFC-15-150 with a maximum input of 150,000 Btu/h and a manufacturer rated AFUE efficiency of 92.6%. There are thermostats in each unit that can be controlled by the occupants.

The conventional duplex has two natural gas boilers which meet the space heating and domestic hot water demand of both units of the duplex. The two boilers are connected in series to provide a backup for the duplex. Two pump-controlled heating loops pass through the units; one upstairs and one downstairs. The boilers are Viessmann Atola ECD with a maximum input of 140,000 Btu/h and a manufacturer rate AFUE efficiency of 82.9%. There is a thermostat for each floor of each unit that can be controlled by the occupants.

Monitoring is conducted on all four space heating lines; one for each of the NSH units, and one for each floor of the conventional unit. The heating energy required is calculated using a flow meter and two temperature sensors: heating fluid supply and return temperatures. The gas required for this heating energy is calculated using a constant estimated boiler efficiency.

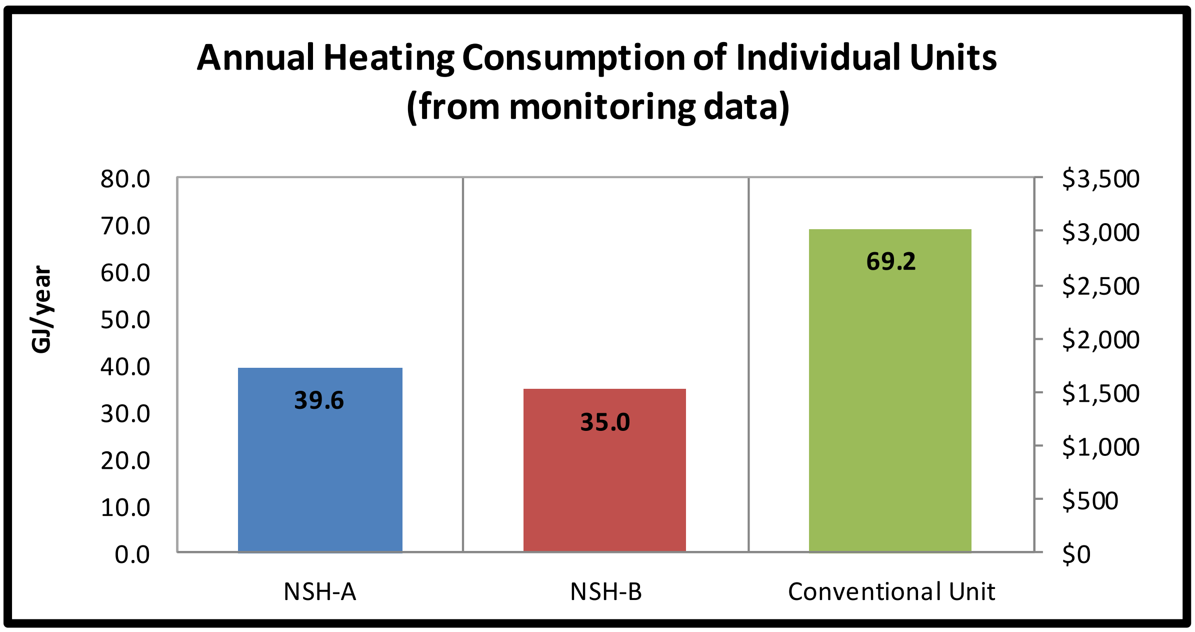


FIGURE 4-3: ANNUAL HEATING FOR NSH UNITS & CONVENTIONAL UNIT BASED ON MONITORING DATA, YEAR 1

Based on the monitoring data, there is approximately double the energy required for heating the conventional unit compared with the NSH, even though the occupants keep the temperatures higher in the NSH than the conventional unit. The costs to heat the NSH units are $1500- $1700 per year compared with $3,000 for the conventional unit.

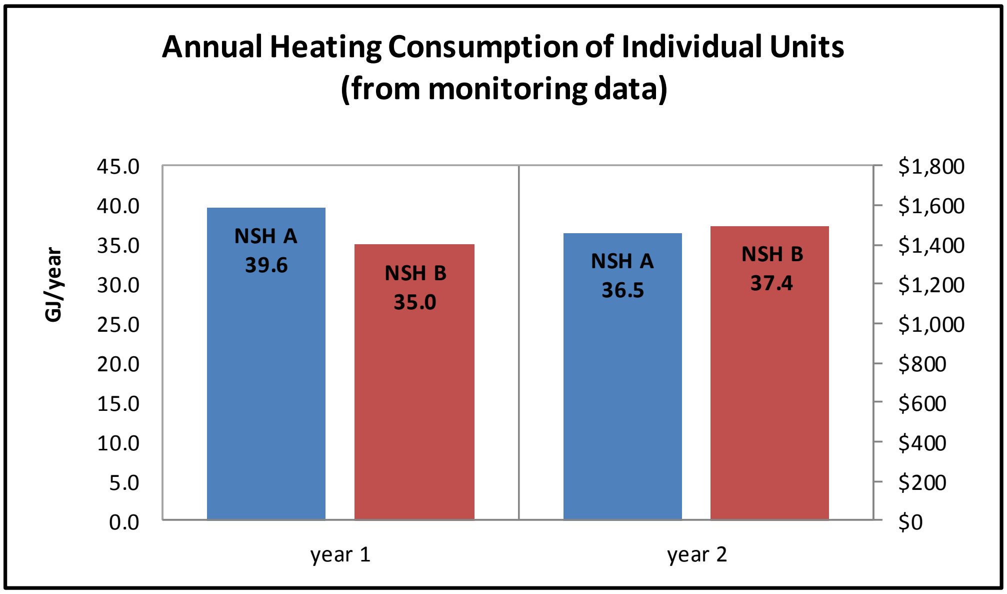


FIGURE 4-4: ANNUAL HEATING CONSUMPTION COMPARING YEAR 1 AND YEAR 2

NSH A shows the larger decrease in heating, but with NSH B increasing in heating, the total heating load for the duplex remains about the same over the two years.

4.3 Domestic Hot Water

The hot water in the NSH is pre-heated by four Enerworks TL glazed flat-plate solar collectors. An Enerworks Energy Pak with a double-wall heat exchanger transfers heat to a large storage tank. The pre-heated water flows to a domestic hot water tank where it is heated via a loop from the boiler as required.

The hot water in the conventional unit is heated via a loop from the boiler.

Monitoring is conducted on all three hot water lines; one for each of the NSH units, and one for the conventional unit, as well as on the solar hot water line. The heating energy required for hot water is calculated using a flow meter, the supplied hot water temperature and the delivered cold water temperature. The heating provided from the solar hot water is removed from the total hot water required for each of the NSH units in proportion to what each unit requires for the month. The gas required for this heating energy is calculated using a constant estimated boiler efficiency.

The total annual energy required for the NSH units is higher than the conventional as their hot water loads are higher due to more people living in the units. However, the purchased energy is less for the NSH in year 1 as the solar thermal system is offsetting some energy required for water heating.

The NSH uses less energy than the conventional unit in the summer months due to the solar contribution. During the winter months the NSH uses more energy as there are higher hot water loads; there are also more people.

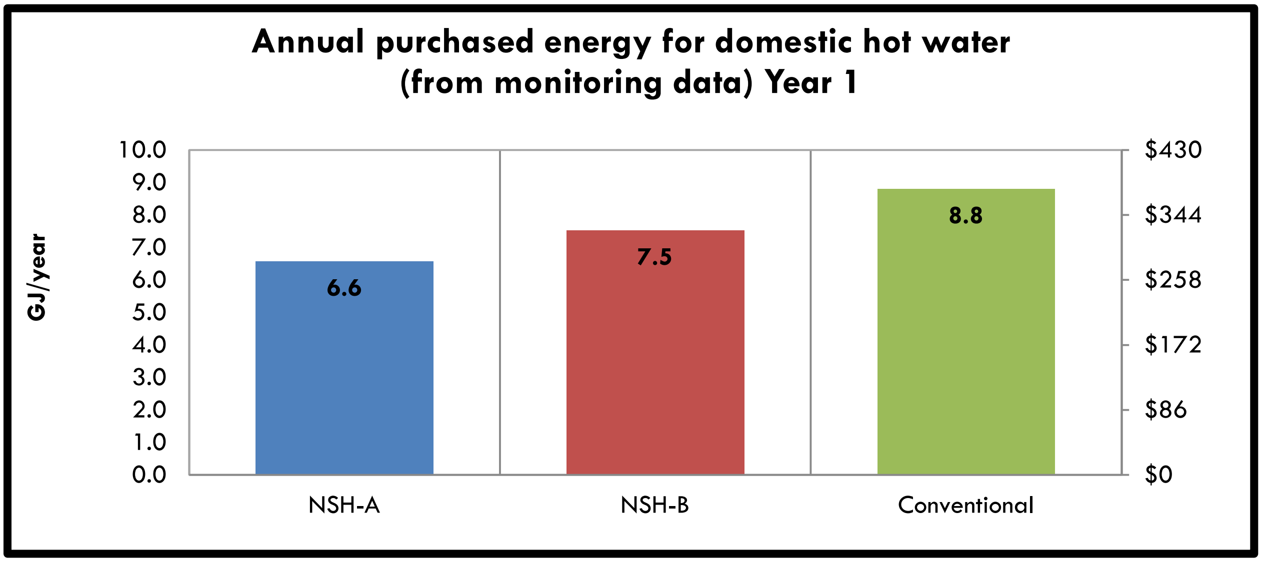


FIGURE 4-5: ANNUAL PURCHASED ENERGY FOR DOMESTIC HOT WATER FROM MONITORING DATA, YEAR 1

The annual energy required to heat water in the NSH is 15% to 25% less than the conventional unit due to the solar thermal collectors. The costs to heat water for the NSH units are $280 - $320 per year compared with $380 per year for the conventional unit.

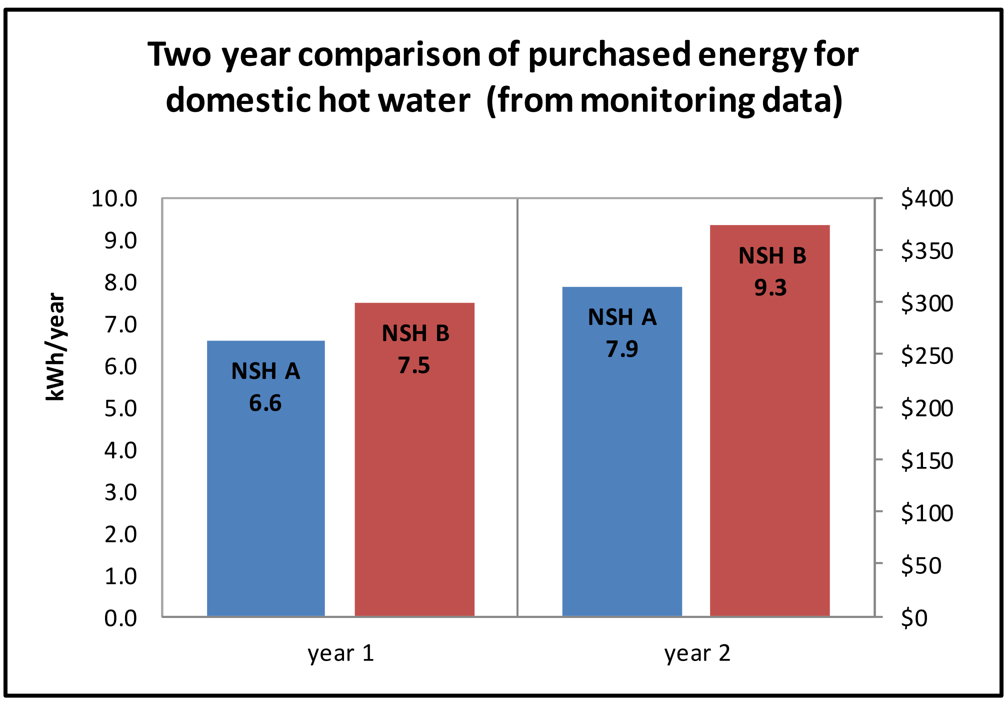


FIGURE 4-6: ANNUAL PURCHASED ENERGY FOR DOMESTIC HOT WATER, YEAR 1 AND 2

The amount of hot water purchased increased for both sides of the duplex from year 1 to year 2. The solar hot water system had troubles during the second year and the increased usage would be mainly due to that.

4.4 HRV preheat

Each housing unit of the NSH has a mechanical heat recovery ventilation (HRV) system that provides pre-heated fresh air to every room. The exhaust is drawn from the bathrooms and kitchens and fed back into the HRV. The VanEE 90H-V ECM are ENERGY STAR® rated with an apparent sensible effectiveness of 83% at 0°C and 89% at -25°C and have a wide range of air flow rates. A preheat coil is available at the intake of outdoor air to condition the very cold air before reaching the HRV core.

The conventional house has exhaust fans from the bathroom and kitchen with no heat recovery ventilators. There is no supplied ventilation to the conventional unit and no energy used for preheat.

Monitoring is conducted on both HRV preheat lines; one for each of the NSH units. The heating energy required is calculated using a flow meter and two temperature sensors: heating fluid supply and return temperatures. The gas required for this heating energy is calculated using a constant estimated boiler efficiency. See section 8 for more details on the HRV.

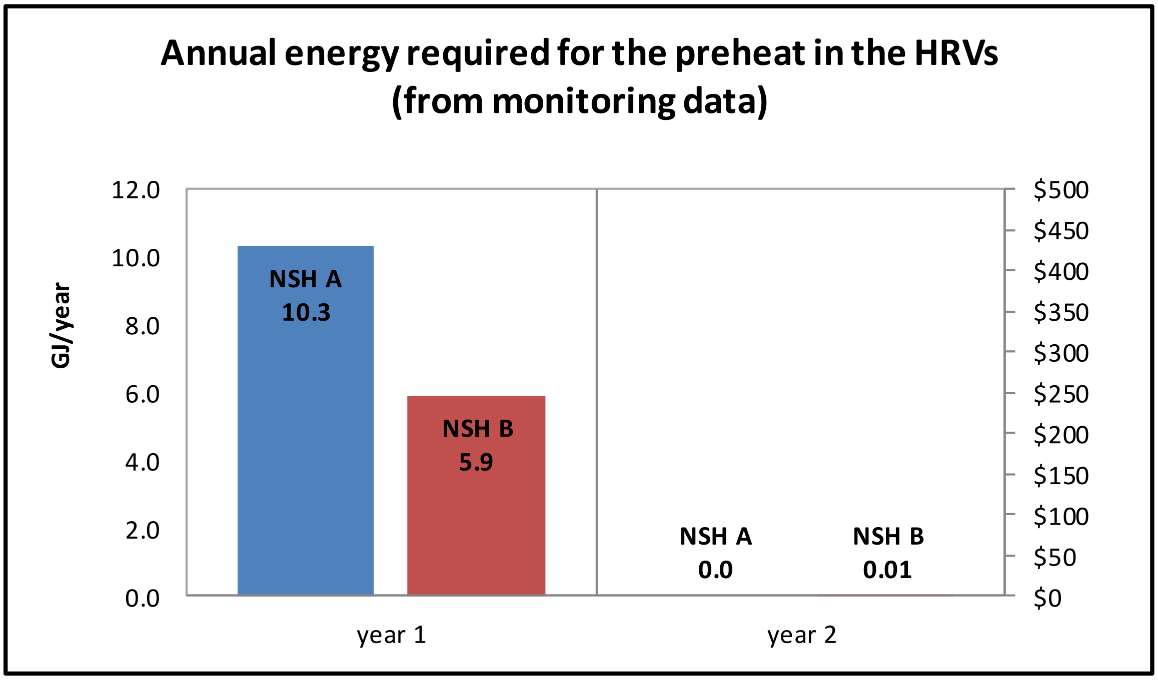


FIGURE 4-7: ANNUAL ENERGY REQUIRED FOR THE PREHEAT IN THE NSH HRVS, YEAR 1

The annual energy used for preheating the HRVs in the first year was 5.9 - 10.3 GJ, or $250 - $440 per year. During the second year of monitoring, data for NSH A was missing and the HRV preheat was turned off in NSH B.

4.5 Losses

The sum of the gas used in year 1 for heating, water heating, and HRV preheat for the year amounts to 105 GJ from the monitored data, as opposed to 137 GJ from the bills. This discrepancy of 25% is likely due to losses in the mechanical room, changes in efficiency of the boiler as opposed to the assumption of constant efficiency in all calculations, and monitoring equipment inaccuracies. The monitored data and billed data are much closer during the winter months.

The direct comparison between bills and monitored data is not possible for the conventional unit as only one unit of the duplex is being monitored while the gas bills are for the entire duplex.

The billed and monitored gas data for year 2 also did not match up. The total monitored gas usage was 91 GJ and the bills showed 133 GJ, a difference of about 30%.

5 ELECTRICITY USE

The price paid by the local housing authority for electricity is $0.65/kWh + GST for the period of monitoring. The occupant pays $0.09/kWh for their own usage only and not that of the mechanical room. The electricity generated by the PV is first used in the house and the surplus is fed into the main electrical grid under a net billing program. The price paid for the surplus is $0.2144/kWh. The territory has since adopted a net metering program to replace their net billing program, although the northern sustainable house still remains grandfathered in to the net billing program

5.1 Individual unit usage

5.1.1 NSH vs. Conventional

The electrical usage of each unit is being monitored on an individual circuit level. The individual unit electricity takes into consideration only the electricity being used in the home and not in the mechanical room. The total electricity use in the unit is calculated by summing the individual circuits. Approximations are used for missing data when required using an estimate from actual data. The amount produced by the solar PV is not used in this calculation as this is the total usage of the house, not the net usage.

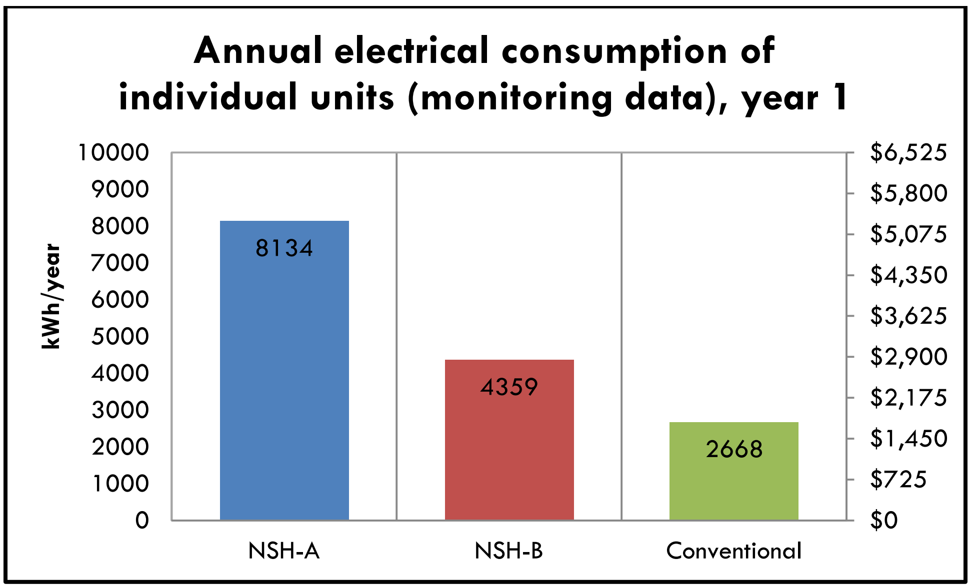


FIGURE 5-1: ANNUAL ELECTRICAL USAGE OF EACH UNIT, YEAR 1

One unit of the NSH uses double to triple the electricity than the other units; this is due to different occupant behaviors.

As a point of comparison, most communities have subsidized rates up to 600 kWh/month for April to August and up to 1000 kWh/month for September to March. This would normally include the electricity used for their mechanical systems.

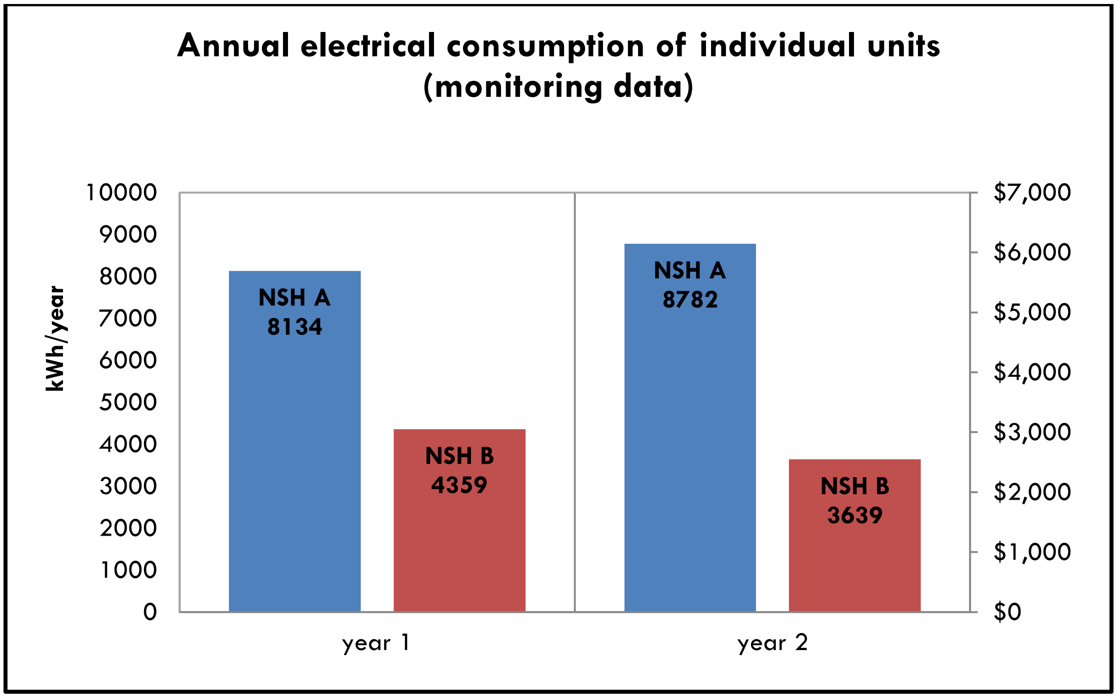
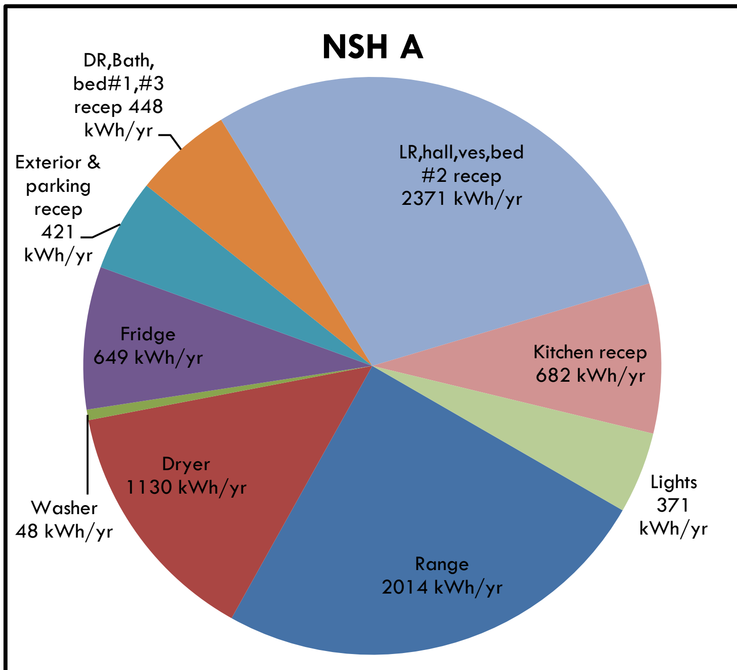


FIGURE 5-2: ANNUAL ELECTRICAL CONSUMPTION OF NSH, YEAR 1 COMPARED WITH YEAR 2

In year two, NSH A still has quite a bit more electrical usage than NSH B, now it uses almost 2.4 times that of NSH B.

5.1.2 Breakdown by circuit



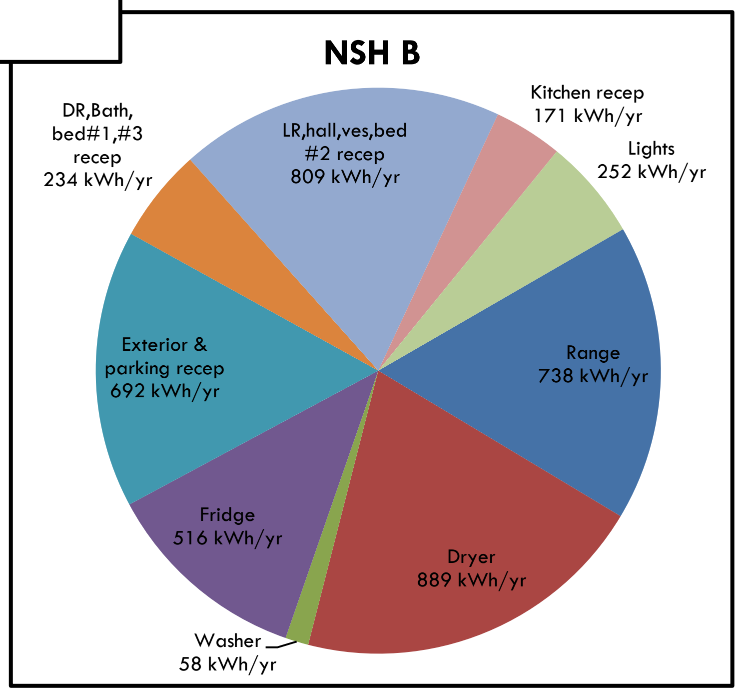


FIGURE 5-3: BREAKDOWN OF ELECTRICTY USAGE IN NSH A AND NSH B, YEAR 1

NSH A's top three electricity users are: the receptacles in the living room, hall and bedroom; the range; and the dryer. NSH B's top three electricity users are: the dryer; the receptacles in the living room, hall and bedrooms; and the range.

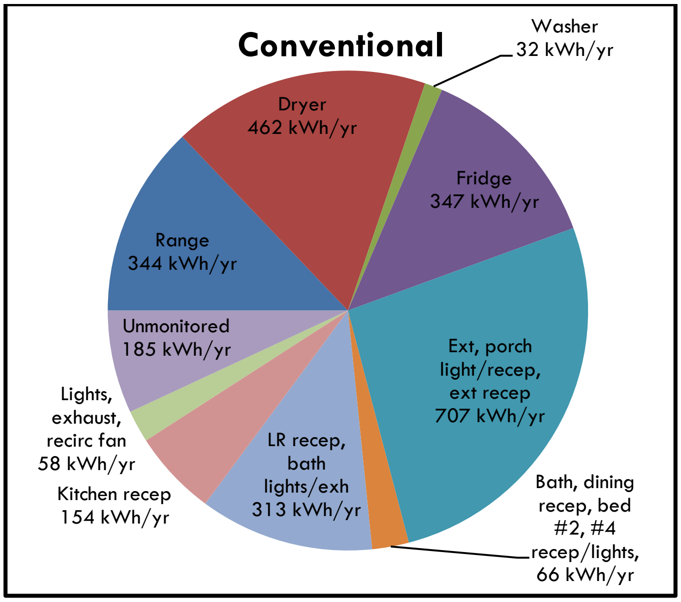


FIGURE 5-4: BREAKDOWN OF ELECTRICTY USAGE IN THE CONVENTIONAL UNIT

The conventional unit's top three electricity users are: the exterior lights and receptacles; the dryer; and the fridge.

5.1.3 Net electrical usage

The net electrical usage is the actual usage of the unit less the amount that was offset by the PV.

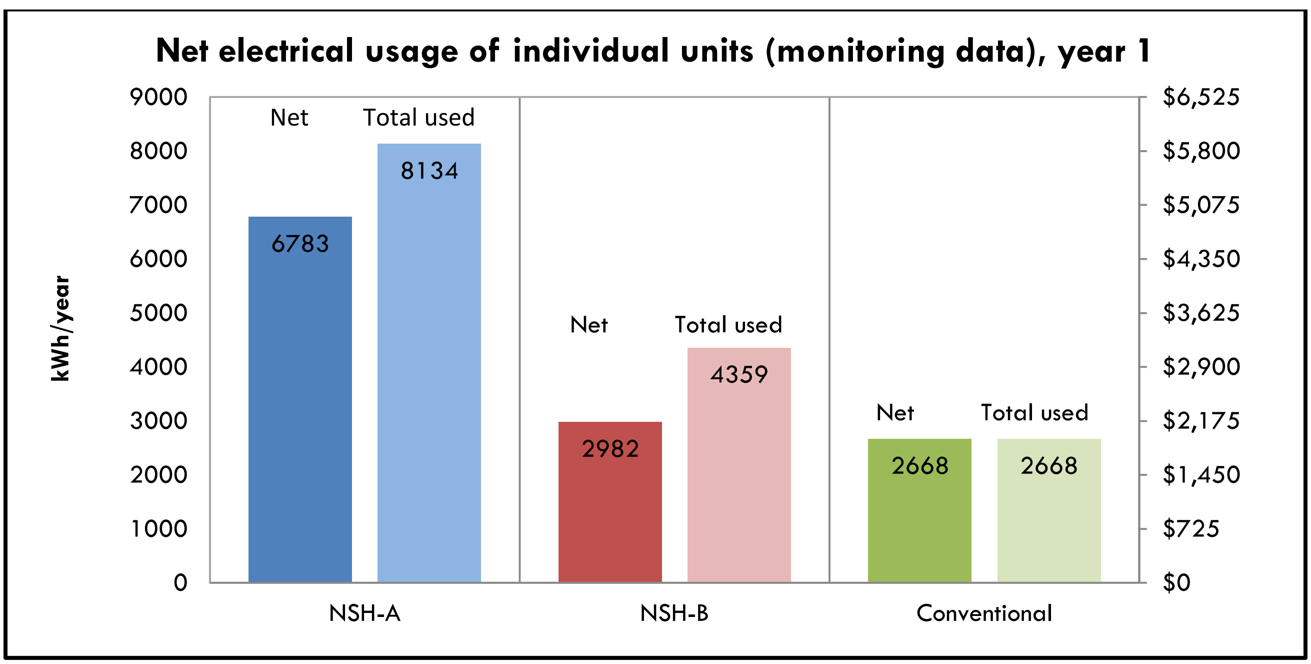


FIGURE 5-5: NET ELECTRICAL USAGE IN INDIVIDUAL UNITS, YEAR 1

The NSH units reduced their total electrical consumption by 17% - 32% due to the electricity produced by the PV in year 1

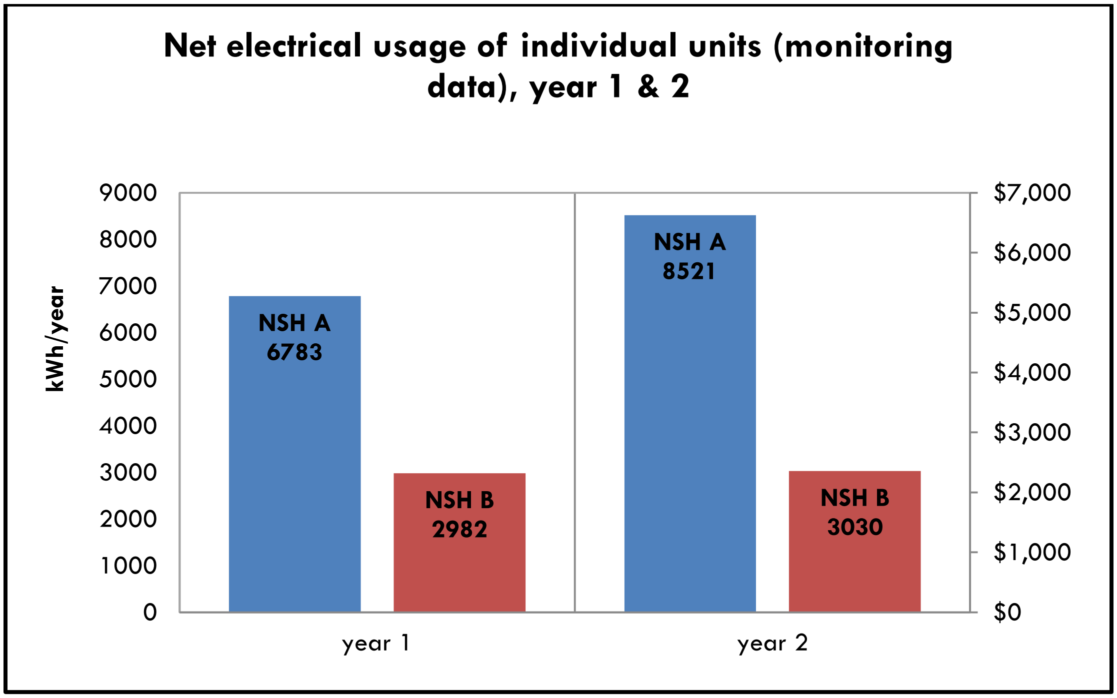


FIGURE 5-6: NET ELECTRICAL USAGE NSH5-6

NSH B received more benefit from the solar panels due to a loss of generation for side A in the fall of 2015.

5.2 Mechanical room usage

5.2.1 NSH vs. Conventional

The electrical usage of each mechanical room is being monitored on an individual circuit level. The total electricity use in the unit is calculated by summing the individual circuits. Approximations are used for missing data when required using an estimate from actual data.

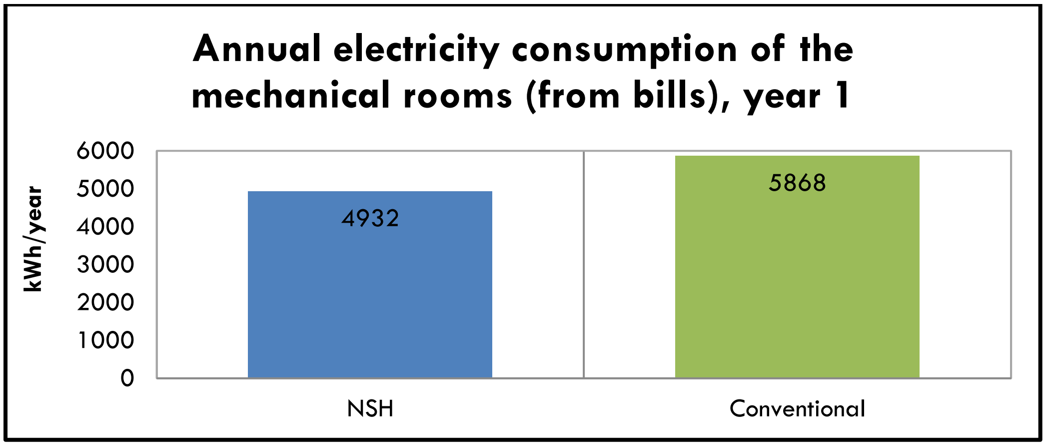


FIGURE 5-7: ANNUAL ELECTRICITY USAGE OF THE MECHANICAL ROOMS

The NSH mechanical room uses 15% less electricity than the conventional.

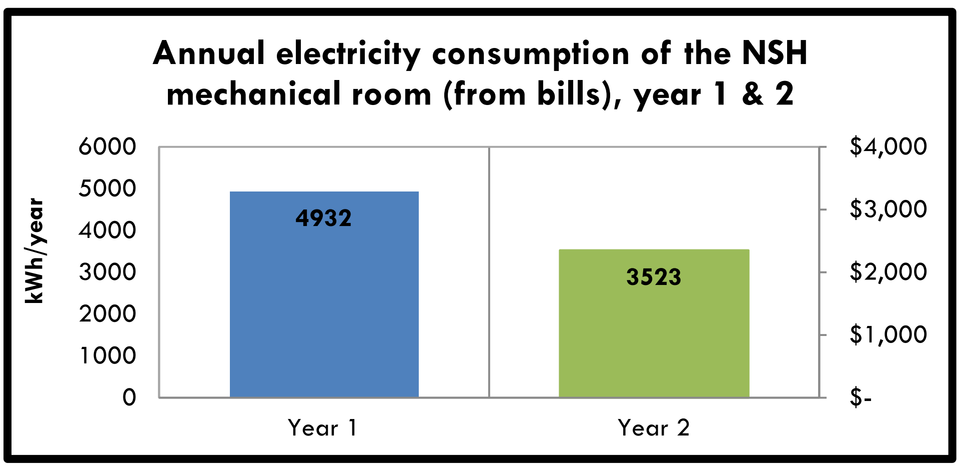


FIGURE 5-8: ELECTRICITY CONSUMPTION OF NSH MECHANICAL ROOM

The electricity consumption of the NSH mechanical room decreased by 28% in year 2. The HRV preheat circulation pump for one unit was turned off the second year as well as a glycol circulation pump that would have been a part of the SHW system. One of the HRVs also didn't appear to run as much as it had the 1st year.

5.2.2 Breakdown by circuit

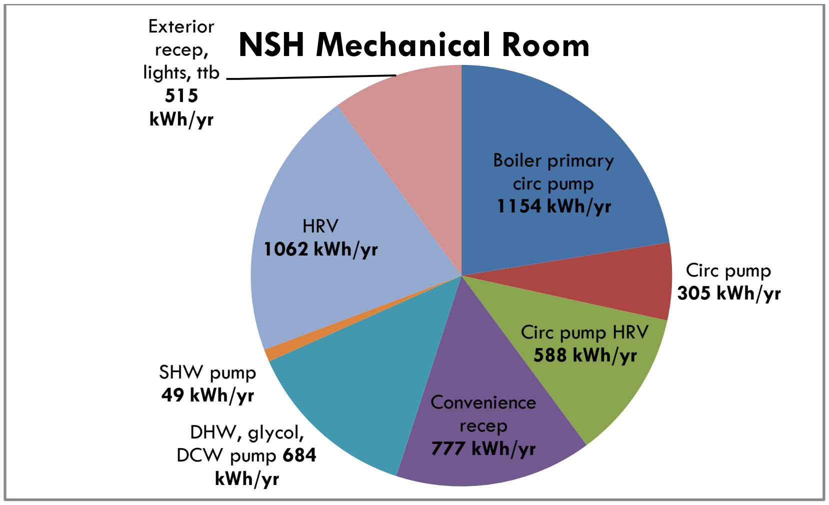


FIGURE 5-9: BREAKDOWN OF ELECTRICITY USAGE IN THE NSH MECHANICAL ROOM, YEAR 1

The top three electricity users in the NSH's mechanical room are the boiler primary circulation pump, the HRV and the convenience receptacle.

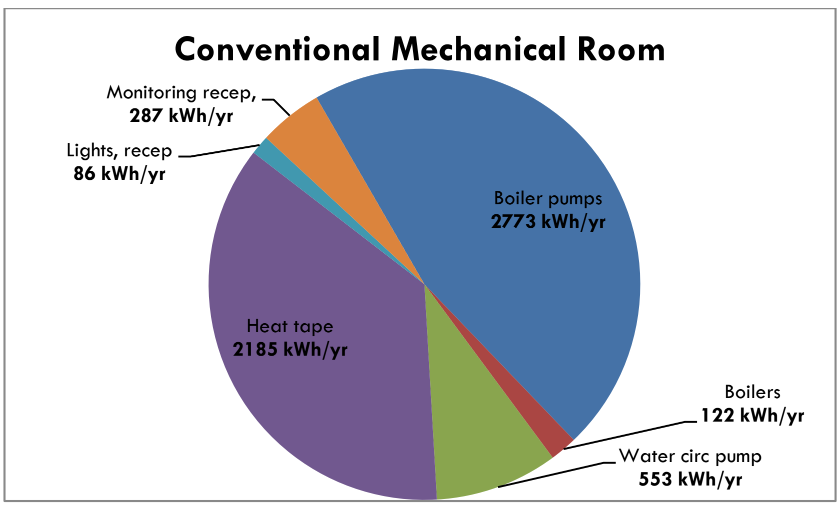


FIGURE 5-10: BREAKDOWN OF ELECTRICITY USAGE IN THE CONVENTIONAL MECHANICAL ROOM, YEAR 1

The top three electricity users in the conventional unit's mechanical room are the boiler pumps, the heat trace tape and the water circulation pump.

The heat trace in the conventional unit is used as a freeze protection for exposed pipes. In many newer houses the sewage and water pipes are located in conditioned crawlspaces, which means there is more space to heat but less electricity is used.

6 WATER USE

The price paid by the local housing authority for water is $10.50/m³ ($0.0105/L) + GST for the period of monitoring. The occupant does not pay for water.

Water is being billed separately for both sides of the conventional house. Water consumption is billed for the entire NSH duplex. Water consumption is being monitored for one side of the NSH duplex in order to get individual unit consumption. The water consumption is the total consumption for each unit and includes hot water and cold water used in the units. For the second year of monitoring each unit of the NSH duplex was monitored separately.

6.1 Total Water Use

6.1.1 NSH vs. Conventional

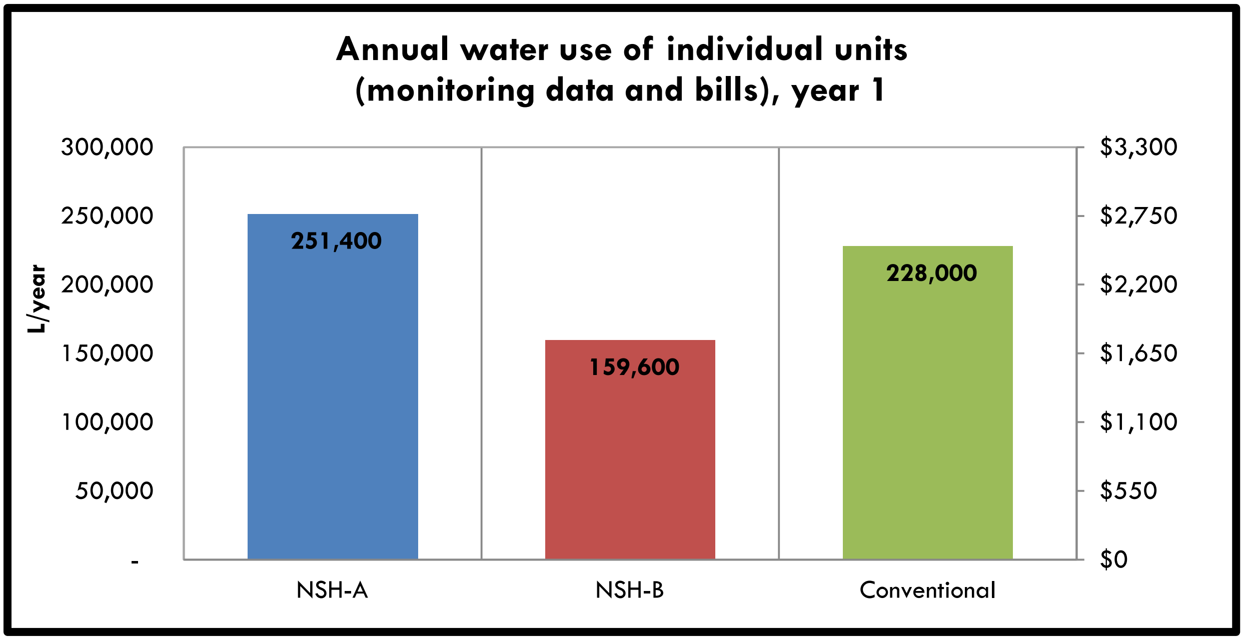


FIGURE 6-1: LITERS OF WATER USED BY UNITS, YEAR 1

The water use by the three units varies from 160,000 to 250,000 L per year at a cost of $1,750 to $2,800 annually.

Per person, NSH A uses about 230 L/day (3 adults in the unit), NSB B uses 145 L/day (3 adults in the unit) and the conventional unit uses 310 L/day (2 adults in the unit).

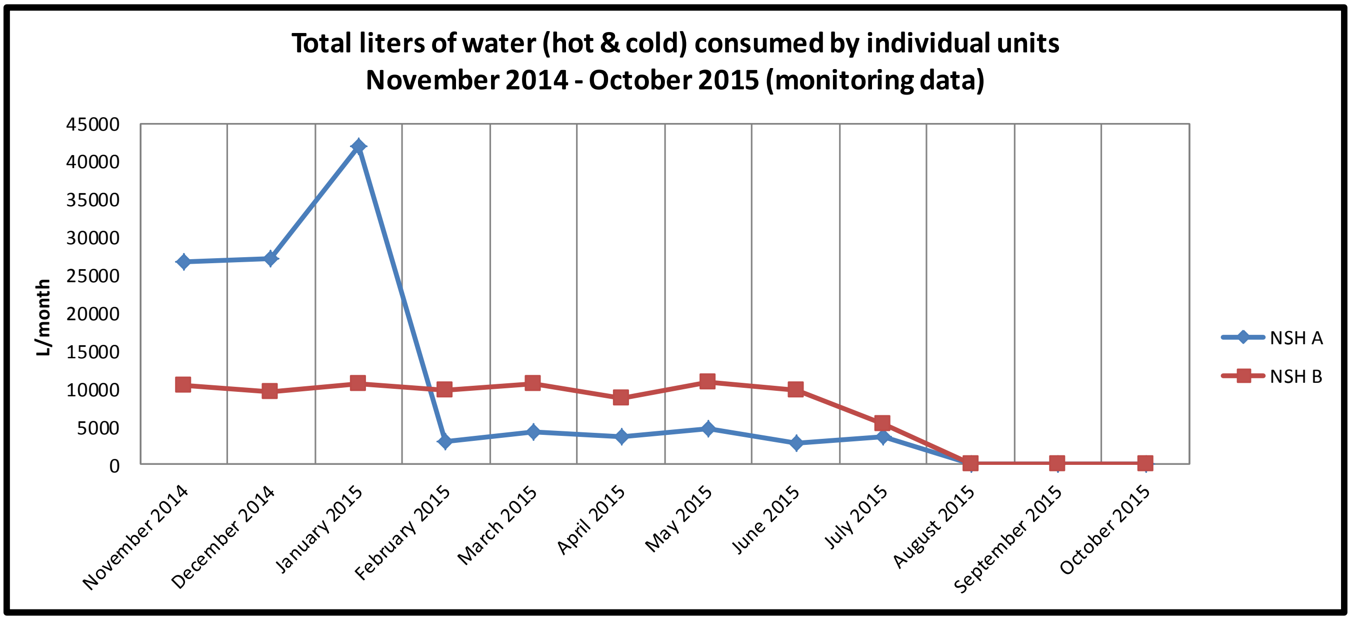


FIGURE 6-2: LITERS OF WATER USED BY UNITS, YEAR 2

For the second year of monitoring, the monitored water usage is about half of what the bills showed. The flow meter in NSH A in particular is likely not recording the correct usage since there is a strange drop in usage in Feb 2015.

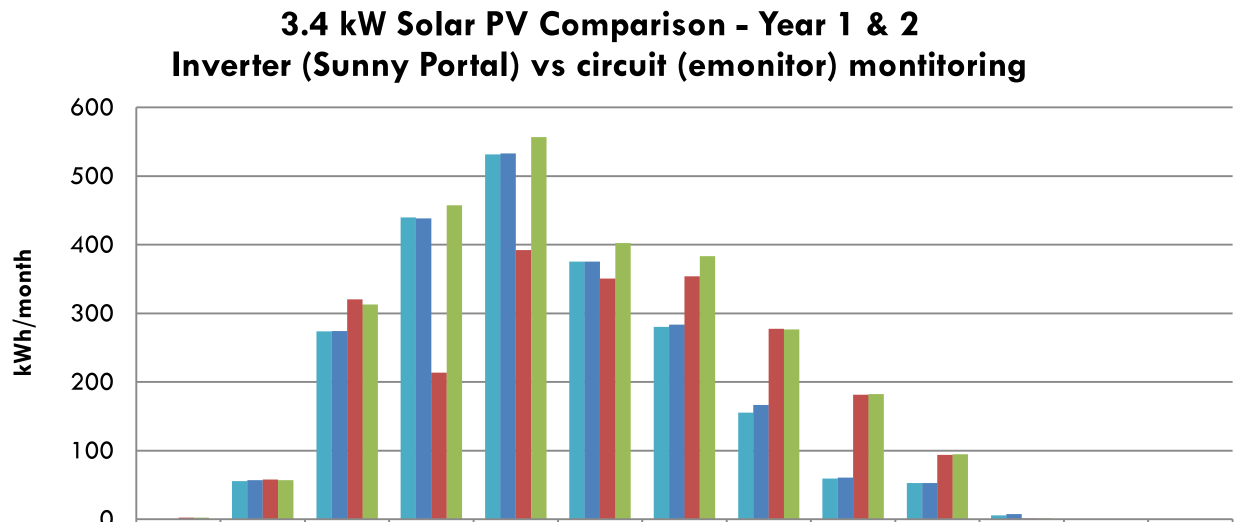
Using NSH B as a baseline and correcting for the missing data, that leaves NSH A with usage of 290,000 L and NSH B with 110,000 L.

7 RENEWABLE ENERGY PRODUCTION

7.1 Solar PV production

7.1.1 Monitored comparison

The solar PV production is being measured by two different monitoring devices. There is both inverter monitoring (Sunny Boy) and circuit monitoring (emonitor).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Year 2 Circuit monitoring	0	56	274	440	532	375	280	155	60	53	6	0	2230
Year 2 Inverter monitoring	0	57	274	439	533	375	284	167	61	53	8	0	2251
Year 1 Circuit monitoring	3	58	321	214	392	351	354	278	181	94	2	0	2247
Year 1 Inverter monitoring	3	57	313	458	557	402	383	277	182	95	2	0	2729

FIGURE 7-1: COMPARISON OF THE TWO DIFFERENT MONITORING EQUIPMENT RESULTS

The results are fairly similar for the emonitor and the inverter monitoring. The only discrepancy is when the equipment was down in April and May in year 1 and data was lost from the emonitor.

The electricity generated from the PV for year 1 was about 2700 kWh and for year 2 was 2200 kWh for the 3.4 kW system covering both NSH A & B.

7.1.2 Connection to electrical grid

The NSH is set up for net billing. The solar PV is connected to the main electrical grid and any electricity not used instantaneously in the house is exported to the grid. The electricity used in the house offsets the electricity being bought from the grid at $0.7863/kWh to purchase during year 2 and $0.6457/kWh during year 1 and the electricity exported to the grid is sold for $ 0.2144 in year 1 and $.2041/kWh in year 2.

The Northwest Territories has since moved to net metering program instead of net billing but government entities are not eligible. However, the housing authority was eligible under the net billing program and falls into a unique category and has remained part of the net billing program. They receive a statement at 1 – 3 month intervals with a credit for the amount of electricity they sent to the grid.

The electricity exported to the grid is the amount of electricity produced by the PV and not used directly by the house. The bi-directional meters were installed on the 2 units at different times during year 1. The electricity exported to the grid is only recorded from the time the meter was installed. NSH A's meter was installed July 19, 2012 and NSH B's meter was installed October 16, 2012. The breakdown of which meter is exporting to the grid is unavailable for year 2 as it is all lumped under NSH A and is the total of what is exported for NSH A and B. There is one bill missing for September in year 2.

NSH A & B exported 1043 kWh of electricity during year 1 and 870 kWh during year 2.

This brought in revenue of $224 for year 1 and $178 for year 2. The true savings however are from the electricity not purchased.

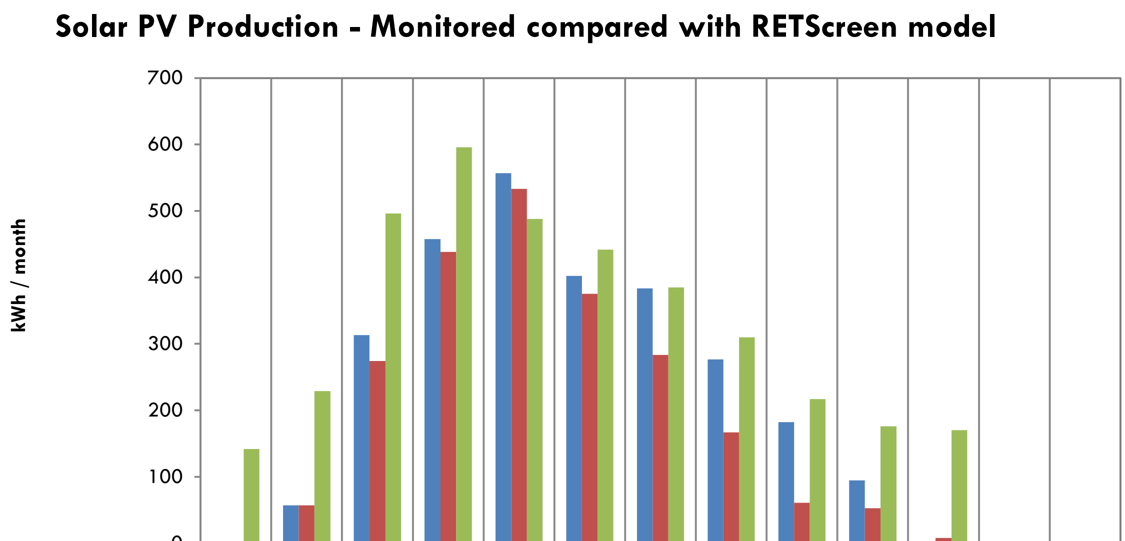
In year 1, NSH A & B saved 1686 kWh or $1143 in electricity not purchased and $224 in credits for electricity exported to the grid, for $1378 total. In year 2, NSH A & B saved 1381 kWh or $1140 of electricity not purchased and $178 in credits for electricity exported to the grid, for $1326 total.

The photovoltaic system saved NSH A & B $1378 during year 1 and $1326 during year 2.

7.1.3 RETScreen model

In order to achieve NWTHC's design goal and to evaluate the value of using solar technologies on projects developed by NWTHC in the future, solar hot water and solar photovoltaics (PV) were included in this project.

The two photovoltaic arrays on each unit are rated at 1.8kW with 8 panels of 13.4m^2, for a total system size of 3.6kW. In the model inverter efficiency of 95% was included as well as miscellaneous losses of 15%.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Year 1 Inverter monitoring	3	57	313	458	557	402	383	277	182	95	2	0	2729
Year 2 Inverter monitoring	0	57	274	439	533	375	284	167	61	53	8	0	2251
RETScreen Model	142	229	496	596	488	442	385	310	217	176	170	0	3650

FIGURE 7-2: SOLAR PV PRODUCTIONRESULTS MONITORED COMPARED WITH RETSCREEN MODEL

The modelled PV production was overestimated by 35% in year 1 and 60% in year 2 when compared with the monitored results. Additional losses of 25% and 35% would need to be included in the model in order to match the annual production numbers. In this case the winter months would still be overestimated and the summer months would underestimated.

A detailed RETScreen analysis showed that a 16-panel PV system for each unit would offset about 3,650 kWh of purchased electricity per unit per year. In reality the PV system offset 2,250 and 2,700 kWh of electricity per unit per year. The panels did have snow on them throughout the winter but were cleaned periodically. The accumulation of dust during the summer months likely also resulted in production loses. In the fall of year 2, there was an issue with NSH A's system which resulted in 0 power being produced for mid-August through to October which affected the results in year 2.

The parameters in RETScreen that cannot be changed limit its applicability. For example ground reflectance, amount of diffuse light content, the use of NASA rather than ground data sometimes, and monthly simulations instead of hourly all affect the outputs (Natural Resources Canada, n.d.). When modeling high latitude solar systems, RETScreen is a great tool for relative percentage differences but may not capture the true picture in terms of absolute values. Monitoring is imperative for all new renewable systems in the North. There is very little data on Northern systems.

An alternate tool, NRCAN's PV maps (Natural Resources Canada, 2007) uses hourly values and is likely to make this set of solar radiation data from PV map closer to reality compared to RETScreen. However it is only available for South-facing and preset tilt angles.

7.2 Solar hot water

7.2.1 Annual energy for hot water from SHW

The solar hot water production is being measured by using a flow meter and temperature sensors to determine the amount of useful energy produced by the solar hot water. The system was functional in year 1 but not in year 2.

The SHW system was non-functional in year 2 and was not be resurrected by the local housing authority due to the following:

1) The cost of yearly maintenance required by the manufacturer was expensive and required time that was better spent by limited maintenance staff in other areas
2) A lack of local capacity to properly troubleshoot problems with the system. High priced help from the south is not an option.

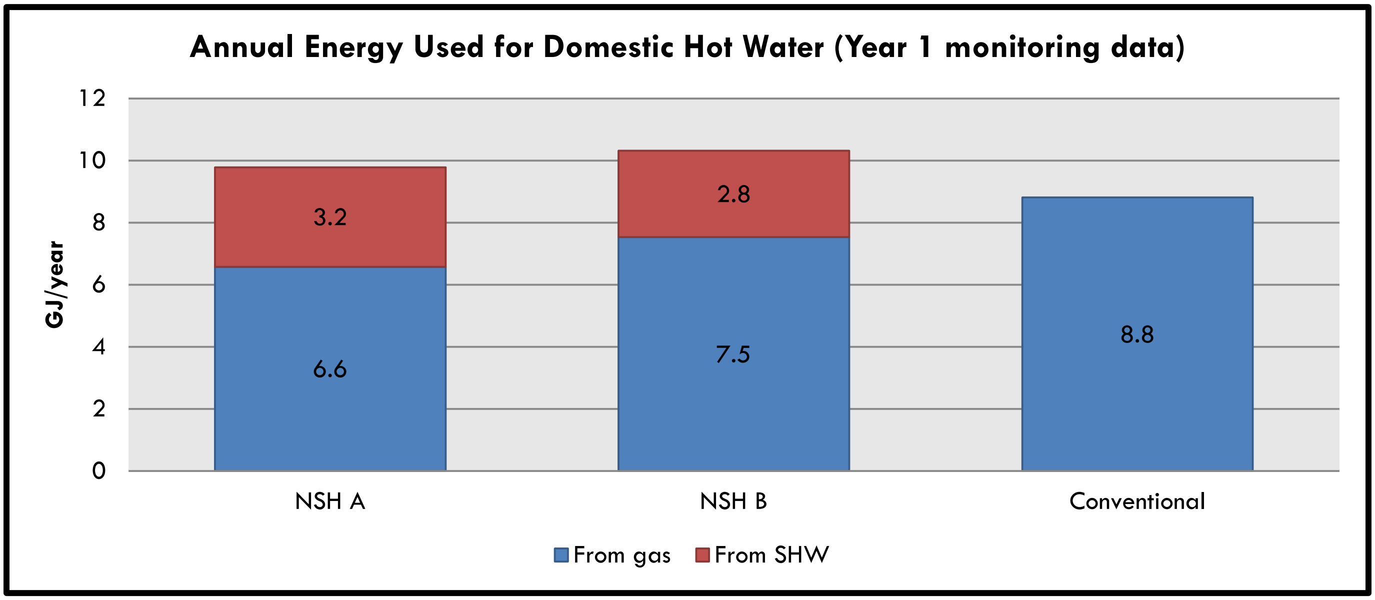
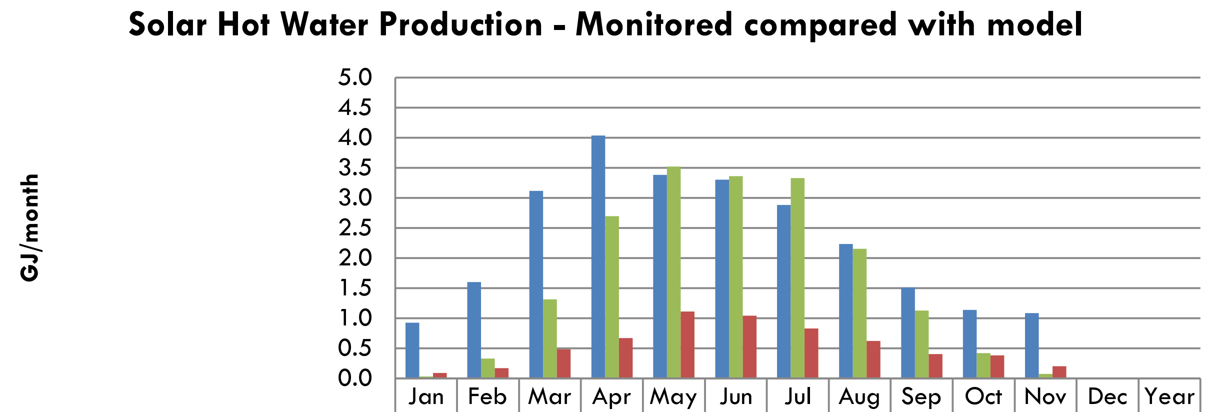


FIGURE 7-3: ENERGY USED FOR HOT WATER USAGE FROM GAS AND SHW

27% - 33% of the annual hot water loads are met by the SHW in the NSH units in year 1.

7.2.2 Modeled results vs. monitored



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
RETScreen SHW output using a constant annual efficiency	0.9	1.6	3.1	4.0	3.4	3.3	2.9	2.2	1.5	1.1	1.1	0.0	25.2
HOT2000 SHW output	0.0	0.3	1.3	2.7	3.5	3.4	3.3	2.2	1.1	0.4	0.1	0.0	18.3
Monitored SHW results	0.1	0.2	0.5	0.7	1.1	1.0	0.8	0.6	0.4	0.4	0.2	0.0	6.0

FIGURE 7-4: SOLAR OT WATER PRODUCTION RESULTS COMPARED WITH RETSCREEN MODEL

The modeled solar hot water production was overestimated significantly when compared with the monitored results.

RETScreen actually only outputs an annual value for SHW production but the monthly values are derived from the available radiation and assuming a constant seasonal efficiency. RETScreen doesn't take into consideration whether all the hot water produced by the solar will be useful. HOT2000 does take daily use into consideration but is getting its initial expected output from the results from RETScreen so is based on the same solar radiation data. The monitored results are lower than expected. It was expected that the SHW would cover all hot water needs during the summer.

Possible reasons for the major differences between modelled and monitored results could be: a) the controls for the SHW are not optimising production; b) the monitored temperature sensors are not correctly placed to give a true picture of what is being produced; c) the SHW is not working correctly, d) the use of steady state calculations is underestimating more than predicted; e) the solar radiation data in RETScreen is not close to reality.

The average annual efficiency of the collectors is calculated as 25% for the RETScreen modelling, 18% for the HOT2000 modelling and 6% for the monitored results. Higher efficiencies were expected.

As demonstrated in year 2, the system is not being maintained to provide optimal performance.

8 HEAT RECOVERY VENTILATION

See section 4.4 for details on the HRV in place in the NSH.

The HRV preheat was set up incorrectly. During the first year of monitoring, the controls were not running as in the initial design intent. During commissioning a problem was discovered with the preheat controls, which was duly noted in the commissioning report but was never rectified. The pre heat loop ran uncontrolled throughout the first year of monitoring.

After consulting with the design engineer and a local contractor, it was discovered that the Tekmar controller, specified by the engineer, would not meet the required low (-5C) activation temperature required and a new one was sourced. After much consultation with Tekmar, it was discovered that they had no controller that would go to that low temperature before turning on so they had to reprogram an existing unit. This modified controller was installed and tested before year 2 monitoring.

The HRV preheat data from year 2 is unreliable or missing from the data file. The temperature sensors were still collecting data, as seen in Figures 8-7 and 8-8, but the heating data was missing due to a faulty flow sensor.

8.1 Preheat energy

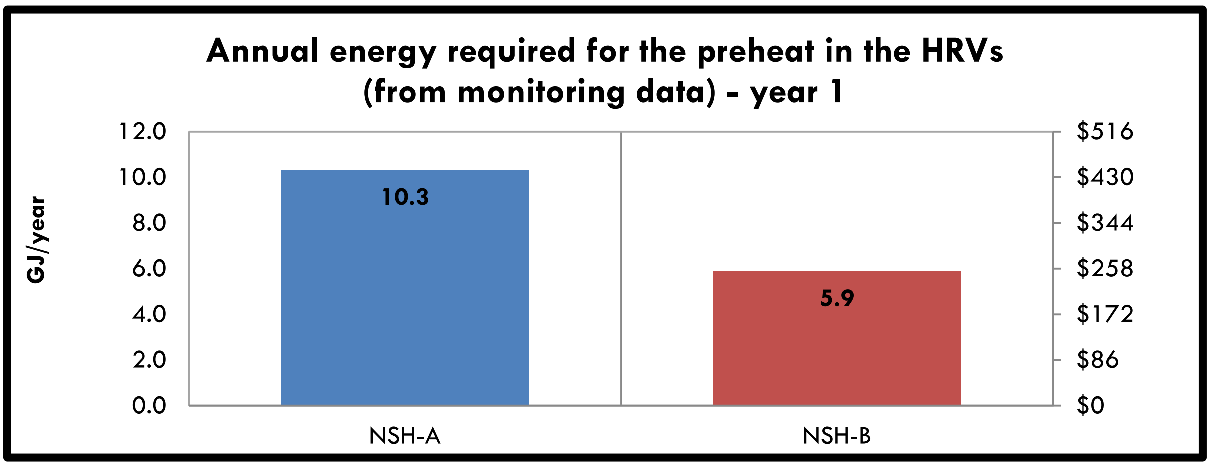


FIGURE 8-1: PREHEAT ENERGY USED IN THE HRVS – YEAR 1

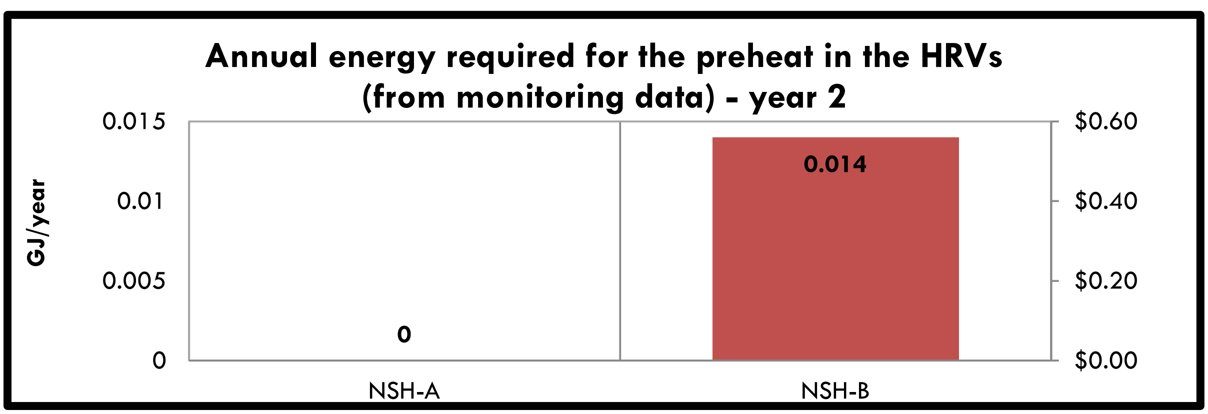


FIGURE 8-2: PREHEAT ENERGY USED IN THE HRVS – YEAR 2

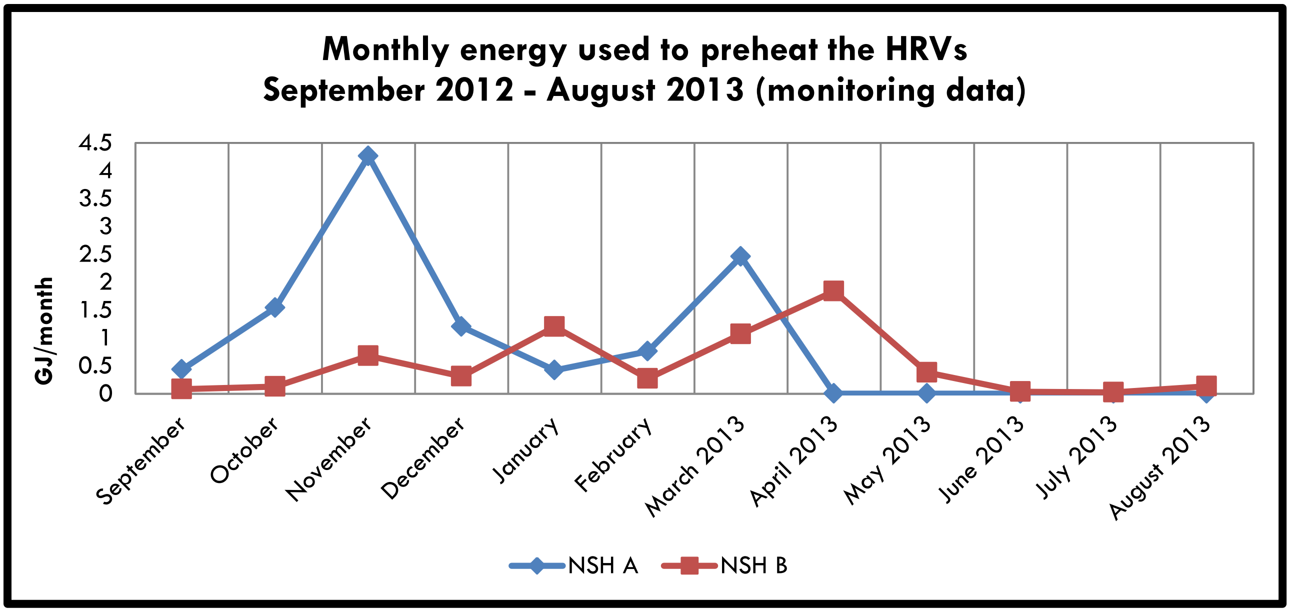


FIGURE 8-3: MONTHLY ENERGY USED FOR PREHEAT IN THE HRV – YEAR 1

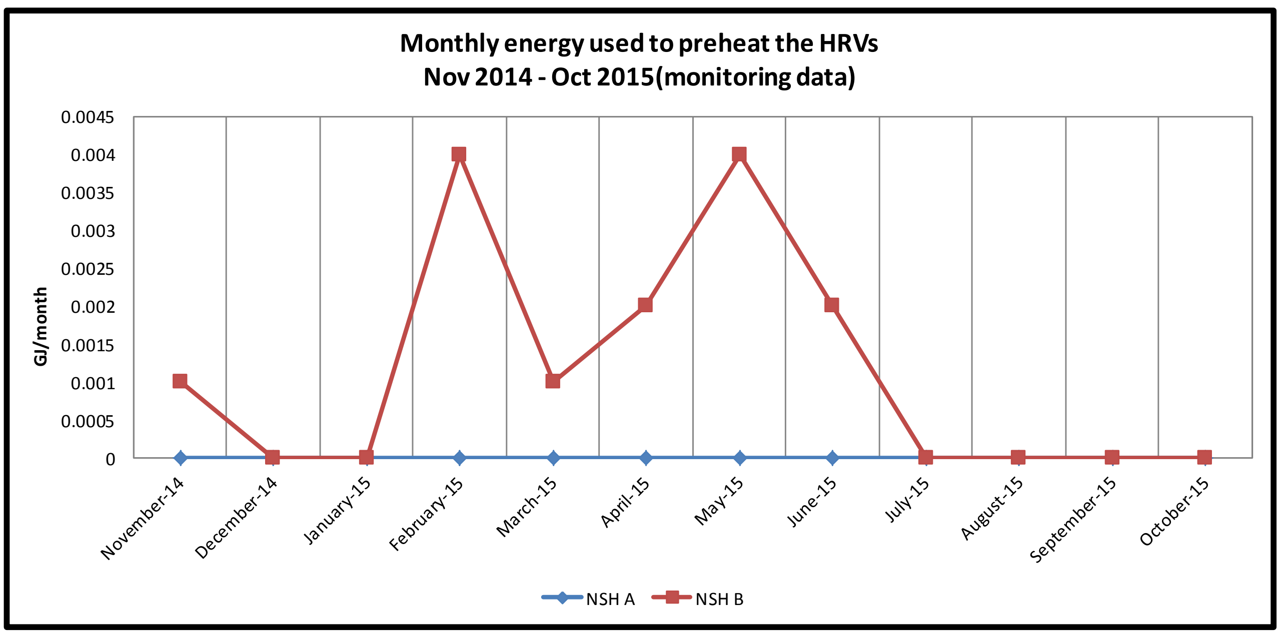


FIGURE 8-4: MONTHLY ENERGY USED FOR PREHEAT IN THE HRV – YEAR 2

8.2 Temperatures in HRV

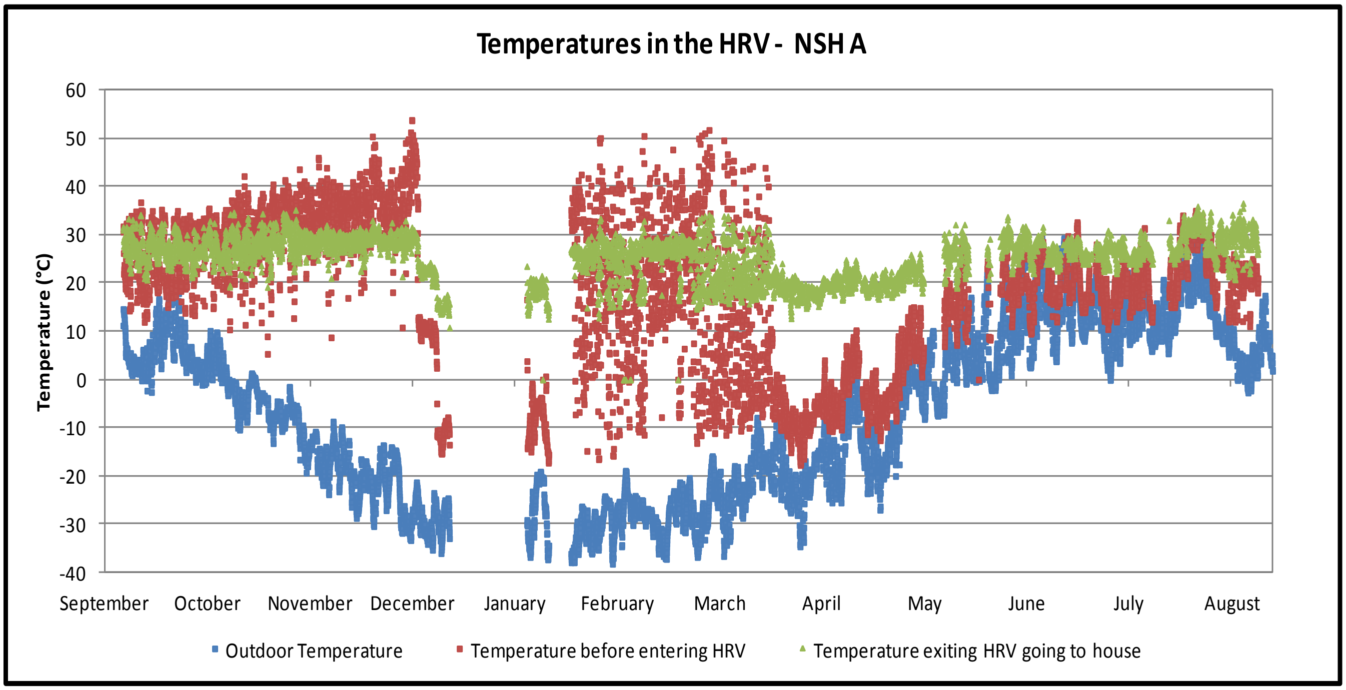


FIGURE 8-5: TEMPERATURES IN THE HRV FOR NSH A – YEAR 1

During the first year of testing, the preheat controls were not set up as designed for both NSH A and B. The preheat was turned on at all times and the temperature was uncontrolled, resulting in the preheat temperature being hotter than the temperature entering the house for a period of time. This indicates that the heat flow in the HRV would have been working in reverse. The preheat in NSH A was turned off mid-March to see the difference between A and B and it was noted that even at -30°C outside temperatures, the temperature entering the house was still around 20°C.

There is a buffering effect happening caused by the heat from the mechanical room; this can be seen in mid-March after the preheat is turned off. Since every mechanical room will be different and have a different buffering effect, the control for the preheat should be based off of the temperature entering the HRV and not simply the outside temperature.

When designing controls for an HRV preheat, the supply temperature should be taken just before it enters the HRV and not the actual outdoor temperature since the mechanical room can raise this temperature a few degrees already as is demonstrated with this monitoring.

The -5°C outdoor temperature set point used in the NSH could likely be lowered. In the case where the preheat is turned off, even at -30°C outdoor temperature, the temperature entering the house is close to 20°C due to the buffering effect and heat recovery from the HRV. This would have to be adjusted accordingly though since the main point of the preheat is to prevent freezing in the HRV core.

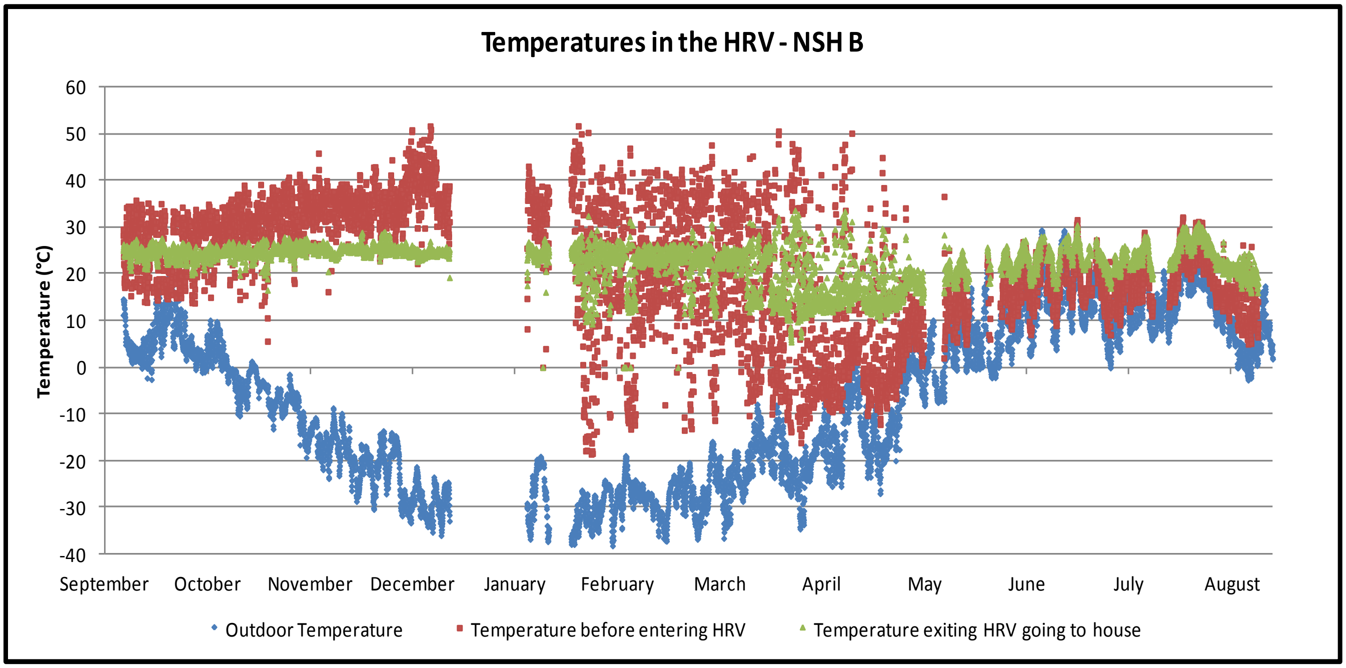


FIGURE 8-6: TEMPERATURES IN THE HRV FOR NSH B – YEAR 1

The preheat for NSH B was not turned off in the spring and it is can be seen that the temperature entering house in April fluctuates more than in NSH A. For a preheat to work as intended and still take advantage of the HRV, the preheat should have a control that maintains a consistent temperature entering the HRV to prevent freezing of the HRV core while still low enough to optimize efficiency of the HRV.

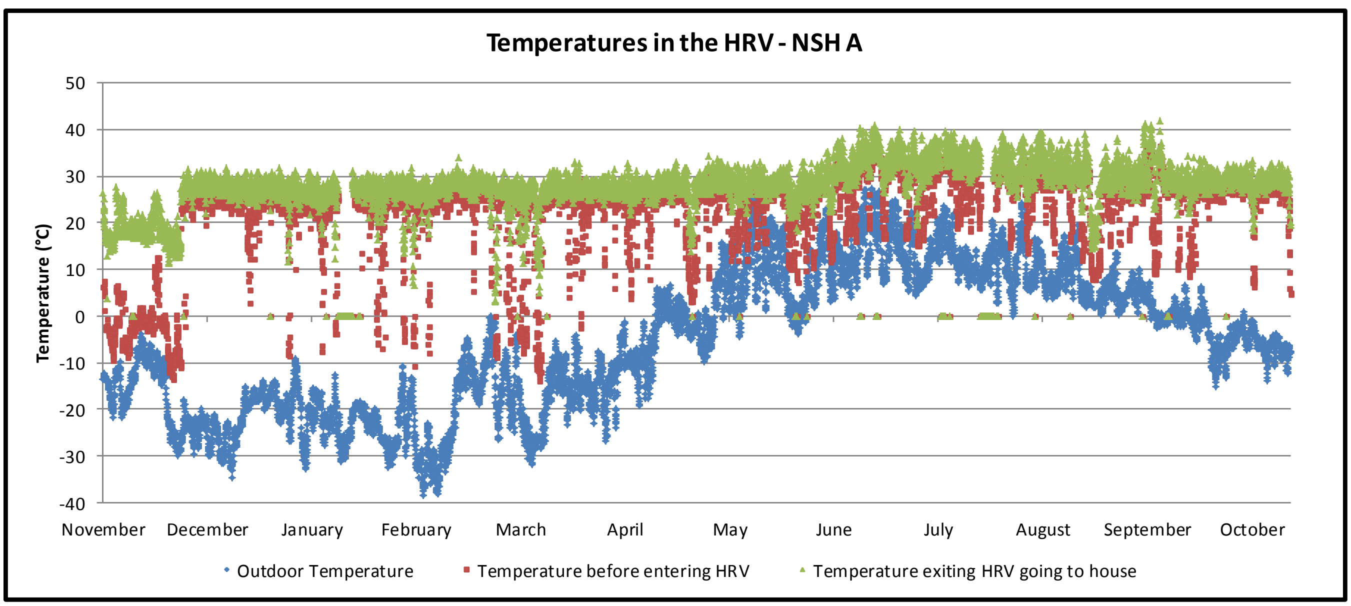


FIGURE 8-7: TEMPERATURES IN THE HRV FOR NSH A – YEAR 2

A distinct difference can be seen between the preheat data for NSH A and B during year 2. In NSH A, the preheat appears to turn on at an outside temperatures drop of about -25°C but then it doesn't turn off again in the summer when the temperatures rise. Another point to notice is that the preheat temperature is roughly the same as the inside temperature of the unit which still means it is heating the air too high for the HRV to work properly. The preheat controls are still not operating correctly.

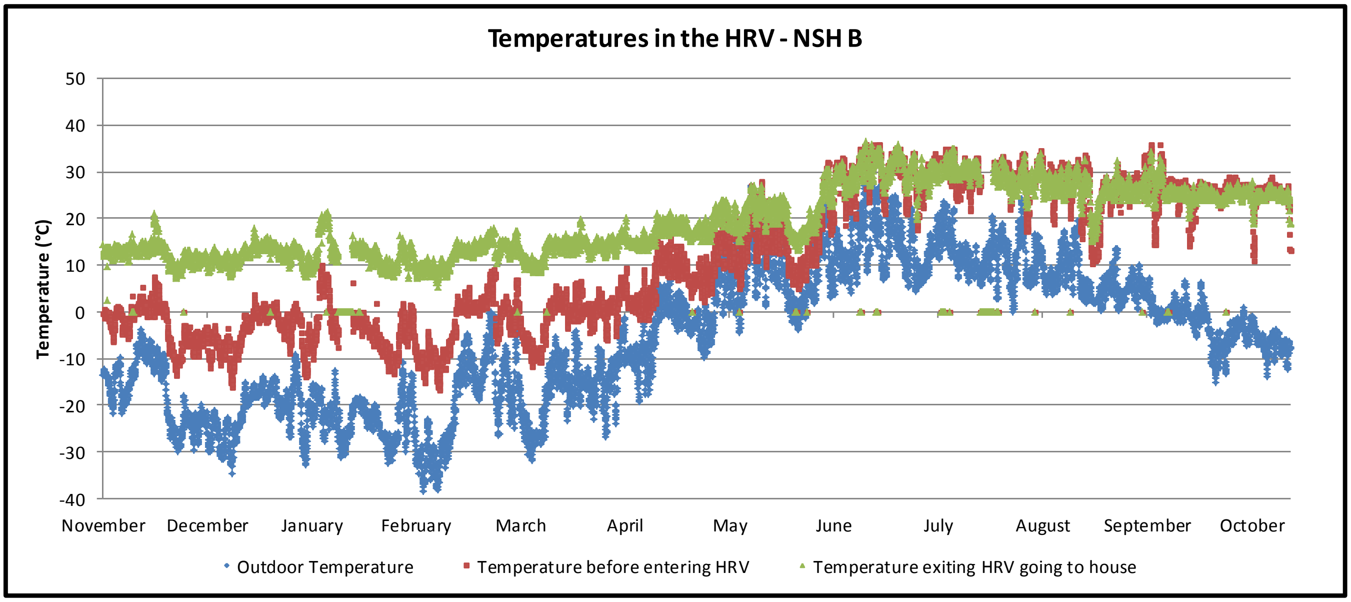


FIGURE 8-8: TEMPERATURES IN THE HRV FOR NSH B – YEAR 2

In NSH B, the preheat doesn't appear to turn on during the winter. The recorded preheat temperature is about 10 to 20 degrees warmer than the outside temperature; this is thought to be a buffering effect from the mechanical room. The data follows a similar trend to NSH A and after the summer, it appears the preheat is on.

Even with the preheat off, the temperature to the house still averages about 10°C to15°C. The buffering effect from the mechanical room alone adds about 20 degrees to the outside air then the HRV adds about another 20 degrees. If the preheat controls were set to maintain a 0 to +5 degrees entering the HRV (instead of -5°C outdoor temperature), this would prevent freezing and the supply temperature should remain around 20°C. If the preheat temperature was set to maintain the original -5°C set point entering the HRV, this would still prevent freezing but the temperature going to the house would be around 15°C which some occupants might find too cold.

However it is thought that the HRV controls are based on the outdoor temperature and not the temperature before entering the HRV. In this case, these temperatures are quite different due to the buffering effect.

9 INDOOR ENVIRONMENT

9.1 Standards and Guidelines

Based on health considerations Health Canada recommends that the acceptable long-term exposure range for carbon dioxide in residential indoor air is ≤3500ppm (≤6300 mg/m^3) (Health Canada, 1987). As a point of comparison, the average concentration of carbon dioxide in the atmosphere (outdoor air) is about 340ppm. The major sources of carbon dioxide indoors are gas stoves, unvented kerosene heaters and humans. In poorly ventilated rooms, levels may exceed 3000ppm from human metabolism alone.

Exposure to levels over 50 000ppm have produced effects on the central nervous system (headache, dizziness, visual distortions), although subjective symptoms have been associated with carbon dioxide levels of 500 to 3200ppm.

Indoor Air Quality was only measured during year 1.

9.2 Indoor Air Quality Monitoring Results

9.2.1 Temperature

	NSH A	NSH B	Conventional	Outdoor Air
Living Room	21°C to 32°C Typically 26°C to 29°C ***Average 27°C***	21°C to 32°C Typically 25°C to 28°C ***Average 27°C***	15°C to 35°C Typically 25°C to 29°C ***Average 27°C***	-40°C to 30°C Typically -29°C to 15°C ***Average -6.4°C***
Bedroom	23°C to 32°C Typically 25°C to 30°C ***Average 27°C***	19°C to 30°C Typically 22°C to 27°C ***Average 24°C***	17°C to 31°C Typically 22°C to 28°C ***Average 25°C***	

9.2.2 Relative Humidity

	NSH A	NSH B	Conventional	Outdoor Air
Living Room	6% to 53% Typically 12% to 35% ***Average 22%***	5% to 44% Typically 10% to 32% ***Average 21%***	5% to 49% Typically 9% to 35% ***Average 21%***	17% to 96% Typically 49% to 91% ***Average 73%***
Bedroom	19% to 51% Typically 26% to 41% ***Average 34%***	7% to 54% Typically 10% to 40% ***Average 25%***	10% to 56% Typically 16% to 47% ***Average 31%***	

9.2.3 Carbon Dioxide

	NSH A	NSH B	Conventional
Bedroom	680ppm to 1680ppm Typically 710ppm to 1230ppm ***Average 900ppm***	700ppm to 1530ppm Typically 750ppm to 1030ppm ***Average 880ppm***	710ppm to 1840ppm Typically 750ppm to 1320ppm ***Average 980ppm***

10 OCCUPANT INTERVIEWS

10.1 Description of occupants

Northern Sustainable House A: There are 3 adults living in this unit, including the main occupant, who is a traditional elder, along with her son and granddaughter. The elder and granddaughter are at home during the day, while the son is regularly at work. There is a large extended family that often visits during meal times. There is a lot of activity and cooking in the house and TV watching. The son and granddaughter live fairly independently with their own entertainment systems in their rooms. The indoor temperature is kept the warmest in this unit.

Northern Sustainable House B: There are 3 adults, 1 child and a new baby living in this unit. The baby, child and 1 adult moved in during the last year. 1 adult is mostly at home during the day with the children and the 2 others are typically out during the day. There is less activity than NSH A and few guests. There is also less cooking going on.

Conventional House: There is 1 adult and 1 child living in this unit. The elder is mostly at home in the mornings and out in the afternoons and the child is at school during the day. The indoor temperature is kept the lowest in this unit.

10.2 Entrance Interviews

Northern Sustainable House A: Interview was conducted in October 2012.

The tenant feels this is a very good house for elders because it is on one level, nice and warm, very quiet and because there is no frost on the windows, you can see who is at the door. There is an issue with the high step to the metal decking, which is 14 inches, and should have a small step to make the journey in and out of the house safe for elders. The floors are generally nice and warm except for the draft under the living room door.

The windows in the bedrooms seem a bit drafty and the tenant wonders if the space between window frame and rough opening is properly insulated. Both entrance doors are also drafty and have frozen closed several times. The tenant thought power bills would be lower with the solar PV but actually seem higher than in previous house.

Northern Sustainable House B: Interview was conducted in October 2012.

The tenants like the newness, size, open concept, and one level aspects of this house. They dislike the metal decking. They find it quite slippery and noisy. The floor is cold for the young child and it is difficult to leave the heat down at night and still have a warm floor in the morning.

Conventional House: Interview was conducted in October 2012.

The tenant has been living here since 2009. The windows are double pane sliders and they find them quite drafty but IHA installs plastic over 2 large windows downstairs and that makes a huge difference in the comfort level. 2nd floor windows are not plasticized because daughter has asthma and opening the window a crack may help her condition.

10.3 Exit Interviews

Northern Sustainable House A: Interview was conducted October 2013.

The tenants have nothing new to add about what they like about the house. After 2 years of living there they still appreciate the size and layout of the units. They dislike the maintenance delays and the frosting of the front door which results in not being able to open the door.

The house is warmer and cheaper than the last house. The thermostat is down more often as the house warms up and stays warm longer. The front door is still not working properly, and they have to lock the door to keep it closed and can't open it in the winter due to frost build up.

When asked whether the tenants had changed any of their energy habits during the last year they said that they now turn the heat down at night and unplug appliances when not in use (i.e. toaster, coffee pot).

Northern Sustainable House B: Interview was conducted November 2013.

The tenants like the low power bills and the layout of the house. They are getting tired of all the interviews they have had to do especially since nothing they have mentioned has been changed. The bedrooms are too hot. Front grate is noisy and echoes through the house when people walk on it. Wind blows snow up through grating and drifts build up in front of house. Noise seems to carry through floor from other unit. Snow accumulates in front of door from roof.

When asked whether the tenants had changed any of their energy habits during the last year, they said they turn things off more. They turn the lights and appliances off as much as possible and have installed a block heater timer for their vehicle. They keep the windows closed except when it is too hot in the bedroom.

Conventional House: Interview was conducted October 2013.

The tenants are glad to have a home to live in and say that the house is good. No dislikes at this time. The energy bills are cheaper now.

When asked whether the tenants had changes any of their energy habits during the last year, they said they are using the stove less due to the high energy use. They said they are more aware of the energy use and realize the freezer uses too much energy. They want to get rid of one of the freezers.

10.4 Monthly interviews

There are three main things that could be changed in the NSH to increase occupant comfort and safety based on the responses from the interviews.

1. The doors are freezing shut. The front door could be replaced with double metal door, the weather-stripping could be doubled up or if there is too much moisture in the air, the HRV could be reset or the exhaust fans could be run more.
2. The heat in the bedrooms is too high when the living room is comfortable. These are on one zone valve. The drawing specified a damper to the bedrooms which was not installed.
3. At times the units are stuffy. The HRV could be adjusted and the filters cleaned on a regular basis.

The table below reflects the values taken during monthly interviews during the winter months. January to April 2013 and September – November 2013.

Thermostat settings at the conventional house was not relevant because tenant sets to maximum downstairs to warm living room in cold weather and leaves the upstairs thermostat at the lowest possible setting to try and concentrate the heat in living area.

		Living Room				Bedroom				Thermostat Setting
Unit		Floor Temp	Air Temp	RH	CO_2	Floor Temp	Air Temp	RH	CO_2	
NSH A	Range	23°C-25°C	21°C-25°C	21%-50%	1415ppm	22°C-26°C	23°C-25°C	17%-44%	1536ppm	Day 23°C-24.5°C; Night 19°C
NSH B	Range	20°C-26°C	21°C-25°C	16%-24%	1609ppm	20°C-26°C	21°C-25°C	14%-24%	1536ppm	Day 21°C-23°C; Night 20°C
Conventional	Range	19°C-23°C	20°C-22°C	16%-36%		20°C-24°C	18°C-22°C	19%-44%		N/A

11 COST-BENEFIT ANALYSIS

11.1 Cost Summary

The total cost of construction of the NSH including the solar components was $330/ft^2 ($876,165), or $318/ft^2 ($818,000) not including the solar components. The maximum construction costs in Inuvik for standard construction is estimated at $244/ft^2 ($648,064) and for specialized construction is 277/ft^2 ($735,712), not including the solar components.

The estimated incremental construction costs for the NSH are $228,101, including the solar components.

11.2 Energy Savings

11.2.1 Renewable energy systems

The estimated cost of the PV system, the SHW system, and the recommissioning of the systems is $58,165.

In year 1 the NSH saved 1686 kWh or $1143 in electricity not purchased and $224 in credits for electricity exported to the grid, for $1378 total. In year 2, the NSH saved 1381 kWh or $1140 of electricity not purchased and $178 in credits for electricity exported to the grid, for $1326 total.

In year 1 the NSH saved 6 GJ/year in hot water not produced by the gas fired boiler for $258 in savings.

The total annual savings was approximately $1326 and $1378/year in electricity and $223/year in gas from the renewable energy systems, for a total of about $1610/year at the rates paid by the housing corporation. This does not take into consideration the maintenance costs involved with these systems.

11.2.2 Envelope & Mechanical System

The estimated cost of the modified envelope and upgrades to the mechanical equipment was $169,976. This cost includes the following: a) SIP panel floor system, b) Prairie double-wall system, c) Special-order high heel trusses, d) Increased insulation in attic space, e) Fiberglass doors, f) Triple-pane and quad-pane fiberglass windows (as opposed to double-pane), g) High efficiency boiler, h) Hot water tank and mechanical systems, i) HRVs.

The annual savings for heating during year 1 is 67 GJ or $2884/year from the monitored data. The annual savings from water heating (not including savings from the SHW) is 2 GJ or $86/year. The total annual savings are estimated to be $2970/year at the current rates paid by the housing corporation.

11.3 Simple Payback

The simple payback of these measures is not an accurate measure of how cost effective it is to implement these upgrades to a house.

- The costs were much higher due to one-off, first time learnings on how to install the systems and the fact that contracts were awarded late in the year and thus costs were higher due to winter building.
- The records of the incremental costs are incomplete at best and this is a best guess.

That having been said, using the information available, the simple payback for the renewable energy systems is 36 years and for the mechanical systems and envelope is 57 years at current energy rates. With increasing energy costs, this payback is expected to decrease.

12 LESSONS LEARNED AND NEXT STEPS

This monitoring project is the third of its kind that CMHC has embarked on with the NSHs and the first that the NWTHC has embarked on. There has been significant learning from this project.

12.1 Project coordination

- The building should undergo a full commissioning before monitoring begins in order to demonstrate design intent. This should be coordinated by the housing provider and building operator. The commissioning process should include the building maintainers. It will give them a much better understanding of new technology incorporated in the building and confidence in dealing with problems in the future. This should not be an option as these systems will not work without well trained and enthusiastic maintenance staff. The contract for monitoring should begin only after the building is fully commissioned as the two tasks require a different set of skills.
- There are 2 main classes of monitoring for remote systems. The first is partial monitoring and relies on bill tracking which is inexpensive and involves tracking bills. The second is full monitoring and involves expensive equipment and extensive data analysis. Determine what information is really required as there is a significant price difference.
- Set precise goals at the beginning of the project. What are the questions you most want to answer?
- Long term commitment is required. It takes more than a year to get a good year's worth of data. Leave at least a few months to a year of trouble shooting.
- Keep a lot of records and include redundancy in all aspects.
- There is a steep learning curve and coordinating efforts across the North will save significant time and money.

12.2 Monitoring Equipment

- If full monitoring is required, spend the extra money on monitoring equipment. It will be expensive.
- Redundancy is key with remote systems. Have the equipment connect to the internet for remote access AND have it downloadable or readable on site. At least one of these systems will fail during the course of monitoring on a remote system and a backup is key.
- Internet access may not be reliable in remote Northern communities. It will likely go down frequently and the equipment must be robust enough to handle this and start up again automatically. If it is imperative that no data is missing, choose equipment with an internal memory.
- Occupancy read-out is possible but not to be counted on. The worst case scenario is if the remote system goes down you could have a manual readout or computer on site collecting data so someone can go in and read off the data manually.
- Power outages are common. Equipment must be able to automatically reboot.
- Power quality may not be great and may affect electronics. Get robust equipment. There may be spikes and brownouts and may either blow fuses or destroy equipment.
- Equipment that is tested on a Southern grid may not necessarily work on the Northern grids. But not all sites are the same and need to be evaluated individually.

12.3 Data analysis

- Manual data interpretation is time consuming and expensive especially if patching together different equipment systems and readouts.
- Involve a data programmer from the beginning that can coordinate the output from the equipment and automate the generation of reports.

12.4 Public outreach

- There is a lot of learning that can come from monitoring projects and time should be set aside for public outreach.
- The level of potential learning spans from homeowners to housing providers to designers to contractors to researchers and politicians. There are a lot of interested stakeholders.
- There is a need for home grown solutions in terms of equipment and dashboards which are made in the North solutions and easily adaptable to different applications.
- A tri-territorial equipment log and expert database would be helpful. It may be easiest to develop sensors/data loggers/UPSs specific for remote Northern grids
- Public outreach may be the most time consuming part of monitoring but also the most promising and beneficial.

12.5 Mechanical systems

- Although the SHW system functioned well in the first year, it became nonfunctional in year 2 and will not be resurrected by the LHA because:

  1) The cost of yearly maintenance required by the manufacturer was expensive and required time that was better spent by limited maintenance staff in other areas

  2) The lack of local capacity to properly troubleshoot or repair problems with the system. High priced help from the south is not an option.
- The HRV preheat controls are difficult to set up correctly and need some further designing.
- The heat trace on the conventional unit was on all-year with an estimated annual cost of $1500.

TABLE OF FIGURES

REFERENCES

Canada Mortgage and Housing Corporation. (2013). *Design and Construction of the Inuvik Northern Sustainable House*. Canada Mortgage and Housing Corporation.

Health Canada. (1987). *Health Canada*. Retrieved November 1, 2013, from Exposure Guidelines for Residential Indoor Air Quality: A Report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/air/exposure-exposition/exposure-exposition-eng.pdf

National Research Council . (1997). *Model National Energy Code of Canada for Houses 1997, Canadian Commission on Building and Fire Codes*. National Research Council Canada.

Natural Resources Canada. (2007, 05 09). *Photovoltaic potenital and solar resource maps of Canada*. Retrieved from Natural Resources Canada: pv.nrcan.gc.ca

Natural Resources Canada. (2011). *EnerGuide for houses*. (N. R. Canada, Producer) Retrieved from http://oee.nrcan.gc.ca/energuide/15896

Natural Resources Canada. (2011). *HOT2000 Software*. (N. R. Canada, Producer) Retrieved from http://canmetenergy.nrcan.gc.ca/software-tools/hot2000/84

Natural Resources Canada. (n.d.). *Clean Energy Project Analysis: RETScreen Engineering & Cases Textbook*.

cmhc.ca